Beef Cattle Performance, Forage Productivity and Quality from a Mixed Small-Grain/Ryegrass and Warm-Season Annuals Grazing System

by

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A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
May 14, 2010

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Abstract

A two-phase grazing experiment was conducted to evaluate the feasibility and productivity of a cool-season/warm-season annuals grazing system for growing-finishing beef cattle. Eighteen Angus × Simmental steers grazed replicate 1.42-ha mixed pastures (3 steers/paddock) of oats (O; *Avena sativa*), rye (R; *Secale cereale*) and ryegrass (RG; *Lolium perenne*) as winter pasture from Jan 8 to May 28, 2009. Steers then rotationally grazed replicate 2.02-ha pastures of cowpea (*Vigna unguiculata*), lablab (*Lablab purpureus*) and pearl millet (*Pennisetum glaucum*) during a summer finishing phase. Data were analyzed as a completely randomized design by the PROC GLM procedure of SAS. Average daily gain was greater ($P < 0.10$) for O-RG (1.39 kg/d) than R-RG (1.13 kg/d), but was not different from O-R-RG (1.26 kg/d). Number of steer-grazing days was 547 d, 655 d and 625 d for R-RG, O-RG and O-R-RG, respectively. No differences in ADG were observed among summer-annual forage treatments. Forage concentrations of CP, NDF, ADF and ADL, and percentage IVDMD decreased with increasing plant maturity after the first 28 d of the summer grazing trial, all of which negatively impacted ADG. Results indicate that cool-season forage mixtures containing oats were superior to R + RG for supporting beef cattle production from winter grazing. Summer annuals supported satisfactory ADG of finishing cattle early in the summer grazing phase, but were unable to sustain satisfactory ADG for the remainder of the season because of rapidly advancing maturity.

Acknowledgments

First, I would like to thank God for giving me the strength and knowledge to complete this task. I especially would like to thank Dr. Russ Muntifering for his direction and advisement during this process. I am grateful for his expertise and sound guidance as a mentor, professor, and friend throughout my undergraduate and graduate career, without which the completion of this work would not have happened. I would also like to thank Dr. Chris Kerth for his support and guidance with this research project. I would like to thank Dr. Darrell Rankins for his guidance as my advisor at the undergraduate level, and for serving as a graduate committee member. I also would like to express my gratitude to Dr. Don Ball for his expertise and input in this project, and for serving as a committee member. Thanks are also due to Brian Gamble, Rob Peacock, and Greg Pate for their support in the daily management of this project at the Wiregrass Research and Extension Center and E.V. Smith Research Center. Thank you, Dr. John Lin for teaching me the methods and appreciation of laboratory work in forage quality, as well as serving as a mentor throughout my undergraduate and graduate career. I am also thankful for my fellow graduate students Dr. Elias Bungenstab, Leanne Dillard, Clint Rowe, Erin Hunter, and Dr. Adolfo Pereira, along with other graduate students for their help in the field and lab. Finally, I would like to thank my family and my boyfriend, Daniel Mullenix, for their love, understanding and support of my goals in pursuing higher education.

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I. LITERATURE REVIEW

SMALL GRAINS GROWN IN MONOCULTURE

Background

Small grains are cool-season, annual grasses that may be grown for grain, forage, silage or hay production. Oats (*Avena sativa*), rye (*Secale cereale*), wheat (*Triticum aestivum*), barley (*Hordeum vulgare*) and triticale *(Triticum secale*) are the five predominant species that constitute the small grains grouping.

Common oats (*Avena sativa*) is a cereal grain of unknown origin; however, it is believed to be derived from wild oats (*A. fatua*) and wild red oats (*A. sterilis*) found in the Mediterranean region and Middle East (Murphy and Hoffman, 1992). Oats can be found throughout North America and readily grows in all US states. Oats can be grown for forage, grain, hay or silage. In Alabama, there are 20,000 ha of oats planted annually for all purposes, with 6,000 ha being harvested for grain (NASS, 2009).

Oats is a cool-season, annual, C_3 bunchgrass (USDA, 2009b). In the mature stage of growth, oats may attain a height of 0.6 to 1.2 m. Though varieties may differ, oats are generally more cold-sensitive than other small grains and can be susceptible to winterkill (Ball et al., 2007). Compared with wheat, oats makes more fall growth, heads out slightly later in the spring, and typically has slightly lower DM yield (Jennings, 2005).

Rye (*Secale cereale*) is a cereal grain native to the Middle East where it was widely used as a bread cereal (Zohary and Hopf, 2000). Rye is annual, C_3 graminoid winter forage (USDA, 2009g). In 2009, over 5 million ha of rye were planted for all purposes (NASS, 2009).
The majority of rye grown is the US is used as cover crop, pasture or hay, with less than half of the acreage planted being used for grain production (Oelke et al., 2000a).

Rye is well-adapted to sandy or acidic soils characteristic of those found in the southeastern US. Optimum growth is exhibited in soils of pH 5.8 to 6.5 (USDA, 2009g). In the Wiregrass physiographic area of Alabama, peanut (*Arachis hypogaea*) producers have traditionally used rye for winter grazing in rotation with peanuts (Kouka et al., 1994). Rye is more cold-tolerant than other small grains and is often a popular choice among producers for this reason. Grazing may be initiated when the plant reaches approximately 15 cm in height and should be terminated at 7 to10 cm in height (Oelke et al., 2000a).

Barley is a C_3, erect annual grass derived from wild barley (*Hordeum spontaneum*). Barley is considered to be one of the founder crops of the Old World and was first discovered and domesticated in the Fertile Crescent region of Israel and Jordan (Badr et al., 2000). Barley is a staple cereal crop around the world, with 227,383 thousand bushels harvested in the US in 2009 alone (NASS, 2009).

Barley is best adapted to soils with a pH of 5.0 to 8.5. Compared with other small-grain species, barley is better adapted to alkaline soils (USDA, 2009c). Barley may reach up to 1.2 m in height under adequate growing conditions and, in the mature stage of growth, forms a seed head with a panicle (Ball et al., 2007).

Common wheat (*Triticum aestivum*) also originated in the Fertile Crescent region of the world, along with barley (Zohary and Hopf, 2000). Wheat is the most abundant small grain produced in the US. In 2009 alone, 23,930,530 ha of wheat were planted in the US, and 20,257,970 ha were harvested (NASS, 2009). Major classifications of wheat grown in the US include hard red, soft red, hard white, soft white and durum wheat (NASS, 2009). While wheat grown in the US is utilized predominantly for human consumption, wheat is also grown as a feed source for animal production. Wheat shows active growth in the fall, winter and spring (USDA, 2009h). It grows rapidly and typically reaches a mature height of around 1.2 m at an optimum soil pH of 5.5 to 8.0 (USDA, 2009h). As winter-hardy, high-quality forage, wheat is reported to grow in all 50 states in the US because of its adaptation to a wide range of climatic conditions and soil types, and tolerance to grazing (USDA, 2009h; Jennings, 2005).

Triticale (*Triticum secale*) is a synthetic cross between wheat and rye. Although not as widely utilized as the other small grains, hybrids of triticale were first developed in the late 1800s (Oelke et al., 2000b). However, it was not until late in the 1900s that genetically modified varieties of triticale were developed for improvement of DM yield (Oelke et al., 2000b). Triticale retains the palatability of wheat with the growth vigor of rye. While not as cold-tolerant as rye, Arkansas forage tests indicate that triticale may produce DM yields similar to rye, but with a heading date later than rye (Jennings, 2005). Only a few thousand ha of triticale are planted annually, which typically are used as hay and silage (Oelke et al., 2000b; Ball et al., 2007).

Yield and nutritive quality

Maximizing fall growth of winter-annual forages may limit the need for supplemental hay during winter months. In a forage variety trial in Wisconsin, Maloney et al. (1999) reported that fall forage yields were increased by selecting oat or barley cultivars rather than rye or winter wheat. Several studies have also illustrated that fall forage yield increases with earlier planting dates (Grigg, 2006; Lyon et al., 2001). Gunsaulis et al. (2008) conducted a 2-yr study to evaluate eight cultivars of small grains for fall growth at two locations in Arkansas. Cultivars were seeded in early September and harvested six times during the trial. At Fayetteville in 2004, oat and triticale accumulated DM in a cubic pattern because growing tillers exhibited stem elongation. Maximum yield was highest for oats (4,661 kg/ha) followed by wheat (2,554 kg/ha). At the Batesville location in 2005, wheat, rye and triticale cultivars accumulated over 4,148 kg/ha of forage DM by the January 4 final harvest date. However, oat cultivars were sensitive to freezing temperatures and ranked last among all species for DM yield at the final harvest date. There was little evidence of winterkill for cultivars of wheat and rye. Results indicate that selecting cultivars that exhibit some stem elongation under expected climatic conditions will maximize fall yield (Gunsaulis et al., 2008).

Most production of small grains occurs from November to April after seeding in late September to early October (Ball et al., 2007). Distribution of forage growth differs greatly among these species and is extremely important in planning grazing systems. Oats is generally more cold-sensitive than rye and does not produce as well early in the winter grazing season. Rye is generally available earlier in the season, but matures and loses quality earlier and faster than oats. Bruckner and Raymer (1990) noted that differences in forage growth distribution among species were greatest during January and February when rye produced greater forage yields than wheat, triticale and oats. Yield of rye was 27, 33 and 78% greater than forage yields of triticale, wheat and oats, respectively, during the 3-yr trial.

Moyer and Coffey (2000) conducted a 2-yr comparison of various cultivars of rye, wheat and barley (*Hordeum vulgare*) interseeded into bermudagrass or as monocultures in prepared seedbeds for potential use in forage-based grazing systems. In year 1, early forage yield [growing degree days (GDD) < 1,000] was highest for Bonel rye compared with all other cultivars. Bonel rye and Winter King rye had comparable early-spring yield in year 2, and were greater than all other cultivars. Late forage yield (GDD > 1,000) of monocultures was highest for Post barley (5,250 kg/ha) compared with all other cultivars in year 2 of the study. Wheat cultivars were more balanced in seasonal production than rye or barley. Forage DM yield of wheat was approximately 3,000 to 3,500 kg/ha in both early-yield and late-yield periods (Moyer and Coffey, 2000).

Neilsen et al. (2006) evaluated triticale grown in rotation with corn (*Zea mays*) and foxtail millet (*Setaria italica*) in Colorado for water use efficiency and yield potential of triticale for forage or grain production. Winter triticale DM yield ranged from 731 to 10,632 kg/ha during the 3-yr trial, with average production of 3,916 kg/ha. Dry weight of triticale produced was significantly affected by rainfall, with the maximum DM yield recorded in years with the highest amount of annual precipitation (Neilsen et al., 2006)

In a 3-yr comparison of oats and barley as forages in North Dakota, forage DM yield of oats averaged 3.84 Mg/ha and 2.91 Mg/ha for barley (Carr et al., 2004). Concentration of CP in oat forage was 61 g/kg, and was 90 g/kg for barley harvested in the soft-dough stage of production. Total cell-wall constituents were 39 to 41 g/kg lower for barley than oat forage. Results indicate that, while barley produced less DM yield than oats, forage quality was slightly higher for barley (Carr et al., 2004).

Moyer and Coffey (2000) also reported differences in forage quality among small-grain cultivars grown in monoculture. Average IVDMD for cultivars of rye, wheat and barley was 74.5%, 69.8% and 72.1%, respectively. After the second harvest date (April 2), IVDMD decreased for all cultivars. At the first harvest in March 1992, CP concentration in Caldwell wheat (30.6%) was greater than both rye cultivars (Winter King rye, 22.2%; Bonel rye, 22.5%) and similar to all other cultivars (Karl wheat, 27.9%; Arkan wheat, 26.9%; Post barley, 28.3%). At the first harvest in 1993, all wheat and barley cultivars were higher than rye cultivars in CP concentration. Concentration of CP varied significantly among cultivars after the first harvest, indicating that time of forage demand would determine which grass would best serve the need of grazing animals (Moyer and Coffey, 2000).

Forage quality of small grains declined with the onset of maturity at the May harvest date in Ohio forage variety trials (Samples and Sulc, 2000). Ball et al. (2007) reported a decline in concentration of CP in rye of 28, 24 and 13% at the vegetative, flower/boot and fruit/head stages of maturity, respectively. Juskiw et al. (2000) evaluated forage yield and quality of small grain of barley, triticale and oats grown in monocultures or in mixtures for silage production. Mean concentration of cell-wall constituents in barley harvested at the dough stage of development was 59.4 and 34.9% for NDF and ADF, respectively. Crude protein concentration was low (8%) at the dough stage of development for barley cultivars. AC Mustang oats contained 55% NDF, 32% ADF and 7% CP when harvested at the dough stage of development. Triticale contained 54% NDF, 32% ADF and 7% CP at the dough stage of development. Results indicate that quality of cool-season annuals declines with increasing maturity.

Animal performance

Nutritive quality of small-grain forage is sufficient to support economical performance of growing/finishing beef cattle. Small grains can be interseeded into a warm-season pasture to provide pasture year-round for stocker cattle (Coulibaly et al., 1996). Utley et al. (1976) illustrated the feasibility of oats overseeded into perennial sods or planted in prepared seedbeds for winter grazing. Cattle ADG was 1.05 kg/d and total gain per ha was 504 kg/ha for cattle grazing oats in prepared seedbeds. Cattle grazing oats overseeded into perennial sods had a comparable ADG of 1.12 kg/d, but lower total gain per ha (253 kg/ha) than oats planted in prepared seedbeds (Utley et al., 1976). When oats, rye and wheat were interseeded into bermudagrass, final BW of cattle grazing wheat tended to be greater (322 kg) than the average of oats (300 kg) and rye (309 kg) (Beck et al., 2007).

A comparative study in Georgia evaluated performance of steers grazing tall fescue (*Festuca arundinacea*; F), rye seeded into dormant bermudagrass (BR), rye conventionally seeded after soybeans followed by 35 days on tall fescue (R), or rye seeded into tall fescue sod (FR) as part of a forage-finishing system (Stuedemann et al., 1981). Steers grazing BR gained more than those grazing rye alone, and gains from both BR and R were higher than those from the F or FR treatments. Average cumulative gain per steer was 95.9, 70.6, 53.1 and 58.5 kg for the BR, R, F and FR treatments, respectively (Stuedemann et al., 1981).

Small grains grown in monoculture produce high DM yields that may increase carrying capacity of pastures and improve ruminant animal production (Moyer and Coffey, 2000). Horn et al. (1995) reported that steers grazing wheat grown in monoculture without supplementation gained from 0.80 to 0.97 kg/d over a 3-yr period. Arzadun et al. (2003) evaluated the effects of different grazing pressures of ‘Pinean’ wheat on beef and grain production. Pastures were managed to allow 10, 15 and 20 kg $DM\cdot heifer^{-1}\cdot d^{-1}$ for high, medium and low grazing pressure treatments, respectively. Gain/ha was increased, and ADG and wheat forage mass were decreased with increased grazing pressure. Mean gain/ha over the 3-yr trial for heifers grazing wheat pasture was 283, 225 and 176 kg for the high, medium and low grazing pressures, respectively.

Beck et al. (2005) observed that calves grazing rye had superior performance during cool, dry years compared with wheat, oats and ryegrass alone. In a 3-yr comparison of rye, wheat, oats and ryegrass, ADG during the winter and spring did not differ among treatments during year 1, averaging 1.44 and 1.45 kg/d, respectively. In the fall and winter of year 2, ADG of steers grazing rye was 25% greater than calves grazing oats, ryegrass or wheat treatments. Decreased gains from all small grains except rye were attributed to low temperatures that caused winter kill of oats and delayed regrowth of wheat and ryegrass during year 2 of the trial. In the fall-winter of year 3 when temperature and rainfall were above normal, ADG of cattle grazing wheat pasture was greater (1.17 kg/ha) than the rye treatment (0.86 kg/ha). During the spring of year 3, cattle grazing oats and ryegrass had the best performance.

Later-maturing barley forage has been shown to have forage quality and yield comparable to those of oats in several agronomic studies (Carr et al., 2004). However, few studies have been conducted with barley as a forage source for ruminant animal production. Barley is typically used as a grain supplement in feedlot diets or as silage. Poland et al. (1997) reported that heifers grazing pastures seeded to barley had fewer grazing days, higher ADG and similar total gains compared with oat pastures.

Small grains may be integrated into crop-livestock systems to increase profitability by adding diversity to exisiting production systems. Franzluebbers and Stuedemann (2004) evaluated rye and pearl millet cover crops that were ungrazed or grazed for 60 to 90 d with an average stocking rate of 4.45 animals/ha. Cattle ADG for rye was 1.54 kg, illustrating the opportunity to provide significant gains during the fallow period for row crop production. Siri-Prieto et al. (2007) evaluated the effects of double-cropping cotton following winter-annual grazing of stocker cattle at the Wiregrass Research and Extension Center in Headland, AL. A

3-yr study was conducted using oats and annual ryegrass (*Lolium mutiflorum*). Average total gain was 541 kg/ha for oats and 561 kg/ha for ryegrass. At a stocking rate of 5 animals/ha, liveweight gain per ha for oat pasture was 7.17, 7.04 and 5.65 kg/d for February, March and April, respectively. Only in the last grazing period was there a tendency for ryegrass to produce ADG superior to oats (Siri-Prieto et al., 2007).

Selection of small grains well adapted to expected environmental conditions is important for providing high-quality pasture for the duration of the winter grazing season. In south Alabama, an area characterized by mild winters, Kouka et al. (1994) reported that oats showed a production and profit response greater than that of rye. A recent 3-yr grazing study by Pereira et al. (2009) showed that animals grazing oats had higher total gain/ha (504 kg) compared with rye (425 kg) and ryegrass (408). In Arkansas, Beck et al. (2005) reported that profitability of grazing pastures containing rye was greater when cold weather limited growth of wheat, ryegrass and oat forage. However, rye alone was not as profitable as ryegrass, wheat and a wheat + ryegrass mixture in years with milder winter temperatures (Beck et al., 2005). Results illustrate the effects of location and climatic conditions on forage productivity, quality and ability to support ruminant animal production.

ANNUAL RYEGRASS

Background

Annual ryegrass (*Lolium multiflorum*), also known as Italian ryegrass, is a C_3, annual, cool-season forage grown throughout the US (USDA, 2009e). Ryegrass was first cultivated and grown in northern Italy. Ryegrass was first brought to America during Colonial times and quickly became a popular forage crop in the southern US. Although ryegrass is used primarily for pasture, it is sometimes used for hay or silage (Ball et al., 2007).

Ryegrass has shiny, dark green, smooth leaves in the vegetative state, and may reach 0.6 to 0.9 m in height (Lacefield et al., 2003). Though best adapted to well-drained soils, it will tolerate wet, poorly drained soils for a short period of time (Ball et al., 2007). Because of its rapid regrowth, early spring growth and extended grazing in late fall/early winter, ryegrass has greater overall productivity than most other cool-season grasses during its growing period (Lacefield et al., 2003). Optimum growth is seen at a pH of 6.0 to 7.0 when seeded from late August to October, although planting date may vary upon geographic region and climatic conditions. Grazing may be initiated when the plant reaches 20 to 25 cm in height, and should be terminated when plants reach a height of 5 to 7 cm (Lacefield et al., 2003).

Extensive research has been conducted to develop varieties of ryegrass that are well-adapted to different physiographic regions of the US in order to increase DM productivity and decrease disease susceptibility. ‘Gulf’ annual ryegrass was the first improved cultivar developed by Texas A&M University for increased rust resistance and DM yield (Lacefield et al., 2003). Many other cultivars of ryegrass have been developed and released since the 1960s, with ‘Marshall’ ryegrass being the first cold-tolerant cultivar noted for its superior early-spring forage production (Redfearn et al., 2005).

Yield and nutritive quality

Forage varieties of ryegrass vary significantly in total DM yield potential and seasonal distribution, depending on the location or region in which they are grown. Ball et al. (2007) reported that seasonal growth can be expected from November to May in the Gulf Coast region of the southeastern US, and from late February through May farther north. Under favorable climatic conditions, high forage yields may be expected.

In a comparison of commercially produced varieties of ryegrass at Overton, TX, high-yielding varieties had forage yields between 2,700 and 3,200 kg DM/ha during the 3-yr trial (Nelson et al., 2004). Redfearn et al. (2002) evaluated ‘Gulf’, ‘Jackson’, ‘Marshall’, ‘Rio’, ‘Rustmaster’ and ‘Surrey’ annual ryegrass for differences in forage yield, yield distribution throughout the growing season, and nutritive quality. Over the 2-yr trial at four locations in Oklahoma, 40% of the total forage production from all cultivars occurred early in the growing season (December through February), and 60% occurred as late-season growth (March through May). Average DM yield was roughly 1,000 kg DM/ha from December through February, and 2,500 kg DM/ha from March through May. Concentration of CP decreased from 26 to 12%. Concentration of NDF increased (39 to 58%) across the growing season, and *in vitro* true DM digestibility declined (84 to 70%) with increasing plant maturity (Redfearn et al., 2002).

In a 12-yr ryegrass cultivar study across five locations in Louisiana, mean early-season yield (total before March 1) ranged from 2.3 to 4.6 Mg/ ha, and late-season yield (total after March 1) averaged 5.1 to 7.4 Mg/ha (Redfearn et al., 2005). Some cultivars were more frequently among the highest-yielding entries in early-season yield, while others were more consistently among the top late-season producers. Results illustrate the importance of cultivar selection to ensure a uniform seasonal distribution.

Annual ryegrass may be seeded in the late summer and stockpiled for grazing in early winter. Ryegrass exhibits autumn growth, accumulating as much as 49 kg DM$\cdot$ha$^{-1}\cdot$d^{-1} (Cuomo et al., 1999). Kallenbach et al. (2003) reported that stockpiled ryegrass harvested monthly from December through March yielded from 825 to 2,356 kg DM/ha during a 2-yr trial. Although forage quality declined throughout the growing season, concentration of NDF never exceeded 45.5% and ADF never exceeded 25.2% of forage DM (Kallenbach et al., 2003).

When planted in prepared seedbeds, annual ryegrass has more consistent establishment and production. Ryegrass may be planted using no-till systems; however, forage production potential has been inconsistent, particularly early in the growing season (Cuomo et al., 1999). First-harvest yields of ryegrass may be improved by increasing seeding rates from 400 to 1,600 pure live seed/m^2 (Venuto et al., 2003), but total forage yield is not increased.

Animal performance

Annual ryegrass serves as a primary forage resource for livestock producers throughout the southeastern USA during the winter growing season (Venuto et al., 2003). Ryegrass exhibits fall-growth potential, which may help minimize the transition from summer pasture to winter grazing. Ryegrass may be seeded alone or overseeded into dormant perennial pastures in an effort to lengthen the grazing season.

Utley et al. (1976) illustrated a reduction in land preparation when annual ryegrass was overseeded into perennial sods for livestock grazing systems. Ryegrass planted in prepared seedbeds provided an ADG of 1.07 kg/d, and 1.15 kg/d when overseeded into perennial sods (Utley et al., 1976). Hoveland et al. (1978) observed cattle gains of 217 kg/ha for cows and 473 kg/ha for calves grazing Coastal bermudagrass pastures overseeded with ryegrass. Hill et al. (1985) evaluated Coastal bermudagrass and Pensacola bahiagrass (*Paspalum notatum*) perennial pastures with or without sod-seeded ryegrass for pasture for cow-calf pairs. Overseeding pastures with ryegrass increased calf ADG during the spring grazing interval from February through May, causing increased weaning weights. Calf ADG during spring grazing was 0.88 kg/d for the bermudagrass-ryegrass system.

Hafley (1996) reported that steer performance was similar for ‘Marshall’ and ‘Surrey’ ryegrass in a 2-yr grazing trial in Louisiana. Cattle ADG for continuously grazed ‘Marshall’ ryegrass was 1.42 kg/d and 1.50 kg/d for ‘Surrey’ ryegrass in year 1 of the study. In year 2, ADG over an 84-d grazing period was 1.19 and 1.18 kg/d for ‘Marshall’ and ‘Surrey’ ryegrass, respectively. Bransby et al. (1997) reported total weight gains of 159 kg/steer grazing ‘Marshall’ ryegrass in south Alabama, and 90 kg/steer for Gulf ryegrass over a 112-d grazing season. Coffey et al. (2002) reported a total gain of 113.9 kg for cattle grazing ryegrass given ad libitum access to hay along with a grain sorghum-based supplement during a 3-yr study in Arkansas. Cattle grazing ‘Passerel Plus’ ryegrass in Florida gained 1.12 kg/d over a 90-d grazing period (Myer et al., 2008). At a total stocking rate of 3.8 heifers/ha, cattle were estimated to gain 366 kg/ha over the trial (Myer et al., 2008).

SMALL GRAINS GROWN IN MIXTURES

Background

Small grains can be planted in mixtures with other cool-season annuals in order to extend the winter grazing season. A mixture of several small grains may lead to a more uniform, increased yield distribution and will thus produce superior animal performance (Beck et al., 2005). Ryegrass is most productive from February through May, after the small grains have declined in production, making it a popular annual for mixed pasture systems. Research has shown that adding ryegrass to forage mixtures increases performance of growing steers and increases gain per hectare (Beck et al., 2005). Winter annual clovers have also been used to extend the grazing season, particularly in the southeastern US (Hoveland et al., 1978).

Yield and nutritive quality

Coffey et al. (2002) evaluated forage quality and animal performance of stocker calves grazing sod-seeded winter-annual mixtures. Over a 112-d grazing season, concentration of CP was 20.3% and 21.4% for rye + ryegrass and wheat + ryegrass, respectively. Percentage IVDMD of wheat + ryegrass averaged 73.9% and was similar to that of rye + ryegrass. Seasonal distribution of DM yield was evident over the grazing season. In yr 1 at the beginning of the grazing trial in mid-December, average DM availability for rye + ryegrass and wheat + ryegrass was 1,682 kg DM/ha. Forage availability decreased to 495 kg DM/ha by day 84 of the trial for the rye + ryegrass mixture, but increased to 1,358 kg DM/ha by day 112. The wheat + ryegrass mixture availability decreased to around 700 kg DM/ha on day 28, but increased to 1,347 kg DM/ha during the next period.

Contreras-Govea and Albrecht (2005) evaluated combinations of kura clover (*Trifolium ambiguum*), small grains and ryegrass for potential to extend the winter grazing season in the northern US. Winter small grains including oats, barley, wheat and rye increased total forage yield of mixtures in the early spring. Ryegrass also increased overall productivity compared with kura clover by 15%. Concentration of CP in binary mixtures of kura clover and small grains ranged from 17 to 52 g/kg, illustrating the effect of different proportions and maturities of grasses present in the stand on forage chemical composition.

Myer et al. (2008) noted that small-grain mixtures of rye + oats and oats + rye + ryegrass planted in prepared seedbeds had superior DM yield compared with those that were sod-seeded.

Mixed pastures yielded 5,682 kg/ ha and 3,903 kg/ha for prepared seedbeds and sod-seeded paddocks, respectively. Concentration of CP was 27.7% for forage from prepared seedbeds, and 22.0% for mixtures that were sod-seeded.

Animal Performance

Hoveland et al. (1978) evaluated cow-calf performance on Coastal bermudagrass overseeded with winter-annual clovers and grasses. Cattle grazing mixtures of rye, arrowleaf clover (*Trifolium vesiculosum*) and crimson clover (*Trifolium incarnatum*) grazed for 268 days compared with 240 days for ryegrass alone. Total animal gain/ha was 269 kg/ha for cows and 628 kg/ha for calves grazing rye-clover mixed pasture. In Mississippi, grazing trials showed higher gains for steer calves grazing ryegrass-crimson clover with wheat, rye or oats than on ryegrass-crimson clover (Burris et al., 1979). Ryegrass-wheat-crimson clover pastures produced the highest ADG (0.74 kg/day) and total gain/ha (649 kg/ha) compared with other mixtures.

Cleere et al. (2004) reported that steers grazing a combination of rye + ryegrass gained from 1.01 to 1.28 kg/d from December to May across two stocking rates and grazing systems. In northern Arkanasas, Beck et al. (2005) evaluated the performance of stocker cattle grazing cool-season annual grass mixtures of rye + ryegrass, wheat + rye, wheat + ryegrass, or wheat + rye + ryegrass. Over the 3-yr trial, animal performance during the fall and winter averaged 1.16 kg/d. Spring ADG was greater for cattle grazing rye + ryegrass (1.32 kg/d) than wheat + rye (1.17 kg/d) and wheat + rye + ryegrass (1.12 kg/d). Addition of ryegrass to rye or wheat produced the greatest ADG and gain per hectare in 2 of 3 yrs of the trial (Beck et al., 2005). Results indicate that utilization of small-grain mixed pasture systems may provide significant gains during winter and spring grazing.

Myer et al. (2008) evaluated cattle performance from mixtures of oats + ryegrass and oats + rye + ryegrass in Florida. Cattle ADG was 1.00 kg/d and 0.98 kg/d for oats + ryegrass and oats + rye ryegrass, respectively. Average stocking density was 3.7 head/d/ha for oats + ryegrass over a 114-d grazing season. Total grazing days for oats + rye + ryegrass was 118-d at a stocking density of 3.6 head/ha. The decision to use a mixed pasture system should include consideration of consider geographic location and climatic conditions specific to the area.

SUMMER ANNUAL GRAZING SYSTEMS IN THE SOUTHEAST

Background

Summer grazing systems in the southeastern region of the US are based largely on perennial C_4 grasses such as bahiagrass and bermudagrass. Nutritive quality of these forages declines as they mature and is often insufficient to meet the needs of growing-finishing beef cattle. While not widely utilized throughout the Southeast, summer-annual forages may provide a higher quality alternative to perennial C_4 grasses for use in summer grazing systems (Foster et al., 2009). Summer annuals are currently not widely utilized in the region for grazing because of their slow establishment, cost of establishment, lack of persistence under grazing, and disease and pest issues (Hoveland, 2000). However, increasing costs of fuel and fertilizer have made legumes an attractive forage option for producers. Warm-season legumes have the potential to provide needed nutrients and, when stored as hay, silage or haylage, they can be fed in the winter to supplement stored or stockpiled grasses (Foster et al., 2009). Moreover, while annual grasses may be lower yielding and less responsive to applied nutrients, they are generally of higher nutritive quality than perennial grasses (Robinson, 1996). Summer annuals adapted to the Southeast include both legumes and grasses.

Lablab

Lablab (*Lablab purpureus*) is a warm-season annual legume with high nutritive quality as a browse or forage for ruminant animals. Lablab is a member of the pea family (*Fabaceae*) and is also commonly referred to as hyacinth bean, Egyptian bean, field bean, or garbanzo (Murphy and Colucci, 1999; USDA, 2009d). Wild forms of the legume originated in India and were introduced into Africa from India during the 8th Century (Deka and Sarkar, 1990). In 1819, seeds of lablab were planted in the Botanical Gardens in Sydney, Australia. The first improved cultivar "Rongai" was released in Australia in1962. After release of this cultivar, use of lablab as forage increased (Murphy and Colucci, 1999). Rongai seed was imported to the US in the late 1960s as supplemental forage for white-tailed deer. Until recently, most lablab in the US has been primarily used for food plots for wildlife and game (Ball et al., 2007). In 2006, the Rio Verde cultivar was developed by the Texas A&M AgriLife Research and Extension Center. Rio Verde was the first lablab cultivar developed in the US for tolerance to defoliation, forage production and seed production (Smith et al., 2008). Various other cultivars have been developed and utilized around the world (Murphy and Colucci, 1999).

Lablab is a vining herb in which stems are trailing to upright and may grow up to 1.3 m in height (USDA, 2009d). Leaves are large and trifoliate, with leaflets having a broad ovate-rhomboid shape. Lablab grows well under warm, humid conditions with an optimal temperature range of 18 to 30°C. Below 20°C, the plant begins to show reduced growth. Lablab may be grown in arid, semi-arid and humid regions of the world with 250 to 2,500 mm of rainfall once it has been established (Hendricksen and Minsen, 1985). While it is relatively drought tolerant, 10 to 20 mm of rainfall is required for establishment (Murphy and Colucci, 1999). Lablab may survive short periods of flooding, but does not tolerate water logging (Smith et al., 2008).

Lablab can be grown in a wide range of soil types, but is best adapted to sandy, sandy loam and clay loam soils. A soil pH range of 5 to 7.5 is required for growth, with an optimum soil pH of 6. Some iron chlorosis may be noted in plants grown at a soil pH greater than 7.5 (Smith et al., 2008). Lablab may be planted from May through July, provided that soil moisture and temperature are adequate to support growth. As reported in Texas, Rio Verde lablab initiates flowering in late August, with 50% bloom occurring by the beginning of September. In contrast, Rongai lablab is very late-flowering and generally does not flower until close to frost in central or northeast Texas (Smith et al., 2008). Grazing may be initiated when the plant reaches between 30 and 50 cm in height, and should be terminated at no less than 10 cm.

Productivity of lablab varies under different rainfall conditions, soil types and times of seeding. Murphy and Colucci (1999) reviewed dryland production of lablab, reporting an average of 4,444 kg DM/ha over several studies. Under irrigation, Muir et al. (2001) reported total yield of over 9,000 kg DM/ha from three harvests of lablab in North Texas. Muir (2002) conducted a 2-yr study in which hand-plucked samples of several annual legumes were evaluated to determine their yield potential for forage production. Lablab harvested all season long in year 1 of the study produced 2,739 kg DM/ha, and 1,891 kg DM/ha when harvested in autumn only. In the second yr, drought conditions caused lablab yield to be reduced to 78 kg DM/ha in plots harvested year-round and 185 kg DM/ha in plots harvested in autumn only. These data indicated that productivity was improved when lablab was harvested continuously throughout the growing season compared with forage harvested only in autumn. In years with sufficient rainfall, lablab provided an average of 2,000 kg DM/ha/year in leaf portion alone, which would be sufficient to support livestock production (Muir et al., 2002).

Lablab is a high-quality forage legume with high palatability for ruminant animals (USDA, 2009d). Quality of forage changes throughout the growing season based on management, rainfall and other climatic conditions. Smith et al. (2008) evaluated leaf and stem CP percentage in Rio Verde lablab at two fall harvest dates in Overton, Texas. At the September and October harvests, leaf CP was 26.0 and 32.0%, respectively. Stem protein was 13.0% at both harvests. Murphy and Colucci (1999) reported the average concentrations of CP, NDF, ADF and ADL for the leaf, petiole and stem portions of the plant over a 147-d growing season. Concentration of CP was 24.7, 11.4 and 10.2% for the leaf, petiole and stem portion, respectively. Concentration of NDF was lowest in the leaf portion (37.3%), but increased in the petiole and stem portions (50.7 and 61.8%, respectively). Concentration of ADF followed a similar pattern, with the leaf portion being the lowest (23.4%), followed by petiole (42.3%) and stem (49.4%). Lablab leaf contained the lowest percentage of ADL (4.4%). Petiole and stem portions contained 6.3 and 9.1% ADL, respectively.

Although varieties have been developed for grazing tolerance, few studies have been conducted in the US regarding beef performance on lablab. Texas A&M University has recently conducted grazing trials using Rio Verde, but data have not yet been published (Smith, personal communication, 2009). Fribourg et al. (1984) at University of Tennessee evaluated Rongai lablab as annual forage for beef cattle production. Two plots (2 ha/plot) of lablab and sorghum were established, and 6 British-type cattle (4 heifers and 2 steers) were allowed to continuously graze each treatment for 42 d (July 28 to September 9). Cattle ADG was 0.37 kg/d for the lablab pasture and 0.20 kg/d for the sorghum pasture. Total gain per unit area was 83 kg/ha and 34 kg/ha for the lablab and sorghum pasture, respectively. Low gains during the grazing period may have been associated with unusually dry and hot climatic conditions during the year of the study.

Results indicate that lablab can grow well and produce a greater amount of beef gain compared with a more commonly used summer annual during hot, dry summer periods.

Cowpea

Cowpea (*Vigna unguiculata*) is a warm-season, annual herbaceous legume commonly used as a grain crop, forage or vegetable. Cowpea is a member of the pea family (*Fabaceae*) and is commonly referred to as southern pea, blackeye pea or crowder pea (Davis et al., 2003; USDA, 2009i). Cowpea originated in Africa where it was used in West African cereal farming 5 to 6 thousand years ago. Cowpea was closely associated with the cultivation of sorghum and pearl millet as a grain crop during this time period. Currently, cowpea is grown in Africa, Latin America, Southeast Asia and the southeastern US, primarily as a grain crop for human consumption. Other historical uses of cowpea in the US include use as a cover crop for soil conservation and soil fertility improvement, as well as for wildlife food or habitat (Muir, 2002; Edwards et al., 2004). Globally, cowpea production has increased in the last 25 yr, although the amount of land for growing cowpea has decreased (Davis et al., 2003).

Plant types are often categorized as erect, semi-erect, prostrate or climbing (USDA, 2009i). While there is much variability within species, growth habit ranges from indeterminate to fairly determinate. Leaves are alternately developed, smooth and trifoliate, although there is a wide range in leaf size and shape. Cowpea is well adapted to many areas of the humid tropics and temperate zones of the world and is known to be heat tolerant. Drought tolerance allows the plant to produce well under dryland conditions as well as under irrigation. Plant germination is rapid at temperatures above 18°C, and colder temperatures may slow growth. Germination is dependent upon adequate soil moisture, although the most critical moisture-requiring period is just prior to and during bloom (Davis et al., 2003).

Cowpea grows well on a wide variety of soils and soil conditions, but is best adapted to well-drained sandy loams or sandy soils. A soil pH range of 5.5 to 6.5 will support plant growth, with optimum pH being 6. Optimum seeding date is in early May, although it may be planted as late as July (Davis et al., 2003). Grazing may be initiated when the plant reaches about 50 cm in height and should be terminated when the majority of the leaf material has been removed, leaving the basic frame of the plant intact (Mullen, 1999).

Comparative studies of the forage yield potential and nutritive quality of cowpea with other legumes in the southern US is lacking and must be quantified to determine potential for enhancing ruminant animal production (Foster et al., 2009). Muir et al. (2001) evaluated Combine and Iron-Clay cowpea varieties in a two year study to determine yield and quality characteristics of these forages for potential use in central Texas. Iron-Clay cowpea yielded 4,308 kg DM/ha over two harvests, and Combine cowpea produced 2,152 kg DM/ha in a single harvest. Results indicate that these forages can produce relatively high yields, although feeding and production trials need to be conducted to determine their value for beef production.

Foster et al. (2009) evaluated cowpea, pigeonpea (*Canjanus cajan*) and soybean (*Glycine max*) for yield potential and nutritive quality in a 3-yr study in north Florida. Herbage mass increased linearly for cowpea and pigeonpea in yr 1 and 3 and soybean in yr 3, with production of cowpea being between 2,000 and 4,000 kg/ ha over the growing season. Due to inadequate precipitation at establishment in yr 2, soybean did not emerge and pigeonpea establishment was slow. Cowpea established satisfactorily, and yield was comparable with other years until 12 wk after planting. Overall, soybean and pigeonpea had greater herbage mass than cowpea 8 wk after planting during yr 1, and 10 wk after planting during yr 3. Leaf-to-stem ratio of all forages decreased in quality with maturity; however, cowpea had a higher leaf to stem ratio than other legumes from 10 to 14 wk after planting. At the recommended maturity for harvest, CP concentrations were 12.1, 17.6 and 18.8% for pigeonpea, soybean and cowpea, respectively. *In vitro* dry matter digestibility was highest for soybean (72.9%), intermediate for cowpea (68.9%) and lowest for pigeonpea (35.1%). While pigeonpea and soybean had greater herbage mass than cowpea, cowpea and soybean have more potential as forage based on quality.

Grazing of cowpea may be initiated when the plant reaches 0.5 m in height and should not be grazed to less than 15 cm in height. Hendricksen (1980) collected data on several forage crops in Australia to assess their potential for beef performance, but noted a lack of published data on cowpeas. Holznknecht et al. (2000) evaluated liveweight gain of steers rotationally grazing either pangola grass, heavily grazed cowpea (no leaves and little stem left after grazing), or lightly grazed cowpea (some leaves and stem left). Steers grazing Meringa cowpea grew faster than steers grazing pangola grass (*Digitaria eriantha*). Steer ADG was 0.62, 1.23 and 1.17 kg/d for pangola grass, heavily grazed cowpea, and lightly grazed cowpea, respectively. Level of cowpea utilization had no effect on gain; under either intensity of management, cowpea was superior to the more commonly used C_4 grass for supporting steer performance. When compared with perennial peanut (*Arachis glabrata*) and concentrate feed (pelleted corn and cottonseed meal) for creep systems, creep-grazing cowpea tended to increase ADG in both years of the study. Cowpea was comparable to concentrate for increasing ADG in creep-fed calves, with an ADG advantage of 0.19 kg for cowpea and 0.22 kg for concentrate over the 2 yr of the trial (Foster et al., 2009).

Pearl millet

Pearl millet (*Pennisetum glaucum*) is an erect, leafy grass that grows from 0.9 to 2.5 m in height (Ball et al., 2007). Pearl millet is a member of the family *Poaceae* and is also commonly referred to as millet, cattail millet, candle millet or bullrush millet (USDA, 2009e). Pearl millet originated in Africa and is considered a staple cereal crop in both Africa and India today. The species was first introduced to the US in the early 1900s along with *Sorghum* species. While sorghums and millets are most commonly used for grain crop production in the US, they may also be used as a forage source in beef cattle production systems (Teutsch, 2002).

Pearl millet has smaller stems, tends to be leafier than forage sorghum (*Sorghum bicolor*), sudangrass (*Sorghum bicolor*) and sorghum-sudangrass hybrids, and has substantial regrowth after cutting or grazing (Teutsch, 2002). As a highly productive summer forage, millet is well adapted to drought conditions, more so than comparable *Sorghum* species. Pearl millet grows well under warm, humid conditions with an optimum temperature range of 24 to 32°C. Maximum production is typically seen in well-drained soils with a pH of 5.5 to 6.5 (Teutsch, 2002).

Pearl millet is best adapted to mildly acidic soils with a low water-holding capacity such as many of the soils found in the southeastern region of the US. Optimum planting date is typically in May, when the soil has reached a minimum average temperature of 18°C. The majority of growth occurs in June, July and August, with plant productivity beginning to decrease by September. Grazing may be initiated when the plant reaches between 0.3 to 0.45 m in height and should be terminated when the plant has reached a minimum height of 0.2 m (Ball et al., 2007). Time to grazing after planting is typically 45 to 60 d (Teutsch, 2002). In order to maintain pearl millet in the vegetative state, high stocking rates are often necessary.

Pearl millet is highly productive over a short season, with an average DM yield of 1,800-4,000 kg DM/ha (Teutsch, 2002). McLaughlin et al. (2004) conducted a 3-yr study to evaluate the use of five warm-season annual grasses for DM yield and nutrient uptake alongside the warm-season perennial bermudagrass in a field with swine effluent applied through a center-pivot sprinkler system. Average pearl millet DM yield was between 12.5 and 15.7 Mg/ha during the 3-yr trial, which was comparable with other studies when plant-available nutrients were not limiting. During the establishment year, bermudagrass had the lowest DM yield of all six grasses; however, yield doubled each year following establishment. Yield of sudangrass and pearl millet in the last year of the study, although lower than DM yields of bermudagrass and sorghum-sudan, were approximately double those of browntop millet and crabgrass (McLaughlin et al., 2004). Results indicate that, while pearl millet may not be as high yielding as bermudagrass after establishment, yield potential is sufficient to support ruminant animal production.

A 2-yr study was conducted at the University of Georgia to evaluate the use of two pearl millet cultivars (Tifleaf 1 or Tifleaf 2) planted with two different seeding methods (conventional drill or 3-ft rows) on overall forage quality and beef performance. Four heifers continuously grazed for 84 d on each pasture. Additional heifers were used to manage forage to a height of 0.4 to 0.6 m. No differences were observed among cultivars or seeding method. Average concentrations of cell-wall constituents for both cultivars were 53.5 and 24.9% for NDF and ADF, respectively. Average concentration of CP was 23.9%, and IVDMD was 76.1% (Hill et al., 1999).

McCartor and Rouquette (1977) evaluated a hybrid pearl millet variety (Millex 23) grazed at three different levels of forage availability. During the first yr of the study, ADG was higher (0.96 kg/day) at the low grazing pressure (7.12 head$\cdot$ha$^{-1}\cdot$day^{-1}) than ADG (0.36 kg/day) at the high stocking density (10.61 head$\cdot$ha$^{-1}\cdot$day^{-1}). A similar trend was observed in the second year of the trial, with the lowest stocking density (3.73 head$\cdot$ha$^{-1}\cdot$day^{-1}) having the highest ADG. Hill et al. (1999) reported that, while heifer ADG was unaffected by cultivar, number of grazing days were 13% higher and gain/acre increased 7% for Tifleaf 2 compared with Tifleaf 1 cultivar. Cattle performance differed between years of the study, with higher grazing days/acre in 1993 than 1992. Increased stocking rates in 1993 may have decreased individual ADG of heifers, which is often observed with the put-and-take grazing method.

FORAGE-FINISHING SYSTEMS

Consumer interest in grass-finished beef is increasing in the US, with as many as one-third of consumers preferring the taste of forage-fed beef to grain-fed beef (Cox et al., 2006). Opportunities for year-round, forage-based finishing systems are prevalent in the southeastern US because of mild climatic conditions (Sapp et al., 1999). Traditionally, producers in the Southeast have used perennial warm- and cool-season grasses for cow-calf production, with the calves marketed at weaning for subsequent finishing elsewhere (Stuedemann et al., 1981). However, with significantly higher fuel, fertilizer and feed costs, many cow-calf producers have begun to reevaluate their production regimes. Changes in our current beef production system will likely lead to a new beef/forages paradigm in which considerably less emphasis will be placed on supplementation and more attention will be focused on aggressive management of forage resources (Prevatt, 2008).

The USDA Agricultural Marketing Service standard for the label “grass-finished beef” requires producers to demonstrate 99% or more of the animal’s energy came from grass and/or forage, with the exception of milk consumed by animals prior to weaning (USDA, 2009a). From an animal performance standpoint, cattle finished on all forage-based diets are typically leaner than those finished on a traditional grain-based feedlot diet. Other differences include darker lean color, less fat cover, and grassy sensory attributes (Cranwell et al., 1996; French et al., 2000). In order to provide an adequate amount of energy for finishing cattle, the forage source must be nutrient-rich in order for fat accretion to occur and to provide a product more comparable with feedlot-finished beef (Griebenow et al., 1997).

Perennial grasses such as tall fescue, bermudagrass and bahiagrass form the base of many grazing systems in the southern US (Allen et al., 1996). However, warm-season perennial grasses such as bermudagrass and bahiagrass generally provide low ADG because of their low digestible energy content (Ball et al., 2007). Most tall fescue-based systems in the Southeast are endophyte-infected, and subsequently cause reduced animal performance as well.

Cool-season annuals offer high-quality forage that may support highly satisfactory animal gains, especially for finishing systems, although good pasture management is essential to maintain forage quality throughout the grazing season (Ball et al., 2007). Stuedemann et al. (1981) reported that steers gained more on Coastal bermudagrass overseeded with rye than on tall fescue or a tall fescue-rye mixture. Reagan et al. (1981) finished 14 steers and six heifers on oats, rye and annual ryegrass that graded between Select and Low Choice. Steers finished on ryegrass + arrowleaf clover in Louisiana gained 1.0 kg/d over a 149-d grazing season, with a total gain of 590 kg/ha (Bagley et al., 1989). Choat et al. (2003) reported that cattle fed to a similar 12th rib fat thickness which grazed wheat pasture before finishing required fewer days on feed, and had increased live weight and hot carcass weight at slaughter compared with cattle that had grazed native range grasses in Oklahoma. Kerth et al. (2007) reported that cattle finished on ryegrass alone produced smaller carcasses with less fat and muscling than those on a grain/grass or grain only diet. However, overall magnitude of carcass, fat and sensory disadvantages compared with grain finishing were fairly small, illustrating the potential use of ryegrass for forage-based systems.

Warm-season annual grasses and legumes may also provide pasture for stocker cattle during the finishing phase. However, much less work has been done with finishing cattle in this area due to the cost of establishment and profitability of the short grazing season associated with summer annual species. Pearl millet, sorghums and sorghum-sudangrasses are highly productive and allow high stocking rates, but have relatively high pasture costs (Ball et al., 2007). Larick and Turner (1990) grazed heifers on Tifleaf pearl millet, sorghum-sudangrass, or fescue-clover, and 3 heifers from each forage type were then serially slaughtered after 0, 54 and 82 d of feedlot finishing. Cattle slaughtered directly after the 84-d grazing period finished at a Select-plus quality grade. Since this study, many grazing trials have shown the potential for warm-season annuals for supporting satisfactory liveweight gain during the summer months (Hill et al., 1999; Murphy et al., 1999). However, very few studies have evaluated animal performance and subsequent effects on overall carcass composition and other meat quality attributes of steers grazing summer annual forages. Clemson University scientists have begun to investigate the potential of several summer forage species such as cowpea for finishing systems in the southeast. Schmidt et al. (2009) reported ADG was greater for finishing steers grazing alfalfa (*Medicago sativa*) than bermudagrass, cowpea, or pearl millet treatments, while chicory (*Chichorium intybus*) produced higher ADG than bermudagrass and pearl millet. Cowpea carcasses had the highest quality grades and marbling scores of all forage species evaluated during the 2-yr grazing trial. Dressing percentages were greater for cattle grazing alfalfa and cowpea than bermudagrass or pearl millet; however, dressing percentage from chicory was higher than from bermudagrass.

II. BEEF CATTLE PERFORMANCE, FORAGE PRODUCTIVITY AND QUALITY FROM MIXED SMALL-GRAIN/RYEGRASS PASTURE

INTRODUCTION

A combination of declining feeder calf prices and fluctuating costs of feed, fertilizer and energy are challenging beef producers to place increased emphasis on grazed forages with significantly reduced inputs and improved management (Prevatt, 2008). Winter annuals provide high-quality forage for livestock and have a long production season (Ball et al., 2007). However, distribution of forage growth differs greatly among species, which is an extremely important consideration in planning grazing systems. A significant opportunity exists for using mixtures of ryegrass and small grains that differ in their individual growth pattern to more evenly distribute and ensure availability of high-quality forage through the winter grazing season. While the concept of small-grain/ryegrass mixtures is nothing new, these are all too often used in conventionally managed, continuously grazed systems characterized by underutilization of the small grain component early in the season, resulting in shading out and underproduction of the ryegrass component later in the season (Ball et al., 2007). Research is needed to identify optimum combinations of these forages and improved management practices that will provide greater uniformity and extended availability of high-quality winter forages.

Consumer studies have shown that interest in forage-finished beef exists in the Southeast, with one-third to one-half of consumers preferring the taste of forage-finished beef to that of traditional grain-fed beef (Cox et al., 2006). In order to remain competitive in an increasingly global market, US beef producers must begin to identify the best way to market their product. Rising interest in locally-produced agricultural products provides a base market for forage-finished beef in the Southeast. Moreover, the southeastern US is characterized by optimum conditions for year-round forage production (Sapp et al., 1999), and opportunities to use winter annuals such as ryegrass and small grains such as oats and rye for beef production are prevalent throughout the region.

MATERIALS AND METHODS

Research site

A winter-grazing trial was conducted at the Wiregrass Research and Extension Center in Headland, AL (31.35° lat, 85.34° long). Mean annual precipitation is 114 to 140 cm, and mean annual temperature is 16 to 19 C°. Six paddocks (1.42-ha each) consisting of a Dothan fine sandy loam were demarcated for the experiment. Oats (*Avena* sativa) and rye (*Secale cereale*) were established with ryegrass (*Lolium perenne*) in either binary or ternary mixtures as winter pasture for grazing beef cattle (Figure 1). Pastures had previously been in a winter-annual grazing/summer row-crop rotation and were planted in annual peanut (*Arachis hypogea)* during the late spring until harvest in early fall. Paddocks were tilled on November 4, and forage seed was drilled into the prepared seedbeds on November 5, 2008. Seeding rates were 103 kg/ha of Wren's Abruzzi rye or Harrison oats and 11 kg/ha Marshall ryegrass for binary mixtures, and 52 kg/ha of both rye and oats and 11 kg/ha ryegrass for the ternary mixture. Plots initially received 45 kg N/ha, 67 kg P/ha and 67 kg K/ha as NH_4NO_3, P_2O_5 and K_2O , respectively, on Nov 4, 2008 according to soil test recommendations of the Auburn University Soil Testing Laboratory.

Nitrogen fertilizer in the form of NH_4NO_3 and sulfur fertilizer in the form of $(NH_4)_2SO_4$ were applied on Dec 19, 2008 and Mar 5, 2009 at a rate of 67 kg N/ha and 11 kg S/ha, respectively.

Figure 1. Layout of experimental plots

Treatments

Replicate 1.42-ha pastures of mixtures of oats and ryegrass, rye and ryegrass, and oats and rye and ryegrass were established and initially stocked with 3 yearling Angus × Simmental steers per paddock (initial BW 392 ± 31 kg). Steers were born in the fall of 2007, and were placed on a bermudagrass (*Cynodon dactylon*) pasture after weaning until the beginning of the trial. When forage became limiting during the late fall prior to the experiment, steers were given free access to bermudagrass hay. Steers were treated with Cydectin pour-on dewormer at the beginning of the grazing trial. All steers had free-choice access to salt-mineral mix and water.

Grazing was initiated on January 8, 2009 when forage DM availability had achieved approximately 2,000 kg/ha. Animals were weighed at the end of successive intervals of 28, 28, 32, 29 and 23 d, and grazing was terminated after 140 d on May 28, 2009. Stocking rates were adjusted using put-and-take steers to maintain forages in a vegetative state, and grazing was discontinued when forage availability and quality could no longer support satisfactory animal performance. The study was conducted according to a protocol approved by the Institutional Animal Care and Use Committee of Auburn University.

Forage management, sampling and laboratory analyses

Forages were continuously grazed and aggressively managed throughout the study to maintain a target forage DM availability of 2,000 kg DM/ha. Stocking rate adjustments were made based on calculation of forage availability and animal utilization at the time of sampling (Appendix A). Net change in available forage DM (less trampling, lodging and consumption) was determined for each paddock every 2 wk as the difference in aboveground forage mass between the previous sampling date and the current sampling date. Animal utilization since the previous sampling date was estimated using an assumed DMI of 3% of mean BW. The difference in available forage mass between sampling periods was then added to the amount consumed by cattle within a paddock to derive an estimate of forage DM accumulation during the most recent 2-wk period. Forage accumulation was then added to available forage DM at the time of sampling to determine a projected amount of available forage DM during the next 2-wk period. Amount of projected available forage over 2,000 kg DM/ha was regarded as that requiring management using put-and-take steers. Cattle were predicted to utilize 60% of the total amount of projected available forage growth over 2,000 kg DM/ha to account for waste and trampling. Stocking rate adjustments were determined based on amount of predicted consumption by cattle within a paddock over a 2-wk period.

Forage mass and nutritive quality were determined by clipping 0.25-m^2 quadrats (8 per paddock) prior to the beginning of grazing and every 2 wk during the trial. Forage within quadrats was clipped to leave an aboveground stubble height of approximately 2 cm. Fresh-cut forage was then placed into plastic, zip-closure storage bags and stored on ice for transportation back to the Auburn University Ruminant Nutrition Laboratory. Samples from each paddock were placed in a tared paper bag, oven-dried at 60°C for 72 hr, air-equilibrated and weighed. DM availability was calculated for each paddock based on dry-weight data multiplied by the area of the paddock.

Dried, air-equilibrated forage samples were ground in a Wiley mill to pass a 1-mm screen. Concentration of DM was determined by drying samples to constant weight at 100°C according to procedures of AOAC (1995). Concentrations of NDF, ADF and ADL were determined according to the procedures of Van Soest et al. (1991). Forage concentration of N was determined according to the Kjeldhal procedure (AOAC, 1995), and CP was calculated as N

× 6.25. Samples were prepared for total non-structural carbohydrate (TNC) analysis according to a modification of the Weinmann (1947) procedure for fructosan accumulators. Samples weighing 0.20 to 0.25 g were boiled in 0.05 N H_2SO_4 for 1 h, placed in a shallow ice bath, and 1.0 N NaOH (2.5 to 3.9 mL) was added to adjust the pH of the sample to 4.5. One mL of diluted amyloglucosidase (*Aspergillus niger*, Lot No. A 9913, Sigma-Aldrich, Inc., St. Louis, MO) solution was added to samples, which were then covered and incubated at 60°C for 1 hr. Samples were filtered and brought to volume in a 250-mL volumetric flask with 2 mL of 0.1 N NaOH and deionized H_2O. Ten mL of Sheffer-Somogyi reagent (AOAC, 1995) were combined with a 10-mL aliquot of sample in a 25 × 200 mm capped test tube and boiled for 15 min. Test tubes were then cooled in an ice bath and 2 mL of potassium iodide-potassium oxalate solution were added to each sample. Next, 10 mL of 1.0 N H_2SO_4 and 1 mL of gelatinized starch solution were added to each tube prior to titration. Samples were titrated with 0.02 N sodium thiosulfate until the solution turned sky blue. Concentration of TNC in samples was calculated as the amount of reducing sugar in the sample, multiplied by the dilution factor × 100, divided by the sample weight.

Forage *in vitro* dry matter digestibility (IVDMD) was determined according to the Van Soest (1991) modification of the Tilley and Terry procedure (1963) using the Daisy^{II} incubator system (Ankom Technology^{TM}). Ruminal fluid was collected from a fistulated, dry Holstein cow at the Auburn University College of Veterinary Medicine. The cow was fed a corn silage-based diet containing cottonseed meal and Megalac^{TM} supplement, and given free access to bermudagrass pasture and alfalfa (*Medicago sativa*) hay. Fluid was stored in pre-warmed thermos containers to maintain a temperature supportive of the microbial population and transported to the Auburn University Ruminant Nutrition laboratory where it was then prepared for the batch-culture IVDMD procedure.

Statistical analyses

Data were analyzed using the PROC GLM procedure (SAS Inst. Inc., Cary, NC) for a completely randomized design. Data were analyzed by individual weigh period because of unequal number of days in each period. Treatment means were separated by the LSMEANS procedure (SAS Inst. Inc., Cary, NC) when protected by a F-test significant at $\alpha = 0.10$. Stepwise linear regression analysis was conducted according to the PROC REG procedure (SAS Inst. Inc., Cary, NC) to detect predictive statistical associations between forage characteristics and steer ADG.

RESULTS

Temperature and precipitation

Monthly mean air temperatures were slightly higher than 30-yr averages for Headland, AL (Table 1). For January and February, monthly total precipitation (Table 2) was 69 and 60% lower, respectively, than the 30-yr average. Precipitation was 16, 50 and 118% greater than the 30-yr average in March, April and May, respectively.

Table 1. Monthly mean air temperatures (°C) for January to May 2009, and 30-yr averages for Headland, AL.

Month	Avg. High, C°	Avg. Low, C°	Mean, C°	30-yr avg., C°
January	18	6	12	9
February	18	5	12	11
March	22	11	17	15
April	25	12	19	19
May	29	19	24	23

Table 2. Monthly total precipitation (mm) for January to May 2009, and 30-yr averages for Headland, AL.

Month	Precipitation, mm	30-yr avg., mm
January	50	160
February	53	132
March	182	157
April	146	97
May	233	107

Dry matter availability

Differences were observed in DM availability among forage treatments within each period of the experiment. From Jan 8 to Feb 5, R-RG had 494 and 437 kg DM/ha greater available forage DM than O-RG ($P = 0.0456$) and O-R-RG ($P = 0.0242$), respectively. The opposite pattern was observed in the second period, in which R-RG had lower DM availability than O-RG ($P = 0.0421$) and O-R-RG ($P = 0.0098$). However, beginning in the third period, mixed pastures containing rye had decreased DM availability compared with O-RG. Differences among treatments were most evident in the fourth period, in which O-RG had 129% and 157% greater available DM than O-R-RG ($P = 0.0001$) and R-RG ($P = 0.0001$), respectively. In the final period, DM availability decreased dramatically for all forage mixtures, although O-RG available DM was still 78% and 134% greater, respectively, than that in the O-R-RG ($P = 0.0012$) and R-RG ($P = 0.0001$) mixed-pasture systems.

Table 3. Forage availability (kg DM/ha) in mixed small-grain/ryegrass pastures.

	Treatment[1]			
Period	O-RG	R-RG	O-R-RG	SE
Jan 8 to Feb 5	2,110^{a}	2,604^{b}	2,167^{a}	153
Feb 5 to Mar 5	2,611^{a}	2,145^{b}	2,741^{a}	160
Mar 5 to Apr 6	2,185^{a}	1,488^{b}	1,671^{b}	129
Apr 6 to May 5	3,260^{a}	1,270^{b}	1,426^{b}	134
May 5 to May 28	1,787^{a}	767^{b}	1,005^{b}	160

[1] O-RG = oats and ryegrass; R-RG = rye and ryegrass; O-R-RG = oats and rye and ryegrass.
^{a,b}Within a row, means without common superscripts differ ($P < 0.10$).

Average daily gain

Cattle ADG from Apr 6 to May 5 (Table 4) was lower for R-RG than the O-RG (P = 0.0075) and O-R-RG (P = 0.0275) treatments. No differences were observed in ADG among treatments from Jan 8 to Feb 5 (P = 0.3902), Feb 5 to Mar 5 (P = 0.7444), Mar 5 to Apr 6 (P = 0.1495) or May 5 to May 28 (P = 0.2943). Average daily gain over the 140-d grazing period was greater for O-RG than R-RG (P = 0.03), but was not different from that of O-R-RG (P = 0.16).

Table 4. Average daily gain (kg/d) of steers grazing mixed small-grain/ryegrass pastures.

	Treatment[1]			
Period	O-RG	R-RG	O-R-RG	SE
Initial BW, kg	351	362	355	4.56
Final BW, kg	536	523	532	13.0
ADG, kg				
Jan 8 to Feb 5	1.60	1.48	1.63	0.08
Feb 5 to Mar 5	2.03	1.87	1.90	0.16
Mar 5 to Apr 6	1.37	1.31	1.06	0.11
Apr 6 to May 5	1.30^{a}	0.68^{b}	1.17^{a}	0.14
May 5 to May 28	0.07	0.26	0.39	0.14
Jan 8 to May 28	1.38^{a}	1.13^{b}	1.26^{a}	0.05

[1] O-RG = oats and ryegrass; R-RG = rye and ryegrass; O-R-RG = oats and rye and ryegrass.
[a,b] Within a row, means without common superscripts differ ($P < 0.10$).

Grazing days

No differences were observed among treatments for steer-grazing-days over the 140-d grazing trial (Table 5). From Apr 6 to May 5, steer-grazing-days were greater for O-RG than R-RG (P = 0.0290) and O-R-RG (P = 0.0391) treatments. No differences among treatments were observed in the other periods.

Table 5. Steer-grazing-days from mixed small-grain/ryegrass pastures.

	Treatment[1]			
Period	O-RG	R-RG	O-R-RG	SE
Jan 8 to Feb 5	84	122	101	24.4
Feb 5 to Mar 5	154	98	133	16.6
Mar 5 to Apr 6	128	118	175	22.7
Apr 6 to May 5	170[a]	101[b]	109[b]	12.3
May 5 to May 28	126	80	69	33.9
Jan 8 to May 28	655	547	625	48.5

[1] O-RG = oats and ryegrass; R-RG = rye and ryegrass; O-R-RG = oats and rye and ryegrass.
[a,b] Within a row, means without common superscripts differ ($P < 0.10$).

Crude protein

Forage concentration of CP (Table 6) was lower for O-RG than O-R-RG (P = 0.0658) and R-RG (P = 0.0308) from Feb 5 to Mar 5. From Mar 5 to Apr 6, CP concentration was lower for O-R-RG than the O-RG (P =0.0513) and R-RG (P = 0.0067) treatments, but not different (P = 0.2399) between O-RG and R-RG. No differences were observed among treatments in forage concentration of CP in any other periods throughout the grazing trial.

Table 6. Forage concentration (%, DM basis) of CP in mixed small-grain/ryegrass pastures.

	Treatment[1]			
Period	O-RG	R-RG	O-R-RG	SE
Jan 8 to Feb 5	21.5	22.0	22.3	2.35
Feb 5 to Mar 5	12.1^a	15.6^b	15.0^b	0.98
Mar 5 to Apr 6	18.6^a	19.5^a	16.9^b	0.52
Apr 6 to May 5	12.6	14.3	13.9	0.62
May 5 to May 28	12.9	13.6	12.2	1.51

[1] O-RG = oats and ryegrass; R-RG = rye and ryegrass; O-R-RG = oats and rye and ryegrass.
[a,b] Within a row, means without a common superscript differ ($P < 0.10$).

Cell wall constituents

No differences were observed among treatments in forage NDF concentration (Table 7) from Jan 8 to Feb 5 (*P* = 0.4848), Apr 6 to May 5 (*P* = 0.7402) and May 5 to May 28 (*P* = 0.5359). However, O-RG forage had lower NDF concentration than O-R-RG (*P* = 0.0654) and R-RG (*P* = 0.0009) treatments, respectively, and O-R-RG contained less NDF (*P* = 0.0229) than R-RG from Feb 5 to Mar 5. Concentration of NDF was also lower for O-RG forage than O-R-RG (*P* = 0.0037) and R-RG (*P* = 0.0081) treatments from Mar 5 to Apr 6. Forage concentration of ADF (Table 8) followed a similar pattern. From Feb 5 to Mar 5, O-RG contained less ADF than O-R-RG (*P* = 0.0231) and R-RG (*P* = 0.0014), and O-R-RG contained less (*P* = 0.1065) ADF than R-RG. From Mar 5 to Apr 6, O-RG forage had 3.3 and 2.3 percentage units lower ADF concentration than O-R-RG (*P* = 0.0253) and R-RG (*P* = 0.0932) treatments, respectively. During the first period of the experiment, concentration of ADL (Table 9) was higher for R-RG than O-RG (*P* = 0.0251) and O-R-RG (*P* = 0.0321) treatments. No differences were observed among treatments in forage concentration of ADL throughout the remainder of the trial.

Table 7. Forage concentration (%, DM basis) of NDF in mixed small-grain/ryegrass pastures.

	Treatment[1]			
Period	O-RG	R-RG	O-R-RG	SE
Jan 8 to Feb 5	37.9	38.7	36.6	1.23
Feb 5 to Mar 5	42.7^a	49.8^b	45.8^c	1.03
Mar 5 to Apr 6	49.8^a	54.5^b	55.2^b	0.98
Apr 6 to May 5	52.4	53.8	51.4	2.16
May 5 to May 28	68.8	65.3	64.7	2.67

[1] O-RG = oats and ryegrass; R-RG = rye and ryegrass; O-R-RG = oats and rye and ryegrass.
[a,b,c] Within a row, means without a common superscript differ (*P* < 0.10).

Table 8. Forage concentration (%, DM basis) of ADF in mixed small-grain/ryegrass pastures.

	Treatment[1]			
Period	O-RG	R-RG	O-R-RG	SE
Jan 8 to Feb 5	28.7	28.5	28.6	3.11
Feb 5 to Mar 5	22.1^a	27.8^b	25.6^c	0.90
Mar 5 to Apr 6	27.6^a	29.9^b	30.9^b	0.87
Apr 6 to May 5	27.9	28.1	27.1	1.06
May 5 to May 28	38.5	39.6	35.5	3.22

[1] O-RG = oats and ryegrass; R-RG = rye and ryegrass; O-R-RG = oats and rye and ryegrass.
[a,b,] Within a row, means without a common superscript differ (*P* < 0.10).

Table 9. Forage concentration (%, DM basis) of ADL in mixed small-grain/ryegrass pastures.

	Treatment[1]			
Period	O-RG	R-RG	O-R-RG	SE
Jan 8 to Feb 5	0.39^a	0.61^b	0.39^a	0.06
Feb 5 to Mar 5	0.53	1.27	0.91	0.26
Mar 5 to Apr 6	1.09	1.65	1.29	0.26
Apr 6 to May 5	1.05	1.87	0.94	0.35
May 5 to May 28	3.20	2.49	2.34	0.42

[1] O-RG = oats and ryegrass; R-RG = rye and ryegrass; O-R-RG = oats and rye and ryegrass.
^{a,b,c}Within a row, means without common superscripts differ ($P < 0.10$).

Non-structural carbohydrates

Concentration of total non-structural carbohydrates (Table 10) from Feb 5 to Mar 5 was greater for O-RG than O-R-RG ($P = 0.0040$) and R-RG ($P = 0.0003$) forages, and O-R-RG was greater ($P = 0.0784$) than R-RG. Concentration of TNC in all treatments decreased from Mar 5 to Apr 6, with R-RG containing lower TNC concentration than both O-RG ($P = 0.0001$) and O-R-RG ($P = 0.0213$), and O-RG containing greater ($P = 0.0008$) TNC concentration than O-R-RG in the third period. No differences among treatments were observed in concentration of TNC from Jan 8 to Feb 5, Apr 6 to May 5, and May 5 to May 28.

Table 10. Forage concentration (%, DM basis) of total non-structural carbohydrates in mixed small-grain/ryegrass pastures.

	Treatment[1]			
Period	O-RG	R-RG	O-R-RG	SE
Jan 8 to Feb 5	18.0	15.8	17.3	3.26
Feb 5 to Mar 5	24.9^a	13.6^b	17.5^c	1.37
Mar 5 to Apr 6	12.0^a	7.4^c	9.0^b	0.42
Apr 6 to May 5	17.8	15.3	17.5	1.61
May 5 to May 28	8.1	6.3	8.0	0.91

[1] O-RG = oats and ryegrass; R-RG = rye and ryegrass; O-R-RG = oats and rye and ryegrass.
[a,b,c] Within a row, means without common superscripts differ ($P < 0.10$).

In vitro dry matter digestibility

Percentage IVDMD (Table 11) was not different between O-RG and O-R-RG (P = 0.7211), but was greater for O-RG (P = 0.0825) and O-R-RG (P = 0.0.0389) than R-RG from Jan 8 to Feb 5. Digestibility of O-RG was greater than that of O-R-RG ($P = 0.0235$) and R-RG ($P = 0.0011$) treatments, and digestibility of O-R-RG and R-RG were not different ($P = 0.1912$) within the second period. Mixed pastures of O-RG had greater digestibility than R-RG ($P = 0.0445$) and O-R-RG ($P = 0.0009$), and R-RG had greater ($P = 0.1004$) digestibility than O-R-RG from Mar 5 to Apr 6. No differences were observed among forage treatments for digestibility in all other periods during the experiment.

Table 11. Percentage IVDMD (%) of mixed small grain/ryegrass pasture.

	Treatment[1]			
Period	O-RG	R-RG	O-R-RG	SE
Jan 8 to Feb 5	95.5^{a}	92.7^{b}	95.0^{a}	0.59
Feb 5 to Mar 5	91.3^{a}	88.3^{b}	89.3^{b}	0.55
Mar 5 to Apr 6	88.3^{a}	83.1^{b}	78.8^{c}	1.74
Apr 6 to May 5	82.4	78.5	79.6	1.94
May 5 to May 28	68.1	65.1	71.1	2.57

[1] O-RG = oats and ryegrass; R-RG = rye and ryegrass; O-R-RG = oats and rye and ryegrass.
[a,b,c] Within a row, means without common superscripts differ ($P < 0.10$).

Stepwise linear regression

Forage concentration of ADF accounted for approximately 74% of the variation in ADG ($r^2 = 0.7425$). Concentration of NDF entered the model with a partial r^2 of 0.0897, and accounted for an additional 9% of the variation in ADG throughout the grazing trial.

Table 12. Linear regression of independent variables of forage characteristics[1] on ADG[2] by steers grazing mixed small grain/ryegrass pasture.

Independent variable	Intercept	Partial r^2	Model r^2
ADF	-0.06297	0.7425	0.7425
NDF	-0.02939	0.0897	0.8322

[1] ADF = acid detergent fiber, NDF = neutral detergent fiber.
[2] ADG = average daily gain.

DISCUSSION

Except for April, mean temperatures between January and May exceeded 30-yr averages for Headland, AL but were still within the optimum temperature range for growth of small grains and ryegrass (USDA, 2009b,e,g). Average precipitation during January and February was considerably below 30-yr averages, but was adequate to support satisfactory forage growth during the experiment (USDA, 2009b,e,g). Beginning in March, average precipitation was considerably greater than the 30-yr average, which may have impacted overall forage productivity. Beck et al. (2005) reported that climatic conditions may have a large impact on the growth of winter annual grasses, and may affect individual species differently. In January, initial DM availability of forage mixtures was greatest for R-RG, with an average of 2,604 kg DM/ha. Bruckner and Raymer (1990) reported that seasonal distribution of small-grain forages was most evident in January and February when rye produced greater forage yields than triticale, oats and wheat. Moreover, because rye is more cold-tolerant than the other common small-grain species, it is often available and ready for grazing earlier in the growing season (Ball et al., 2007). Although mean temperature was similar in January and February, visual frost damage was evident in pastures containing oats during mid-January. Because oats is more cold-sensitive than rye, low temperatures may have temporarily stunted oats production until consistently higher daily temperatures were achieved. Yield distribution favored the production of oats during the second 28-d period when DM availability of O-RG and O-R-RG were greater than R-RG. Differences in seasonal growth distribution of the small grains was evident during this period, with slightly increasing productivity of oats observed following that of rye (Ball et al., 2007). Forage DM availability in mixtures containing rye steadily decreased throughout the remainder of the experiment under intensive management conditions. Vendramini et al. (2006) observed similar results with rotationally grazed R-RG pastures in which herbage mass decreased from 2,100 to 1,600 kg DM/ha from February to April in the second yr of a 2-yr grazing trial. However, forage availability in O-RG mixed pasture continued to exceed 2,000 kg DM/ha until the final period. Differences in forage DM availability were most apparent during the fourth period when DM availability of O-RG was twice that of pastures containing rye. Yield was most likely highest during this time due to oats reaching maximum productivity and maturity, along with peak productivity of ryegrass. Redfearn et al. (2005) noted that the greatest forage production of ryegrass occurs from March onward, although yield is dependent on variety selection. Although Jennings (2005) reported that oats may be slightly lower yielding than the other small-grain species, when planted in a mixture with ryegrass, O-RG proved to be the most productive forage mixture in the present study.

Average daily gain differed among forage treatments during the fourth period of the trial and across the entire grazing season in which mixtures containing oats were superior to R-RG for supporting animal gain. In the present study, increased ADG observed for mixtures containing oats contrasts with values reported by Beck et al. (2005). Results from a 3-yr grazing trial in Arkansas revealed that spring ADG of stocker calves on R-RG was 19% greater than that of cattle grazing oats, rye, wheat + rye, and wheat + rye + ryegrass (Beck et al., 2005). However, when small-grain/ryegrass mixtures were interseeded into bermudagrass sod, Beck et al. (2007) reported ADG from O-RG was intermediate to that of other mixed-pasture systems and not different among treatments during yr 1 of the grazing trial. In yr 2, no significant differences were observed among treatments in spring ADG of mixed pastures, and ADG for cattle grazing O-RG pasture was 1.33 kg/d, which compares favorably with values observed for O-RG pasture in the present study. Cattle ADG from O-R-RG was slightly higher than that (0.98 kg/d) observed by Myer et al. (2008) in a grazing trial in Florida. Although R-RG pasture produced the lowest ADG in the present study, these results agree with those from a study reported by Cleere et al. (2004) in which steers grazing a combination of R-RG gained between 1.01 and 1.28 kg/d from December to May across two stocking rates and grazing systems in Overton, TX.

The number of steer-grazing-days for each pasture treatment is a meaningful indicator of its animal carrying capacity and productivity. Animal carrying capacity is defined as the maximum stocking rate that will achieve a target level of animal performance and forage utilization from a specified grazing method (i.e., intensive grazing management), that can be applied over a defined time period without deterioration of the ecosystem (Forage and Grazing Terminology Committee, 1991). Therefore, as the amount of forage DM availability in a pasture increases, the potential exists to increase the stocking rate, subsequently increasing the number of steer-grazing-days per pasture. Number of steer-grazing-days was greatest for O-RG during the fourth period due to increased forage DM availability, and capacity to support increased stocking rate as indicated by increased necessity for forage management using put-and-take steers. Across the entire grazing season, forage treatments containing oats had ≥ 625 steer-grazing-days. Comparable results were observed for O-RG overseeded into bermudagrass sod for which Beck et al. (2007) observed 595 grazing-days/ha (yr 1) and 697 grazing-days/ha (yr 2) over a 2-yr grazing trial in Arkansas. Myer et al. (2008) observed slightly fewer grazing-days/ha for O-R-RG (421 d/ha) and O-RG (403 d/ha) in a grazing trial in Florida.

Concentration of CP is an important measure of forage quality. While annual forage grasses may be lower yielding and less responsive to applied nutrients, they generally have greater nutrient concentrations than perennial grasses (Robinson, 1996). Concentration of CP was greatest for all treatments (≥ 21%) during the first 28 d of the trial, which is expected for cool-season annual forages in the vegetative state. An increase in CP was observed between the second and third period, which may be attributed in part to application of NH_4NO_3 fertilizer at the beginning of March. Forage concentration of CP decreased from roughly 22 to 12% across the entire grazing season. Redfearn et al. (2002) observed a similar pattern for concentration of CP in ryegrass from December to May (26 to 12%) in Oklahoma. Ball et al. (2007) reported a decline in concentration of CP in rye of 28, 24 and 13% at the vegetative, flower/boot and fruit/head stages of maturity, respectively. Moreover, forage quality of small grains declined with the onset of maturity at the May harvest date in Ohio forage variety trials (Samples and Sulc, 2000). Concentration of CP varied considerably within treatments after the first harvest, illustrating changes in forage quality with increasing plant maturity.

Total cell-wall constituents (i.e., fiber) are key determinants of forage DMI and digestibility. Forage concentration of NDF, which consists of hemicellulose, cellulose and lignin, is inversely related to voluntary forage DMI in ruminants, whereas concentration of ADF, which consists of cellulose and lignin, is inversely related to forage DM digestibility (Van Soest, 1994). During the second period, mixed pastures containing oats contained less NDF than R-RG pastures. Concentration of NDF during the third period was lower for O-RG than the other treatments, which may be partially attributed to the seasonality of the forage mixture. The combination of increased productivity from oats and peaking productivity of the ryegrass component may have provided a greater flush of vegetative plant growth of higher quality than in pastures containing rye. Spring productivity of ryegrass was illustrated over a 2-yr trial at four locations in Oklahoma (Redfearn et al., 2002) in which 40% of the total forage production of different ryegrass cultivars occurred early in the growing season (December through February), and 60% occurred as late-season growth (March through May) . Across the entire grazing season, forage NDF concentration ranged from 37 to 69% for all treatments. These results are consistent with those of Redfearn et al. (2002), who reported that concentration of NDF in ryegrass increased (39 to 58%) across the growing season. Moreover, Juskiw et al. (2000) observed NDF concentration of >50% for barley, oats and triticale in the dough stage of development prior to harvest.

Concentration of ADF decreased between the first and second period, with mixtures containing oats having less ADF than R-RG. The observed decrease in ADF contrasts with the increasing pattern of NDF observed during the same time period. In the third period, O-RG contained less ADF than forage treatments containing rye. Mean concentration of ADF increased within each forage treatment throughout the remainder of the experiment, which is expected with advancing plant maturity. Juskiw et al. (2000) reported 32% ADF for oats in the dough stage of development, and similar values for other small grains. Concentration of ADF in the final period was slightly higher than those reported by Juskiw et al. (2000), which may reflect that forages were slightly more mature than dough stage of development.

Lignin is a polyphenolic compound that confers rigidity to plant cell walls and provides resistance to biodegradation (Van Soest, 1994). Lignin evolved as part of the defense system that plants use to protect themselves against herbivory, and it is considered the most significant factor limiting the availability of plant cell wall material for digestion by herbivores (Van Soest, 1994). Concentration of ADL was lowest during the first period during which forages in all treatments contained less than 1% lignin. Lignin concentration increased with increasing plant maturity as expected, although ADL never exceeded 3.2% throughout the grazing trial. Observed concentrations of ADL for forage species in the present study are relatively low, but are comparable to values reported by Muir and Bow (2009) for cool-season annual forages grown under nutrient-rich conditions. During the first year of the trial, mean concentration of ADL was less than 3% for barley, oats, triticale, rye and ryegrass from September to April in Stephenville, TX (Muir and Bow, 2009). Mean concentration of ADL was greater than 5% for the small grains and ryegrass in yr 2 and yr 3 because of increased yield compared with yr 1, as well as varying environmental conditions.

Carbohydrates are the most abundant class of compounds found in plants, accounting for 50 to 80% of the dry biomass of forage species, and may be structural or non-structural in nature (Moore and Hatfield, 1994). The majority of non-structural carbohydrates are rapidly and completely degraded within the rumen, while degradability of structural carbohydrates varies considerably (Nocek and Tamminga, 1991). Simple sugars and polysaccharides are degraded and rapidly fermented to VFA in the rumen, and can represent a substantial portion of the digestible energy obtained by ruminants consuming forages (Moore and Hatfield, 1994). Concentration of TNC was greater for O-RG than O-R-RG and R-RG forages in the second period of the grazing trial. Van Soest (1994) reported cool-season grasses contain 30 to 60 g/kg DM soluble sugars, 0 to 20 g/kg DM starch and 30 to100 g/kg DM fructans, which additively is comparable to the total concentration of TNC observed in the present study for pastures containing oats. Chatterton et al. (1989) reported higher values for cool-season forages grown at 10°/5°C (light/dark) compared with 25°/15° C. Cool-season forages grown at 10°/5°C contained 312 mg/kg TNC, which is comparable with growing conditions in the present study. Forage concentrations of TNC decreased between the second and third period; however, concentration of TNC in O-RG was still greater than that of mixtures containing rye. Concentration of TNC in forages is highly variable and is dependent upon planting date, diurnal variation, environmental conditions and stage of maturity. Concentration of TNC in two cultivars of perennial ryegrass averaged 19%

over four different growth stages in Pennsylvania (Jung et al., 1976). Chatterton et al. (2006) noted that sugar concentration was generally highest when oat forage plants were young (tiller and joint growth stages) and concentration of fiber was relatively low. Glucose, fructose and sucrose averaged 15% of DM in hay in the boot stage, and declined to 1 to 2% of DM with increasing plant maturity. Starch was present in low concentrations in vegetative plants (3 to 4%) and increased with plant maturity (10 to 15%).

Forage *in vitro* dry matter digestibility (IVDMD) is a reliable predictor of its *in vivo* digestibility by the ruminant animal. Jensen (2003) reported ≥ 893 g/kg *in vitro* true digestibility of perennial ryegrass grown under five water-status regimes and multiple harvests across multiple years. Comparable results were observed during the first period of the present study when IVDMD was ≥ 92.7% for all treatments. In the second period, digestibility was greatest for O-RG compared with mixtures containing rye, and IVDMD values were ≥ 88.3% for all treatments. Values observed for IVDMD of mixed small grain/ryegrass pasture in the first and second period of the present study were higher than those observed in other studies with cool-season annual pastures. Moyer and Coffey (2000) reported average IVDMD for rye cultivars was 74.5%, 69.8% for wheat cultivars, and 72.1% for barley in an evaluation of forage quality of small grains grown in monoculture. Redfearn (2002) observed a decrease in IVDMD of annual ryegrass from 84 to 70% with increasing plant maturity. The relatively high values observed for digestibility during the first two months of the present study may be attributed to the extremely low concentrations of cell wall constituents, notably lignin, observed during the beginning of the grazing trial. Forages in the young, vegetative state are very high in quality (i.e., low concentration of NDF and ADF) and, if not extensively lignified, structural components of the cell wall are more readily available for digestion. Chesson (1982) recognized that the degradation of cell wall polysaccharides is affected as much or more by interactions among cell wall polymers as by the individual properties of the polymers themselves, which regulates the extent to which they are utilized by ruminal microorganisms. Forage IVDMD decreased across the grazing trial for all treatments, which is expected with increasing plant maturity.

Approximately three-fourths of the variation in ADG across treatments was accounted for by forage concentration of ADF as determined by stepwise multiple regression analysis. Forage concentration of NDF also entered the model, but only accounted for an additional 9% of the variation in ADG. Cattle ADG was greatest during the second period for mixtures containing oats, in which a decrease in forage concentration of ADF was observed between the first and second period. Moreover, ADF was lower for O-RG pasture than other forage mixtures during the third period, which presumably translated into greater digestibility of O-RG pasture than other treatments. Environmental factors may have also played a key role in changes in forage quality. Beck et al. (2005) reported that warm, wet conditions may cause increasing forage maturity in the rye component of mixed pastures, causing a reduction in animal performance. Moreover, Ball et al. (2007) noted that, although rye is generally available earlier, it matures and loses quality earlier and faster than oats.

In conclusion, mixed pastures containing oats were superior to R + RG for supporting beef cattle production from winter grazing, primarily as a result of less rapid changes in forage quality across the grazing trial. When DM yield and availability are managed aggressively as in the present study compared with more extensively managed, continuously grazed systems, forage quality becomes the primary factor involved in the support of adequate ADG for finishing beef cattle grazing cool-season annuals.

III. BEEF CATTLE FINISHING PERFORMANCE, FORAGE PRODUCTIVITY AND QUALITY FROM SUMMER ANNUAL PASTURE

INTRODUCTION

While cool-season annual forages have been shown to support highly satisfactory liveweight gain during the winter months, research is needed to identify optimum combinations and sequences of winter and summer forages for growing and finishing beef cattle in year-round production systems. Most summer-grazing systems in the Southeast are based largely on perennial C_4 forage species such as bermudagrass, bahiagrass and dallisgrass. Nutritive quality of these grasses declines in the latter part of growing season and is often insufficient to meet nutrient requirements of finishing beef cattle (Foster et al., 2009). As cattle begin to approach chemical maturity, lean tissue growth continues at a decreasing rate and fat accretion begins to occur more rapidly at this time. However, the energy requirement for fat deposition is greater than that of lean tissue growth. It is estimated that lean protein deposition represents 4 Kcal per 1 g lean tissue compared with 9 Kcal per 1 g of fat tissue (NRC, 1996). Fat accretion in the finishing phase is important because USDA quality grade of beef carcasses is based primarily on the amount of marbling. In order to produce a high-quality product from forage-based finishing systems, it is important to identify grazing system combinations that will support the increased energy needs of animals in the finishing phase.

While annual forage grasses may be lower yielding and less responsive to applied nutrients, these forages generally have higher nutrient concentrations than perennial grasses (Robinson, 1996). Because annual forages tend to be high in quality, opportunity exists to potentially incorporate these forages into grazing systems for finishing cattle. Annual forage-legume species are typically high in nutritive quality with potential to provide the needed nutrients for beef cattle production. Warm-season annual legumes may be used in grazing systems or stored as hay, silage or haylage that may be fed in the winter as a supplement to stored or stockpiled grasses (Foster et al., 2009). Escalating costs of farm inputs have also made N-fixing legumes more attractive to producers as alternative forage. Clovers and other leguminous species have the ability to obtain N from the atmosphere and fix it in nodules of the plant root system, which may reduce the input of commercial fertilizer in forage production systems. Evers (1985) reported that bermudagrass pastures accumulated 60 kg N/ha and, when overseeded with 'Yuchi' arrowleaf clover or subterranean clover, N accumulation was 184 and 217 kg /ha, respectively. Residual N from legume systems may be beneficial in intensive crop rotation systems. Moreover, legumes are high in nutritive quality and digestibility, and decline of nutritive quality in legumes with increasing maturity is less rapid than warm-season perennial grasses, making them an attractive option for summer-finishing systems (Ball et al., 2007).

MATERIALS AND METHODS

Research site

A summer grazing trial was conducted at the E.V. Smith Research Center in Shorter, AL (32^o 26' lat, 85^o 53' long). Mean annual precipitation is 127 cm, and mean annual temperature is 18° C. Six paddocks (2.02-ha each) consisting of a Riverview silt loam and a Toccoa fine sandy loam were demarcated for the experiment. Cowpea (*Vigna unguiculata*), pearl millet (*Pennisetum glaucum*) and lablab (*Lablab purpureus*) were established as summer pasture for a beef cattle forage-finishing system. Pastures had previously been planted in annual ryegrass

(*Lolium perenne*) for grazing beef cattle. Paddocks were tilled on June 3, and cowpea and pearl millet were planted in prepared seedbeds on June 4, 2009. Lablab planting date was delayed due to excessive rainfall and was planted in prepared seedbeds on June 11, 2009. Legumes were inoculated prior to planting in order to promote root nodulation and N-fixation. Seeding rates were 57 kg/ha for Iron-Clay cowpea, 45 kg/ha for Rio Verde lablab and 23 kg/ha for Tifleaf 3 pearl millet. Pearl millet plots initially received 67 kg/ha of N fertilizer in the form of NH_4NO_3 at the time of planting and again in mid-August based on Alabama Cooperative Extension fertilization recommendations.

Treatments

Following establishment, replicate 2.02-ha pastures of cowpea, pearl millet, and lablab were stocked with 6 yearling Angus × Simmental steers per paddock (initial BW 531 ± 94 kg). Steers were born in the fall of 2007 and used previously in the cool-season annual growing phase of this experiment. After the completion of the winter grazing trial, steers were transported from the Wiregrass Research and Extension Center in Headland, AL to the E. V. Smith Research Center in Shorter, AL for the finishing phase of the experiment. Steers were placed on a tall fescue-bermudagrass mixed pasture until the initiation of the summer-annuals grazing trial.

Grazing was initiated on July 14 for cowpea and pearl millet, and on July 21, 2009 for lablab when forage dry matter (DM) availability had achieved approximately 2,000 kg DM/ha. Animals were weighed every 28 d, and grazing was terminated on September 29, 2009 when forage availability and quality could no longer support satisfactory animal performance. The study was conducted according to a protocol approved by the Institutional Animal Care and Use Committee of Auburn University.

Forage management, sampling, and laboratory analyses

Paddocks within forage treatments were rotationally grazed every 2 wk followed by 2 wk of rest to allow adequate regrowth throughout the study and to maintain a forage DM availability of at least 2,000 kg DM/ha. In order to keep forage in a vegetative state and maintain nutritive quality, pearl millet pastures were clipped once in mid-August to prevent forage maturation from occurring too rapidly.

Forage mass and nutritive quality were determined by clipping 0.25-m^2 quadrats (12 per paddock) prior to the beginning of grazing and once a month during the trial. Forage within quadrats was clipped to leave an aboveground stubble height of approximately 2 cm. Fresh-cut forage was then placed into plastic, zip-closure storage bags and stored on ice for transportation back to the Auburn University Ruminant Nutrition Laboratory. Samples from each paddock were placed in a tared paper bag, oven-dried at 60°C for 72 hr, air-equilibrated and weighed. Forage DM availability was calculated for each paddock based on dry-weight data multiplied by the area of the paddock.

Dried, air-equilibrated forage samples were ground in a Wiley mill to pass a 1-mm screen. Concentration of DM was determined by drying samples to constant weight at 100°C according to the procedures of AOAC (1995). Concentrations of NDF, ADF and ADL were determined according to the procedures of Van Soest et al. (1991). Forage concentration of N was determined according to the Kjeldhal procedure (AOAC, 1995), and CP was calculated as N × 6.25.

Forage *in vitro* dry matter digestibility (IVDMD) was determined according to the Van Soest (1991) modification of the Tilley and Terry procedure (1963) using the Daisy^{II} incubator system (Ankom Technology^{TM}). Ruminal fluid was collected from a fistulated, lactating Holstein cow at the Auburn University College of Veterinary Medicine. The cow was fed a corn silage-based diet containing cottonseed meal and Megalac^{TM} supplement and had free access to bermudagrass pasture and alfalfa (*Medicago sativa*) hay. Ruminal fluid was placed into pre-warmed thermos containers to maintain a temperature supportive of the microbial population, and then transported to the Auburn University Ruminant Nutrition laboratory where it was further processed for the batch-culture fermentation procedure.

Statistical analyses

Data were analyzed using the PROC GLM procedure (SAS Inst. Inc., Cary, NC) for a completely randomized design. Data were analyzed by weigh period because of unequal number of grazing days among treatments in each period. Treatment means were separated by the LSMEANS procedure (SAS Inst. Inc., Cary, NC) when protected by a F-test significant at $\alpha = 0.10$.

RESULTS

Temperature and precipitation

Monthly mean air temperatures in July, August and September were comparable to 30-yr averages for Shorter, AL (Table 13). Total precipitation was lower during July than the 30-yr average, but was 128% and 50% greater than 30-yr averages in August and September (Table 14).

Table 13. Monthly mean air temperatures (°C) for July to September 2009, and 30-yr averages for Shorter, AL.

Month	Avg. High, C°	Avg. Low, C°	Mean, C°	30-yr avg., C°
July	31	20	26	27
August	32	21	27	27
September	30	20	25	24

Table 14. Monthly total precipitation (mm) for July to September 2009, and 30-yr averages for Shorter, AL.

Month	Precipitation, mm	30-yr avg., mm
July	75	115
August	192	84
September	148	99

Dry matter availability

No differences were observed in forage DM availability (Table 15) among treatments from Jul 14 to Aug 11 ($P = 0.9180$) and Sep 8 to Sep 29 ($P = 0.2084$). During the second period, DM availability was greater for pearl millet than cowpea ($P = 0.0171$) and lablab ($P = 0.0093$); however, no differences were observed in DM availability between cowpea and lablab ($P = 0.3248$) throughout the trial.

Table 15. Forage DM availability (kg/ha) in warm-season annual pastures.

	Treatment			
Period	Cowpea	Lablab	Pearl Millet	SE
Jul 14 to Aug 11	2,015	2,001	2,150	280
Aug 11 to Sep 8	2,277^{a}	1,943^{a}	3,644^{b}	201
Sep 8 to Sep 29	1,168	2,158	2,376	387

^{a,b}Within a row, means without common superscripts differ ($P < 0.10$).

Average daily gain

No differences were observed in ADG (Table 16) from Jul 14 to Aug 11 ($P = 0.1685$) and Sep 8 to Sep 29 ($P = 0.4186$) during the summer grazing season. Cattle ADG decreased dramatically from the first to second period of the experiment. Negative ADG was observed for cattle grazing pearl millet during the second period, which was lower than ADG observed for cowpea ($P = 0.0025$) and lablab ($P = 0.0279$). No differences ($P = 0.7847$) were observed in ADG among treatments across the entire 77-d grazing trial.

Table 16. Average daily gain (kg/d) of steers grazing warm-season annual pastures.

Period	Treatment			SE
	Cowpea	Lablab	Pearl Millet	
Initial BW, kg	559	519	524	16.9
Final BW, kg	629	573	604	18.1
ADG, kg				
Jul 14 to Aug 11†	0.97	1.19	1.59	0.22
Aug 11 to Sep 8	0.40^a	0.09^a	-0.54^b	0.18
Sep 8 to Sep 29	0.32	0.52	0.50	0.11
Jul 14 to Sep 29	0.59	0.52	0.52	0.08

†ADG reported for steers grazing lablab is based on 21-d grazing period.
[a,b]Within a row, means without common superscripts differ ($P < 0.10$).

Crude protein

No differences were observed among treatments in forage concentration of CP (Table 17) from Jul 14 to Aug 11 ($P = 0.4707$). Concentration of CP was lower for pearl millet than cowpea ($P = 0.0394$) and lablab ($P = 0.0165$) in the second period of the trial. From Sep 8 to Sep 29, CP concentration was greater for cowpea than pearl millet ($P = 0.0080$), but was not different from lablab ($P = 0.2490$).

Table 17. Forage concentration (%, DM basis) of CP in warm-season annual pastures.

	Treatment			
Period	Cowpea	Lablab	Pearl Millet	SE
Jul 14 to Aug 11	21.3	22.8	18.1	2.70
Aug 11 to Sep 8	16.2^a	18.3^a	10.9^b	1.07
Sep 8 to Sep 29	16.6^a	15.4^a	11.3^b	0.60

[a,b]Within a row, means without common superscripts differ ($P < 0.10$).

Cell-wall constituents

Concentration of NDF (Table 18) was lower for cowpea ($P = 0.0047$) and lablab ($P = 0.0053$) than pearl millet from Jul 14 to Aug 11. From Aug 11 to Sep 8, NDF concentration was greater for pearl millet than cowpea ($P = 0.0206$) and lablab ($P = 0.0101$), but did not differ between cowpea and lablab ($P = 0.2045$). During the last period, concentration of NDF was lower for cowpea ($P = 0.0064$) and lablab ($P = 0.0081$) than pearl millet.

No differences were observed among treatments in forage concentration of ADF (Table 19) from Jul 14 to Aug 11($P = 0.4191$) and Aug 11 to Sep 8 ($P = 0.4321$). However, during the third period, ADF concentration was greater for cowpea ($P = 0.0370$) and lablab ($P = 0.0402$) than pearl millet.

Concentration of ADL (Table 20) was lower for pearl millet than cowpea ($P = 0.0013$) and lablab ($P = 0.0019$) from Jul 14 to Aug 11 of the trial. From Aug 11 to Sep 8, ADL concentration was lower for pearl millet than cowpea ($P = 0.0036$) and lablab ($P = 0.0103$), and lablab forage contained less ($P = 0.0817$) ADL than cowpea during the second period. During the third period, pearl millet had 5.9 and 4.6 percentage units lower ADL than cowpea ($P = 0.0370$) and lablab ($P = 0.0402$) treatments, respectively.

Table 18. Forage concentration (%, DM basis) of NDF in warm-season annual pastures.

	Treatment			
Period	Cowpea	Lablab	Pearl Millet	SE
Jul 14 to Aug 11	39.8^a	40.1^a	57.7^b	3.40
Aug 11 to Sep 8	52.1^a	47.6^a	63.8^b	1.98
Sep 8 to Sep 29	53.5^a	54.3^a	64.1^b	1.10

[a,b]Within a row, means without common superscripts differ ($P < 0.10$).

Table 19. Forage concentration (%, DM basis) of ADF in warm-season annual pastures.

	Treatment			
Period	Cowpea	Lablab	Pearl Millet	SE
Jul 14 to Aug 11	28.4	27.7	31.6	2.08
Aug 11 to Sep 8	39.3	34.2	36.6	2.38
Sep 8 to Sep 29	40.8^a	40.6^a	36.5^b	0.84

[a,b]Within a row, means without common superscripts differ ($P < 0.10$).

Table 20. Forage concentration (%, DM basis) of ADL in warm-season annual pastures.

	Treatment			
Period	Cowpea	Lablab	Pearl Millet	SE
Jul 14 to Aug 11	4.38^a	4.21^a	1.35^b	0.46
Aug 11 to Sep 8	8.65^a	6.79^b	2.64^c	0.51
Sep 8 to Sep 29	9.21^a	7.98^a	3.35^b	0.19

[a,b]Within a row, means without common superscripts differ ($P < 0.10$).

In vitro dry matter digestibility

Percentage IVDMD (Table 21) was greater for cowpea ($P = 0.0313$) and lablab ($P = 0.0509$) than pearl millet during the first period of the experiment. No differences were observed among treatments in forage IVDMD from Aug 11 to Sep 8 ($P = 0.4378$) and Sep 8 to Sep 29 ($P = 0.5752$) of the trial.

Table 21. Percentage IVDMD (%) of warm-season annual pastures.

	Treatment			
Period	Cowpea	Lablab	Pearl Millet	SE
Jul 14 to Aug 11	86.4^{a}	85.5^{a}	78.7^{b}	2.14
Aug 11 to Sep 8	74.0	75.6	68.1	3.76
Sep 8 to Sep 29	69.9	68.5	68.0	1.21

^{a,b}Within a row, means without common superscripts differ ($P < 0.10$).

DISCUSSION

Average temperatures for July, August and September were comparable to 30-yr averages for Shorter, AL and were within the optimum temperature range for growth of summer-annual forage crops (USDA, 2009d,f,i). Monthly precipitation was lower during July than the 30-yr average; however, beginning in August, monthly precipitation was considerably greater than the 30-yr average. Cowpea, lablab and pearl millet are relatively drought-tolerant species, so above-average rainfall may have favored increased forage productivity in the latter portion of the trial. Summer annuals are typically lower yielding than warm-season perennials, but they provided sufficient forage DM availability for grazing livestock throughout the present study. During the first period, DM availability was ≥ 2,000 kg DM/ha for all three forage species. Muir et al. (2002) reported that, in years with sufficient rainfall, lablab grown in Texas provided an average of 2,000 kg DM/ha/yr in the leaf portion alone, which would be sufficient to support livestock production. Moreover, cowpea produced between 2,000 and 4,000 kg DM/ha in years with adequate rainfall in Florida (Foster et al., 2009). From Aug 11 to Sep 8, DM availability was greater for pearl millet than cowpea and lablab. Pearl millet is known to be highly productive over a short season, with a typical DM yield between 1,800 to 4,000 kg DM/ha (Teutsch, 2002). Cowpea and lablab paddocks maintained roughly 2,000 kg DM/ha during the second period of the trial, and availability of cowpea decreased by nearly half during the final period. Lablab paddocks continued to maintain around 2,000 kg DM/ha, which is consistent with autumn-harvested lablab (1,891 kg DM/ha) reported by Muir et al. (2001). Availability of pearl millet decreased to by one-third between the second and third period, which may be attributed to a combination of limited regrowth following clipping in mid-August and subsequent grazing.

No differences were observed in ADG among treatments across the summer grazing season. Overall ADG for all treatments was between 0.52 and 0.59 kg over the relatively short grazing season. These values are lower than ADG of 1.23 and 1.17 kg from heavily grazed cowpea (all leaves and some stem removed) and lightly grazed cowpea (2 to 3 expanded leaves remaining per plant and little stem removed), respectively, over a 50-d grazing season reported by Holzknecht et al. (2000). However, Fribourg et al. (1984) reported that cattle grazing lablab continuously from Jul 28 to Sep 9 in Tennessee gained 0.37 kg/d, which is lower than values observed in the present study. Steer ADG was ≥ 0.97 kg/d for all treatments during the first period of the trial, which is highly satisfactory for the summer months. McCartor and Rouquette (1977) reported 0.96 kg/d for pearl millet grazed at a low grazing pressure (7.12 $\text{head}\cdot\text{ha}^{-1}\cdot\text{d}^{-1}$) in yr 1 of a 2-yr trial, and similar values were observed for yr 2. Lower ADG for pearl millet observed in subsequent periods of the present study may have resulted in part from lower grazing pressure and less intensive forage management than that used by McCartor and Rouquette (1977).

Satisfactory ADG was not sustained into the second period, and ADG decreased dramatically for all treatments; cattle grazing pearl millet lost weight (-0.50 kg ADG) during the this period. Low gains during the second period of the grazing trial may have resulted in part from declining forage quality between the first and second period. Forage concentration of CP was 10% for pearl millet during the second period, which in conjunction with high concentration of fibrous constituents (63.8% NDF and 36.6% ADF) may have been limiting to performance of finishing steers. Environmental effects may have also played a role in decreased ADG observed during the second period. Although mean temperature was similar between July and August, seasonally hot temperatures in August may have contributed to decreased grazing activity that in turn may have led to decreased forage DMI and ADG. Finally, at the end of the winter grazing season, steers had been moved temporarily from cool-season annual pasture to a mixed fescue/bermudagrass pasture until the initiation of the summer grazing trial. Cattle allotted to the cowpea and pearl millet treatments grazed the perennial system for 47 d and gained 0.15 and 0.02 kg/d, respectively. Lablab cattle grazed mixed fescue/bermudagrass for 54 d and gained 0.05 kg/d. Low ADG for cattle from the temporary perennial forage system followed by increased gains once on the summer-annual grazing trial may be attributed in part to compensatory growth. Because annual forages tend to be higher in nutrient concentration than perennials (Robinson, 1996), it is conceivable that the increased energy needs of finishing cattle were not met by the perennial system, and so compensatory growth occurred when animals began the summer-annual grazing trial. An increase in ADG was observed between the second and third period, although an increase was observed in forage concentration of total cell-wall constituents and a decrease was observed in forage IVDMD. These changes in forage quality are not consistent with the observed increase in ADG between the second and third period. Subsequently, increased ADG in the third period may be associated with increased grazing activity compared with the second period.

Young, leafy grasses and legumes are normally high in concentration of CP and typically are able to meet protein requirements of grazing animals (Ball et al., 2007). During the first period, forages within all treatments contained > 18% CP, which is typical of summer annual forages in the young, vegetative state. Cowpea and lablab contained the greatest concentration of CP during this time (21 to 23%), in agreement with values reported for legumes in the vegetative state in other studies (Muir et al., 2001). Decreased CP concentration was observed for legume treatments during the second and third period of the trial. Because stem protein concentration is usually less than that of leaves and petioles (Murphy and Colucci, 1999), observed changes in CP concentration may reflect decreasing leaf-to-stem ratio, which is expected with increasing plant maturity. Concentration of CP in pearl millet decreased by 8 percentage units between the first and second period. A rapid increase in DM availability of pearl millet, in conjunction with advancing plant maturity, may be associated with decreased concentration of CP in pearl millet during August and September. While percentage CP was low in pearl millet (10 to 11%) during the second and third period of the grazing trial, a large decrease in CP concentration is expected as forage matures from the vegetative to flower/boot stage. These values are slightly higher than the 6 to 8% CP reported by Ball et al. (2007) for pearl millet in the boot to fruit stage of development. Although concentration of CP was low for pearl millet forage, CP alone was likely not the major limiting factor in meeting nutrient requirements. Beef cattle finished to an endpoint of 636 kg require roughly 8.0% CP in feeds containing 60% TDN (NRC, 1996), which is comparable to the nutritive quality of pearl millet pasture in the present study. Across the entire grazing season, CP concentrations of cowpea and lablab were greater than pearl millet, consistent with the agronomic generalization that N-fixing legumes contain more CP than grasses.

Concentration of total cell-wall constituents differed between legumes and pearl millet throughout the grazing season. During the first period of the trial, concentration of NDF was lower for cowpea and lablab than pearl millet forage. Pearl millet contained 57.7% NDF during the first part of the trial, which is slightly higher than values reported by Hill et al. (1999) for hand-harvested Tifleaf 1 and Tifleaf 2 pearl millet leaves that contained an average of 53.5% NDF. Concentration of NDF in cowpea and lablab increased by 12.1 and 7.5 percentage units, respectively, between the first and second period. A slight increase in NDF concentration was also observed for cowpea and lablab during the third period, which may be associated with advancing plant maturity. Foster et al. (2009) reported NDF concentration of cowpea increased with maturity because of concomitant increases in leaf and stem NDF concentrations and decreasing leaf-to-stem ratios. Ugherughe (1986) reported that decline of forage quality with maturation results primarily from a decrease in leaf-to-stem ratio and decline in quality of the stem component. Fribourg et al. (1984) also observed increasing NDF concentration with advancing stage of development in lablab. Concentration of NDF in pearl millet increased by 10 percentage units between the first and second period, and only slightly increased between the second and third period. Increasing NDF concentration in pearl millet may be associated with the rapid increase in DM availability and advancing maturity observed after clipping during the second period. Concentration of NDF in pearl millet was higher than those of cowpea and lablab in all periods of the trial.

Forage concentration of ADF is negatively correlated with its digestibility *in vivo* (Van Soest, 1994). No differences were observed in ADF among forage treatments during the first and second period of the grazing trial; however, legume treatments contained greater concentration of ADF during the third period than pearl millet. Increased ADF observed for cowpea and lablab from Sep 8 to Sep 29 may be attributed to changes in leaf-to-stem ratio and advancing maturity of individual plant parts. Fribourg et al. (1984) reported similar values (35 to 37.4% ADF) for lablab plants in full bloom, which is comparable to the stage of development during the third period of the present study. Concentration of ADF was lower for pearl millet than cowpea and lablab by an average of 4.2 percentage units during the last period. Concentration of ADF of pearl millet ranged from 31.6 to 36.5% across the grazing season, in agreement with Ball et al.

(2007) who reported a mean ADF concentration of 35 to 40% for pearl millet and sorghum species.

Acid-detergent lignin is the single cell-wall constituent that most limits digestibility of forage crops. During the beginning of the trial, lablab and cowpea contained small vines and stems, and were in the young, leafy stage of development. Concentration of ADL was 4.21 and 4.38% for cowpea and lablab, respectively, during the first period of the trial. Comparable values have been observed in other studies for lablab and cowpea harvested at a similar stage of development. In yr 1 of a 2-yr study, Muir et al. (2001) reported 4.78 and 5.88% ADL for ‘Combine’ cowpea and ‘Tecomate’ lablab, respectively. In yr 2 of the study, Iron-Clay cowpea was evaluated and contained 4.27% ADL. Percentage of ADL increased with each period and ranged from 4.21 to 9.21% across the entire grazing season for legume treatments. Legumes consistently contained more ADL than pearl millet in each period of the trial. Concentration of lignin is generally greater in legumes than in grasses at comparable stages of development; however, for a given lignin concentration, legumes are more digestible than grasses because they contain less NDF (Moore and Hatfield, 1994). Pearl millet contained 1.35, 2.64 and 3.35% ADL across the first, second and third period of the trial, respectively. Lower lignin concentration and higher quality of pearl millet in the first period may be attributed to immaturity of grass stems, which is expected for grasses in the vegetative state. Stems decrease in quality faster than leaves in most plants, especially as plants approach maturity and become increasingly more lignified (Nelson and Moser, 1994).

Forage IVDMD is a meaningful index of forage quality, which is important in the selection of forage species for use in pasture-based finishing systems. From Jul 14 to Aug 11, IVDMD was highest for all treatments. Cowpea and lablab contained ≥ 85.5 % IVDMD and were higher in percentage IVDMD than pearl millet during the first period. These results agree with *in vitro* true digestibility reported for Iron-Clay cowpea sampled across the summer growing season in Florida (Foster et al., 2009). Few studies have evaluated the IVDMD of lablab, and the present study is the first to report IVDMD data for Rio Verde lablab. Murphy (1998) reported 60.9 to 67.5% IVDMD for Rongai lablab harvested across the summer growing season, which is lower than values observed for mean IVDMD of lablab in the present study. Percentage of IVDMD of pearl millet was 78.7% during the first period, which is typical for pearl millet and sorghum/sorghum-sudangrass in the vegetative state (Ball et al., 2007). Similar values have been reported by Hill et al. (1999), who observed 75.3 and 76.9% IVDMD for Tifleaf 1 and Tifleaf 2 leaf samples, respectively, harvested near the end of the grazing trial. Forage IVDMD decreased for legumes and pearl millet in subsequent periods of the grazing trial, although no significant differences were observed among treatments. Increasing concentrations of NDF, ADF and ADL across the grazing season negatively impacted IVDMD of forage treatments, and may be associated with a decline in IVDMD in the second and third periods.

As steers approach harvest age, it is important to consider the changing nutrient needs of animals when implementing forage-based finishing systems. Warm-season annuals are initially high in forage quality, but quality rapidly declines with increasing maturity because of a short production season. Although gains were high for cattle grazing during the first period, negative changes in forage quality combined with environmental factors may have contributed to decreased ADG throughout the summer grazing trial. Overall ADG was not different among forage treatments, and summer annuals were unable to sustain satisfactory gains throughout the latter summer months.

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Appendix

Calculation of stocking rate for the winter-annual grazing system

Net change in available forage DM

Paddock 4

Date of sampling	Forage DM availability (kg/ha)
1/19/2009	1,895
1/31/2009	2,535
Total change in DM	640

Total growth per paddock= [total change in DM × area of paddock]
= 640 $kg \cdot ha^{-1}$ × 1.42 ha
= 896 kg DM

Animal Utilization

Paddock 4

Mean BW of test steers from most recent weigh period: 398 kg
Animal DMI assumed as 3% of mean BW

Animal consumption= [(mean BW of steers) × (3% of mean BW) × (# of animals within the paddock) × (# of grazing days between sampling periods)]
= [398 kg × 11.94 kg × 3 × 14]
= 502.85 kg DM

Estimated forage DM accumulation in successive sampling period

Total accumulation = [total growth per paddock + amount of animal consumption]
= 896 kg DM + 502.85 kg DM
= 1,398.85 kg DM

Projected forage growth for the successive sampling period

Projected growth = [estimated forage DM accumulation + available DM yield at the time of sampling]
= 1,398.85 kg DM + [(2,535 kg DM/ha) × 1.42 ha]
= 4,947.95 kg DM

Amount to manage

Amount to manage = projected growth – [(2,000 kg DM/ha) × area of paddock]
= 4,947.95 kg DM – (2,000 kg/ha × 1.42 ha)
= 2,147.85 kg DM

Animal utilization

Animals within a paddock were predicted to utilize 60% of the total amount of forage in need of management (accounts for loss via trampling).

Utilization = [amount to manage × 60%]
= [2,147.85 kg DM × 0.60]
=1,288.7 kg DM

Stocking rate adjustments

Mean BW of cattle within Paddock 4 = 398 kg

Cattle DMI = 398 kg × 3% of BW
= 11.94 kg DM/day
~12 kg DM/day

Predicted DM consumption for the next 2-wk period =DMI × # days on each paddock
= 12 kg DM/day × 14 d
= 168 kg DM

# of steers needed = Amount to utilize ÷ predicted DM consumption per animal
= 1,288.7 kg DM ÷ 168 kg DM
=7.67
~ 7 steers needed