Animal performance and environmental efficiency of cool- and warm-season annual grazing systems

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ABSTRACT: Annual forage crops can provide short-term grazing between crop rotations or can be interseeded into perennial pastures to increase forage quality and productivity. They also provide an opportunity to increase the economic and environmental sustainability of grazing systems. Cool-season annual forage crops provide high-quality, abundant forage biomass when forage availability from perennial forage species is lacking, reducing the need for stored feeds during the winter months. For example, ADG of 1.5 kg have been reported using small grains alone and in mixtures with annual ryegrass (*Lolium multiflorum* Lam.) while maintaining an average stocking rate of 3.5 animals/ha. No-till (NT) establishment has been shown to be as effective as conventional tillage for establishing small grain pastures. Stocker performance during the fall was not affected by tillage treatment, but during the spring grazeout, BW gain per hectare was 8% greater in NT pastures. An in vitro study showed that daily production of CH_4 was 84% lower, respectively, in turnip (*Brassica rapa* L.) and rapeseed (*B. napus* L.) diets compared with annual ryegrass. Warm-season annuals are frequently used during the summer forage slump when perennial pasture growth and quality are reduced. Research has shown that brown mid-rib sorghum × sudangrass (**BMR** SSG; *Sorghum bicolor* L. × *S. arundinaceous* Desv.) and pearl millet (PM; *Pennisteum glaucum* L.R. Br.) with crabgrass (*Digitaria sanguinalis* (L.) Scop.) tended to have greater ADG (0.98 kg) than sorghum × sudangrass or peal millet alone (0.85 kg). However, non-BMR and BMR SSG tended to have greater gains per hectare than PM or PM + crabgrass (246, 226, 181, and 188 kg/ha, respectively). Feeding of brown mid-rib sorghum × sudangrass reduced daily production of CH_4 and CH_4 per gram of NDF fed by 66% and 50%, respectively, compared with a perennial cool-season forage in continuous culture. Cool- and warm-season annual pastures not only provide increased animal gains, but also increase soil cover and in vitro data suggest that annual forages (i.e., brassicas and warm-season annual grasses) decrease enteric CH_4 emissions. Establishment method, grazing management, and weather conditions all play important roles in the productivity and environmental impact of these systems. A more complete life cycle analysis is needed to better characterize how management and climatic conditions impact the long-term economic and environmental sustainability of grazing annuals.

Key words: animal performance, annuals, environment, grazing

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INTRODUCTION

The stability and resiliency of modern agriculture has become impaired by enterprise specialization, and operation concentration, which have temporally and spatially disrupted nutrient cycles from natural ecosystem cycling (Gates, 2003). Integration of crop and livestock systems may include benefits to the agroecosystem and the development of sustainable agricultural production systems by: 1) more effectively using natural resources and pest control processes, 2) reducing nutrient concentration and environmental risk from erodible soils, and 3) improving soil structure and productivity (Franzluebbers, 2007). Additionally, increasing consumer interest in grass-based animal products, coupled with decreasing profit margins, has made integrated crop–livestock systems attractive to some crop and livestock producers. Annual grazing systems are a popular way to integrate row crops with livestock production, especially in the Southeastern and Mid-Atlantic regions of the United States where forage can be grown almost year round.

Biomass production of cool-season annual (**CSA**) forages can support livestock grazing for 90 + d each year (Rouquette, 2017). As a result, small grains and annual ryegrass (**ARG**; *Lolium multiflorum* Lam.) have been used for years to make stocker cattle production an economically viable option for producers throughout the Eastern United States (Rankins and Prevatt, 2013). Furthermore, forage brassicas (*Brassica* sp.) have been investigated for their potential to extend the grazing season. Warm-season annual (**WSA**) forages have been used in row crop rotations to reduce disease and weed pressure in subsequent crops for many years (SARE, 2012). Grazing of these forages has been shown to be a profitable way to forage-finish cattle in the Southeastern United States (Harmon, 2017). The objective of this article is to investigate the scientific literature on the impact of grazing CSA and WSA forage systems on animal performance and environmental efficiency, specifically in the Southeastern and Mid-Atlantic United States.

COOL-SEASON FORAGE SYSTEMS

Forage Production and Quality

Cool-season annuals may fill gaps in seasonal forage availability and reduce stored feed needs for beef cattle producers in the Southeastern United States. These forages can be established during the fall via sod-seeding, broadcasting on warm-season perennial grass pastures such as bermudagrass (*Cynodon dactylon* (L.) Pers.) and bahiagrass (*Paspalum notatum* Flueggé), or planted into a prepared seedbed. These CSA forages can complement perennial warm-season grass pastures by providing an additional 60 to 120 d of grazing (Rouquette, 2017).

Opportunity exists to use small grains that vary in individual growth distribution to extend the grazing season. Small grains adapted to the Southeast United States include cereal rye (*Secale cereale* L.), wheat (*Triticum aestivum* L.), oat (*Avena sativa* L.), and triticale (× *Triticosecale* Wittm. ex A. Camus [*Secale* × *Triticum*]). These species provide bimodal forage DM production during the fall and early winter months, and can be grown in monocultures or mixtures. Cereal rye generally provides forage DM earliest in the season, followed by triticale, wheat, and 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 DM yield 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. Fall production potential of these species is primarily dependent upon planting method, seeding date, fertility, and variety selection. Most production of small grains occurs from November to April after seeding in late September to early October in the Southeastern United States (Ball et al., 2015). However, forage DM production potential of sod-seeded small grains may be reduced by up to 60% compared with planting these species into a prepared seedbed (Utley et al., 1976; Rouquette, 2017), which can influence the number of grazing days achieved per year and stocking rate decisions. Though small grains provide high-quality forage that may support animal performance in stocker and cow–calf operations with minimal supplementation, they can be grown in mixtures with other small grains or in combination with ARG and/or legumes to further lengthen the window of grazing (Beck et al., 2012).

Mixtures of small grains generally produce more uniform and greater distribution of yield than monocultures of individual small grain crops, resulting in improved animal performance (Beck et al., 2005, 2007c; Myer et al., 2008). Multiple studies have observed that when small grains are grown in combination with ARG, the length of grazing season was extended by 20 to 30 d compared with small grain monocultures (Marchant, 2014; Mullenix et al., 2014). Inclusion of ARG in mixtures with small grains interseeded into bermudagrass pastures increased animal grazing-d/ha by 10% compared with small grains alone (546 grazing-d/ha vs. 600 grazing-d/ha, respectively; Beck et al., 2007c). They also found the addition of ARG did not affect animal performance during the fall and winter, but ADG was increased in the spring by 15% (1.06 vs. 1.22 kg, respectively). Adding ARG to the mixture increased BW gain/ha by 45% over rye alone (514 vs. 354 kg/ha) and net returns were improved by $143/ha (Beck et al., 2007c). When grown in dedicated crop fields in a clean-tillage system, Beck et al. (2005) found that ARG additions had no effect on animal performance during the fall and winter, but increased ADG and BW gain/ha in the spring by 9% and 14%, respectively. Despite increased establishment costs with the addition of ARG, Beck et al. (2005) found that the cost of gain in the pasture-only system decreased, and net returns increased by 19% in cattle ownership scenarios and by 25% when using contract grazing.

The use of CSA legumes instead of, or in addition to, CSA grasses can also extend the grazing season (Hoveland et al., 1978), reduce hay feeding (DeRouen et al., 1991), and provide a more sustained supply of high-quality forage as the forage matures in the spring (Akin and Robinson, 1982; Han et al., 2012). Their use can also reduce the rates of N fertilization (Evers, 2011), and reduce the risk of nitrous oxide emissions (Schils et al., 2013) and nitrate leaching into groundwater systems (Silveira et al., 2016). However, these improvements have not been consistently observed in the research. Positive results (reduction of N fertilizer needs or increase forage quality) generally require at least 20% of the available forage to be legume herbage (Burns and Standaert, 1985). Weather variability, competition with grasses in the sward, soil conditions, N fertilization, grazing management, and other factors often result in a poor contribution by the legume in the sward (Burns and Standaert, 1985) and many have questioned the feasibility of using winter annual legumes in grazing systems (e.g., Biermacher et al., 2012; Butler et al., 2012; Rouquette, 2017).

Forage brassicas have a much higher ratio of readily fermentable carbohydrate to structural carbohydrate than grass-based pastures, while maintaining similar CP content (Barry, 2013). Data reported from variety trails indicate that brassicas (regardless of species) can produce 1,500 to 5,000 kg DM/ha (Griffin et al., 1984; Simon et al., 2014). However, Ingram (2014) found that when grazed, canola (*Brassica napus*) had a mean seasonal herbage biomass of 873 kg DM/ha. Dillard et al. (2017a) reported greater seasonally accumulated herbage biomass during the fall in monocultures of canola, rapeseed (*B. napus* L.), and turnip (*B. rapa* L.) than ARG (1,023 and 242 kg DM/ha, respectively). No difference in fall accumulated herbage biomass was observed among brassica species. Ingram (2014) and Dillard et al. (2017a) reported CP concentrations of multiple brassica forage species ranging from 20% to 30%. Furthermore, NDF and ADF concentrations were considerably lower than similar CSA grasses, with brassicas having 46% and 22% less NDF and ADF, respectively, than ARG (19% vs. 35% NDF and 14% vs. 18% ADF, respectively; Dillard et al., 2017a).

Planting date and weather conditions during early winter are key factors determining the length of the season, which was exemplified in a 2-yr evaluation of wheat and triticale with ARG for stocker cattle as grazed cover crops in Headland, AL (Mullenix et al., 2014). The length of the grazing season varied from 114 d in Yr 1 to 141 d in Yr 2 when these species were planted in a prepared seedbed following row crops (Mullenix et al., 2014). Beck et al. (2011) interseeded wheat and ARG into bermudagrass pastures in either mid-September or mid-October, with or without an application of glyphosate at planting. For the mid-September planting, glyphosate application increased forage mass by 35%, reduced contamination of CSA stands with dormant warm-season grasses, and increased total grazing-d/ha and BW gain/ha by 104 d and 164 kg, respectively (Beck et al., 2011). Glyphosate application did not change forage mass for pastures planted in October, but forage mass was 700 to 1,400 kg/ha less in January for pastures planted in October compared with pastures planted in September (Beck et al., 2011). Growing calves were stocked to September-planted pastures 30 d earlier than October plantings, gained 34 kg more BW, had lower cost of BW gain, and greater net returns/ha (Beck et al., 2011). Beck et al. (2016) established wheat in dedicated crop fields using no-till (**NT**) methods on 15 August, 1 September, or 15 September or using conventional tillage (**CT**) methods on 1 September or 15 September. Fall grazing of NT wheat planted on 15 September started 6 and 11 d later than pastures planted on 1 September using NT or CT, respectively. There were no differences in ADG or total gain per steer during the fall. Steers grazing CT pastures planted on 1 September in the spring had the least ADG, NT pastures planted on 1 or 15 September had the greatest ADG, while ADG of CT pastures planted on 15 September or NT planted on 15 August was intermediate. Total BW gain per hectare was greatest for NT planted on 1 September and NT planted on 15 August did not differ from CT or NT pastures planted on 15 September. Beck et al. (2016) concluded that if planting is delayed, using CT appears to be more productive than NT, and planting NT pastures early did not result in any advantages in forage or livestock productivity.

Animal Performance

Small grains and ARG can support high levels of BW gain in stocker cattle. Even though this system requires greater N input than a tall fescue/white clover system, BW gains are often great enough to offset the additional input costs (Rankins and Prevatt, 2013). High nutritive quality of CSA forages allows for potential ADG in excess of 1 kg/d (Beck et al., 2005, 2012; Bowman et al., 2008; Butler et al., 2012; Morgan et al., 2012; Rouquette, 2017) with greater net returns for CSA forage systems than for grazing programs based on warm-season grasses or endophyte-infected tall fescue (Beck et al., 2013a).

Hill et al. (2004) compared the use of rye or ARG as cover crops during the winter months, and compared systems where the crop was grazed or ungrazed prior to land preparation for row crops. Grazed CSA forages maintained a stocking rate of 2.5 steers/ha for 57 to 84 d, with ADG of 0.9 kg during the 2-yr study. No differences were observed in crop yields among the grazed vs. ungrazed cover crop systems in the Coastal Plain of the United States, illustrating that the use of CSA may diversify land use as part of an integrated crop–livestock system. Siri-Prieto et al. (2007) conducted a 3-yr study using oats and ARG to evaluate the effect of double cropping cotton following winter-grazing of stocker cattle in Headland, AL. Average total gain was 541 kg/ha for oats and 561 kg/ha for ARG. At a stocking rate of 5 steers/ha, gain per hectare for oat pasture was 7.17, 7.04, and 5.65 kg/ha/d for February, March, and April, respectively. In a 3-yr study with steers, Pereira (2009) found that steers grazing oats had greater gain/ha than those grazing rye or ARG (504 kg/ha vs. 425 and 408 kg/ha, respectively). Similar results were observed by Mullenix et al. (2012) when these species were compared as two- or three-way mixtures in a 1-yr demonstration trial for grazed stocker cattle systems in Headland, AL. Several stocker cattle grazing trials conducted in southern Alabama reported that ADG ranged from 1.1 to 1.5 kg for small grains grown alone or in two- or three-way mixtures with ARG (Pereira, 2009; Mullenix et al., 2012, 2014; Marchant, 2014). Oats and ARG grown alone were superior to rye in supporting animal performance, and mixtures containing oats consistently supported greater animal performance than mixtures of rye + ARG (Mullenix et al., 2012). Wheat and ARG monocultures supported a greater level of animal performance than triticale, but no differences in performance were observed among mixtures of wheat and triticale with ARG (Marchant, 2014). Across all studies, an average stocking rate of 3.5 animals/ha was used successfully to maintain adequate forage quantity and quality throughout the grazing season.

In overseeded warm-season perennial systems, Cleere et al. (2004) reported that steers grazing rye + ARG mixtures gained 1.0 to 1.3 kg/d. Gadberry et al. (2004) evaluated heifer performance grazing a two-way mixture of wheat and ARG overseeded into bermudagrass and observed an ADG of 0.7 kg. Utley et al. (1976) illustrated the feasibility of oats overseeded into perennial sods or planted in prepared seedbeds for winter grazing. Cattle ADG was 1.1 kg 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 similar ADG of 1.1 kg, but lower total gain per hectare (253 kg/ha), which demonstrates that reduced yield potential in overseeded systems may influence pasture carrying capacity and animal performance per unit land area (Utley et al., 1976). In a synopsis of grazing experiments conducted over 10 yr, Beck et al. (2013a) found that ADG of growing calves grazing CSA grasses was 1.01 kg/d. The gain response to initial forage allowance (kg forage DM/kg calf BW) was determined using a segmented model and a joint point was estimated using the NLIN procedure of SAS (SAS Inst. Inc., Cary, NC) and found that for fall wheat pasture, the maximum ADG was expected at 5 kg initial forage DM/kg initial calf BW.

Results from addition of winter annual legumes to small grain and/or ARG forage systems have been inconsistent. Hoveland et al. (1978) examined animal performance when “Coastal” bermudagrass was overseeded with ARG + N, arrowleaf and crimson clovers without N, and cereal rye + clovers. The ADG of calves on the ARG + N treatment (0.80 kg/d) was lower than the two clover treatments, which were not different from one another (0.88 kg/d). However, total gains on the ARG + N and clover-only pastures both approximated 465 kg/ha, whereas the rye and clover treatment resulted in gains that were nearly 35% greater (628 kg/ha). Others have been unable to repeat these successes (e.g., Biermacher et al., 2012; Butler et al., 2012; Rouquette, 2017). For example, Butler et al. (2012) compared rye and ARG + N and these grasses with clovers and no N addition in the Southern Great Plains. They found that ADG and total gains in these systems did not differ (1.06 vs 1.07 kg, respectively, and 407 vs. 373 kg/ha, respectively). Despite the total cost being higher for the grass + N compared with the grass and clover treatments ($570 vs. $551/ha, respectively), no significant difference in net return was found ($282 vs. $230/ha). One explanation for the differences in results between that reported by Hoveland et al. (1978) and those that failed to repeat their successes is that the former was conducted in Alabama and each of the latter was conducted in the Southern Great Plains, where differences in late winter and early spring weather patterns (specifically differences in rainfall totals and patterns) may have influenced the results.

Similarly, animal performance when grazing brassicas has been inconsistent, despite their high apparent DM digestibility (≥80%; Barry, 2013). Research from New Zealand has shown ADG of 0.10 to 0.22 kg in young sheep grazing monocultures of swedes [*B. napobrassica* (L.) Mill.], turnips, kale (*B. oleracea* L.), or rapeseed (Barry et al., 1983; Lindsay et al., 2007). Barry et al. (1981) found that yearling cattle gained only 0.23 to 0.27 kg/d when grazing a kale pasture; however, cattle gained 0.38 kg/d when consuming a grass-clover mixed pasture (27% lower gains on kale) during the first 42 d of grazing. However, ADG was 17% greater in brassica pastures than grass-clover pastures from days 42 to 168. Campbell et al. (2011) found that BW gains among sheep grazing turnips were almost 80% greater than sheep grazing a grass-clover mixed pasture (0.27 vs. 0.15 kg/d, respectively). When grazing forage rapeseed, sheep gained 55% more BW than grazing the grass-clover mixed pasture. Brunsvig et al. (2017) observed that cattle gains on a grass-brassica mixed pasture were seven times greater during the second half of the grazing period (d 22 to 48) than the first half (d 1 to 21; 3.96 vs. 26.6 change in kg BW). The authors concluded that adaptation plays an important role in animal performance when grazing brassicas. Inconsistency in animal gains has been attributed to the high moisture content (>85%), and presence of anti-quality factors such as glucosinolates (an organo-sulfur, secondary plant metabolite) and nitrates. Mean nitrate-N concentrations were reported at 3.7 g/kg DM, but ranged from 3.7 to 10 g/kg DM in some samples (Barry, 2013). Dillard (unpublished data) observed measurable concentrations of eight different glucosinolates in monocultures of canola, rapeseed, and turnip. Total glucosinolate concentrations were 18.2, 33.6, and 55.8 mg/g DM in canola, rapeseed, and turnip, respectively.

Environmental Efficiency

Using small grain pastures established using CT or NT in early September over 8 yr (Bowman et al., 2008; Morgan et al., 2012), rainfall simulation experiments were conducted in the fall of 2005 and spring of 2010 (Beck et al., 2013a). The total runoff in the fall was four times greater and the total solids in the runoff were 10 times greater for CT than NT (Beck et al., 2013a). Beck et al. (2013a) reported that ammonia and total P content of the runoff was four and six times greater, respectively, for CT fields compared with NT. This research was supported by total runoff collection monitoring using flow meters and sediment collection devices installed at the bottom of CT and NT fields. Conventionally tilled fields demonstrated a quadratic increase in runoff in response to precipitation intensity. Runoff began in CT fields at very low levels of rainfall corresponding to resistance to water infiltration by crust formation at the soil surface. With additional precipitation, soil surface softened and water began infiltrating soils, reducing runoff until soils became saturated and runoff volume increased. In NT fields, little runoff occurred until >20 mm rain fell in a 24-h period. Runoff volume from CT fields were two times greater than NT for small rainfall events (25 mm simulated rainfall), but were four times greater during larger rainfall events (62 mm simulated rainfall; Beck et al., 2013a). These results are explained by soil quality measures reported by Anders et al. (2010), in NT soil OM, aggregate content and aggregate size was greater than in CT fields providing for greater soil porosity, water infiltration and reduced erosivity of the NT soils. During the spring, forage cover was greater for all treatments and the soils were near the saturation point; thus, no effects of establishment method were observed (Beck et al., 2013a).

Another advantage of using winter annual forages is their ability to scavenge residual N from summer production season, thereby reducing risks of nitrate leaching during the wetter winter months. Brassicas can root to depths of 2 m or more, allowing them to scavenge nutrients from below the rooting depth of most crops, including small grains (SARE, 2012). Combined with quick growth and high biomass production, brassicas provide excellent soil erosion control and nutrient loss reduction when used as a CSA cover crop (Haramoto and Gallandt, 2004). However, the use of grazed forage brassicas to reduce N loss has not been well studied.

In a greenhouse study comparing 13 perennial grass species in New Zealand, short-lived perennial cultivars of Italian ryegrass (*L. multiflorum* Lam.) removed more N and had the lowest nitrate leaching losses (Moir et al., 2012). At a rate of 300 kg N/ha, total N uptake in these ryegrasses averaged 268 kg N/ha and nitrate leaching (2 kg NO_3-N/ha) was not different than the unfertilized control. In a field study in New Zealand, oats had similar nitrate leaching to the ryegrass (131 vs. 167 kg leached NO_3-N/ha, respectively) when provided 350 kg N/ha as urine at the end of the winter-spring drainage period; however, oats reduced nitrate leaching (193 vs. 264 kg leached NO_3-N/ha, respectively) when provided 700 kg N/ha as urine, which is roughly the equivalent of N deposited in one urination by a mature, pasture-based dairy cow (Carey et al., 2017). Unfortunately, little or no research has evaluated nitrate leaching in or after winter annual grass pasture systems in the United States, and the effect of winter annual legume inclusion in these swards has not been evaluated.

In a comparison of effects over the course of 37 yr in Texas, Silveira et al. (2016) compared bermudagrass pastures overseeded with ARG receiving N fertilizer or biological N_2 fixation from arrowleaf and crimson clovers added to the overseeding mixture. Researchers found that bermudagrass pastures where clover was added had soil NO_3-N concentrations that were approximately 58% lower than ARG + N (3.3 vs. 8.0 mg NO_3-N/kg in the 0- to 15-cm soil depth, respectively). Evers (2011) found that N fertilization of winter annual grass and clover pastures with up to 67 kg N/ha applied at the first clover leaf stage and again in December resulted in yields comparable to grass alone with three applications (at planting, December, and March) of up to 67 kg N/ha. However, the amount of biologically fixed N directly transferred from legume to grass is questionable. Morris et al. (1990) found that less than 5 kg N/ha was transferred from arrowleaf clover to ARG in a 2-yr field study in Texas. This is considerably lower than the 10 to 200 kg N/ha/yr observed for perennial grass and legume mixtures (Paynel et al., 2008). The addition of N fertilizer to grass and legume pastures may strongly reduce biological N_2 fixation, but it has been observed to increase grass root growth by 700% to 800% and enhances N transfer from clover to grass by as much as 3-fold (Paynel et al., 2008).

Loss of N as N_2O also poses a potential economic and environmental risk. Nitrous oxide emissions of up to 29 kg N_2O-N/ha/yr from pastures receiving high annual rates of N (390 kg N/ha/yr) have been reported (Hyde et al., 2006) and grass + clover pastures generally have less than half these emissions (Ledgard et al., 2009). However, little work has specifically addressed N_2O emissions from winter annual pastures. Eason (2010) measured N_2O flux on irrigated ARG overseeded into bermudagrass pastures on pasture-based dairies in Georgia, and found emissions of less than 1 mg $N_2O/m^2/hr$ from the pastures, with 2 to 6 mg $N_2O \cdot (m^2)^{-1} \cdot h^{-1}$ in the first week after feces or urine was applied and returning to less than 1 mg $N_2O \cdot (m^2)^{-1} \cdot h^{-1}$ thereafter. Though these emission levels are generally in line with the aforementioned reports on other grass pastures, more work is needed for winter annual forage systems, especially those containing legumes and brassicas. Further, the impact of grazing intensity, rainfall, and soil type is likely to influence N_2O emissions since animal treading during wet or poorly drained soil conditions can increase anaerobic conditions and result in higher N_2O emissions (Ledgard et al., 2009).

Using CSA forages for pasture may also reduce enteric CH_4 emissions. DeRamus et al. (2003) reported that cows and heifers fed bahiagrass hay with or without concentrate supplementation produced 2.00 to 2.15 g CH_4 /kg of metabolic BW/day and up to 20% less when allowed ad libitum access to ARG pasture. Similarly, CH_4 emissions per kg of gain in growing heifers were substantially reduced in response to increased access to ARG pasture. Even when compared with a 4-hr timed grazing of the pastures, ad libitum access to ARG resulted in 25% to 30% decrease in CH_4 emissions per kg of gain. Research has also shown the potential for brassicas to reduce enteric CH_4 emissions when fed to ruminants (Sun et al., 2012, 2015; Dillard et al., 2017b). Dillard et al. (2017b) observed 84% greater CH_4 production in an ARG-orchardgrass (*Dactylis glomerata* L.) diet than either forage rapeseed-, turnip-, or canola-orchardgrass diets in a continuous culture fermentor system. Furthermore, CH_4 per gram of digestible NDF was 85% greater in ARG-orchardgrass than the brassica diets. Sun et al. (2012) found a 25% lower enteric CH_4 emission in lambs fed forage rapeseed compared with perennial ryegrass (*Lolium perenne* L.). However, no difference in grams of CH_4 per kg of DMI was reported between diets. Sun et al. (2015) reported 22% lower enteric CH_4 emissions from lambs fed forage rapeseed for 15 wk compared with perennial ryegrass.

WARM-SEASON FORAGE SYSTEMS

Forage Production and Quality

Warm-season annual forages such as sorghum (*Sorghum bicolor* (L.)), sudangrass (*Sorghum vulgare* (Pers.)), sorghum × sudangrass (*Sorghum bicolor* (L.) × *S. arundinaceous* (Desv.)) hybrid, or pearl millet (*Pennisetum glaucum* L.R.) are highly productive forages that grow during the warm summer months. They are frequently used during the "summer slump" when traditional cool-season perennial pasture growth decreases to maintain forage available throughout the growing season (Clark et al., 1965; Fontaneli et al., 2001). However, WSA forages are often lower in quality, with increased fiber and lignin concentrations and lower leaf-to-stem ratios, resulting in decreased digestibility compared with cool-season forages (Cowan and Lowe, 1998).

Overall, species in the sorghum family are similar to corn in structure, with forage height and stem thickness varying among species and varieties (Undersander et al., 1990). Since introduction into the United States, interest in using sorghums as a forage crop has been stimulated by outstanding heat and drought tolerance as well as the combination of DM production potential and forage quality attributes. In variety plot trials in Georgia in 2016, sorghum × sudangrass hybrids were found to produce DM yields of 12.7 to 25.8 Mg/ha, while forage sorghum produced 7.2 to 13.9 Mg/ha (Gassett et al., 2016). In Kentucky, total seasonal forage yields of sudangrass varieties ranged from 5.92 to 9.03 Mg/ha of DM (Olson et al., 2016). Although regrowth of sorghum × sudangrass occurs from axillary buds and adds to overall DM, Beck et al. (2007a) found that increasing the harvest interval of three sorghum × sudangrass varieties from 34 to 63 d increased forage DM production from as little as 1,120 kg/ha to as much as 7,433 kg/ha.

Chaugool et al. (2013) evaluated the chemical composition of 22 cultivars of sorghum, 15 of which were sorghum × sudangrass varieties. The authors reported that CP concentrations in sorghum × sudangrass ranged from 4.2% to 7.0%, NDF ranged from 65% to 75%, and nonfiber carbohydrates ranged from 0.9% to 2.3%. Additionally, CP concentrations of three forage sorghum varieties were between 5.3% and 5.7%, and 6.3% and 7.5% in two sudangrass varieties. Beck et al. (2013b) compared the effects of maturity at harvest on CP and TDN concentrations in sudangrass forage harvested at either the boot or dough stage in both BMR and non-BMR varieties. The authors reported CP concentrations of BMR sudangrass to decrease from 8.1% to 6.0% and TDN to decrease from 56.0% to 54.8% as maturity at harvest increased.

Under adequate environmental conditions, pearl millet is capable of extensive DM production, as a result of the heavy tillering potential that occurs from basal buds. Several small plot research trials evaluated the DM production capabilities of pearl millet varieties. In Southern Georgia, pearl millet varieties were found to produce from 13.5 to 21.3 Mg/ha of DM during the 2016 growing season (Gassett et al., 2016). During the same year, forage yields of pearl millet were reported to range from 5.4 to 8.0 Mg/ha of DM in Lexington, KY (Olson et al., 2016). Furthermore, McLaughlin et al. (2004) reported that in a multiyear study and during years that drought did not occur, "Tifleaf 3" pearl millet produced 12.5 and 15.7 Mg/ha of DM. Bosworth et al. (1980) compared IVDMD of pearl millet and bermudagrass and found at the heading stage, pearl millet had an IVDMD of 60%, which was greater than the 43% IVDMD of bermudagrass. Similarly, Wilkinson et al. (1968) reported that when harvested in 21-d intervals, CP concentration of pearl millet and bermudagrass was 22.4% and 18.1%, respectively. In a forage finishing trial by Schmidt et al. (2013), pearl millet pasture was found to have a higher concentration of CP and fatty acids, and a lower concentration of NDF and ADF when compared with bermudagrass pasture. Therefore, pearl millet may have a nutritional advantage over select warm-season perennial forages.

Crabgrass (*Digitaria sanguinalis* (L.) Scop.) is an attractive forage for livestock producers due to high palatability and the potential to fill yield and quality gaps often found in perennial forage systems during summer months. In north Arkansas, Ogden et al. (2005) reported cumulative forage production of crabgrass ranging from 3,117 to 4,634 kg DM/ha when sampled on seven dates between July and August. Additionally, the prostrate, creeping growth habit of crabgrass did not limit DM production in a study by Beck et al. (2007b), where authors reported regrowth at 21, 35, and 49 d to be 2,872, 7,335, and 9,788 kg DM/ha, respectively. In one of the earliest studies evaluating the potential of crabgrass, Bosworth et al. (1980) found that common crabgrass harvested in the vegetative, boot, and heading stages had 20% greater IVDMD when compared with bermudagrass harvested at the same stages. Furthermore, Ogden et al. (2005) reported that crabgrass, averaged over seven harvest dates, had an effective ruminal DM disappearance of 72.3%, which was greater than the 66.5% of bermudagrass.

Incorporating WSA legumes into perennial grass systems is an appealing option for beef producers due to their potential for biological N_2 fixation, decreased need for N fertilizer, and greater nutritive value (Brink and Fairbrother, 1988). Though a number of tropical forage legumes have been screened for adaptation, yield, and compatibility with WSA and perennial forages, most are limited by establishment and management challenges. Fewer still have been well researched within grazing systems. Aeschynomene (*Aeschynomene americana* L.) has been evaluated by interseeding into limpograss [*Hemarthria altissima* (Poir.) Stapf and C.E. Hubbard; Rusland et al., 1988] and for creep grazing plantings adjacent to "Coastal" and "Tifton 85" bermudagrass (Corriher et al., 2007). Aeschynomene has reported mean forage yields of less than 4,000 kg/ha/yr and forage quality generally was 20.0% CP and 70.0% IVDMD (Brink and Fairbrother, 1988). Cowpea [*Vigna unguiculata* (L.) Walp.] has been evaluated as a creep grazing crop associated with bahiagrass in Northern Florida (Foster et al., 2013), as a creep grazing crop compared with interseeded within alternating 2-m strips within a bahiagrass stand in Southern Florida (Vendramini et al., 2012), and as the monoculture for pasture-finished beef cattle in South Carolina (Schmidt et al., 2013). Brink and Fairbrother (1988) observed mean forage yields of below 5,000 kg/ha and forage quality of 20.0% CP and 77.5% IVDMD, while Foster et al. (2013) reported the cowpea contained CP levels of 28.0% to 36.0% and in vitro total digestibility in excess of 85.0%. However, Vendramini et al. (2012) observed lower concentrations of CP (16.0%) and in vitro digestible OM (61.0%).

Animal Performance

Newer varieties of WSA, such as BMR, may have greater nutritional quality compared with older varieties and need to be compared with existing forages (Ketterings et al., 2005). Performance of cattle during the summer months may be limited by the combination of seasonal droughts, heat stress, and the characteristically high fiber concentrations found in warm-season perennial forages. In pearl millet forage-finishing systems in the Southeastern United States, Duckett et al. (2013) found steers had an ADG of 1.61 kg, while Schmidt et al. (2013) reported an ADG of 0.56 kg. Although forage nutritive concentrations and DM yields were not available for both studies, it is likely that differences in nutritional value of pastures accounted for large variations in ADG. McCartor and Rouquette (1977) identified a negative correlation between pasture NDF concentration and ADG in cattle grazing pearl millet. The authors also found a significant positive relationship between in vitro true DM digestibility and ADG, with reported gains ranging from 0.27 to 1.01 kg/d. Additionally in Central Georgia, Harmon (2017) found that the inclusion of crabgrass to a pearl millet system resulted in an ADG of 0.97 kg, while cattle grazing the pearl millet monoculture gained 0.85 kg/d. Although there is little information on the performance of cattle grazing pearl millet and crabgrass mixed pastures, Beck et al. (2007b) reported similar ADG, ranging from 1.17 to 1.27 kg, in cattle with ad libitum access to mixed diets consisting of crabgrass hay harvested at three intervals.

While species in the sorghum family have been cultivated for some time, their uses in grazing systems have been limited. In Canada, Holt (1993) reported ADG of steers grazing sorghum × sudangrass to range from 0.97 to 1.18 kg. In the Southeastern United States, Harmon (2017) reported a numeric difference in performance of sorghum × sudangrass and BMR sorghum × sudangrass finishing systems, with cattle gaining 0.86 and 0.99 kg/d, respectively. Many authors have shown the ability of the BMR genotype to have a positive effect on forage digestibility of sorghum × sudangrass (Beck et al., 2007a) and forage sorghum (Oliver et al., 2004; Marsalis et al., 2010). However, the majority of feeding trials has focused on inclusion of conventional and BMR sorghums into lactating dairy cattle rations (Oliver et al., 2004; Miron et al., 2007) and has not focused on their use in beef cattle systems.

Animal performance on WSA legumes has not been as promising as results for the aforementioned grass monocultures. Though Rusland et al. (1988) reported steer ADG improved from 0.39 to 0.70 kg when aeschynomene was interseeded into limpograss, both results are comparatively low. The limpograss + N supported comparatively heavier stocking densities than the limpograss + aeschynomene (2,210 vs. 1,700 kg live weight • ha^{-1} • d^{-1}, respectively). The total gains for the two forage systems resulted in only a tendency for heavier gains on the limpograss + aeschynomene (263 vs. 377 kg/ha, respectively). Similarly, Corriher et al. (2007) reported creep grazing aeschynomene from "Coastal" and "Tifton 85" bermudagrass pastures resulted in greater ADG compared with the bermudagrass + N treatments (0.90 vs. 0.82 kg, respectively), but marginal reductions in stocking rate resulted in no difference in total gains (240 vs. 224 kg/ha, respectively). Similarly, creep grazing with, or interseeding cowpea in bahiagrass in Southern Florida resulted in no improvement in ADG compared with the bahiagrass + N control (0.63, 0.67, and 0.70 kg, respectively; Vendramini et al., 2012). Results in Northern Florida also found no improvement in calf ADG or cow BCS change in either of 2 years when a cowpea creep system was compared with bahiagrass + N alone (Foster et al., 2013). A monoculture of cowpea in South Carolina resulted in carcass traits and meat characteristics that were similar to those produced by cattle finished on alfalfa (*Medicago sativa* L.), but the forage produced ADGs in those steers that were similar to the lowest producing forage (pearl millet; 0.88 vs. 0.56 kg, respectively) and the least gain per hectare of the five forages compared in the trial (Schmidt et al., 2013). This lack of productivity from cowpea is likely attributable to the species' poor persistence under grazing (Brink and Fairbrother, 1988).

Environmental Efficiency

Dillard et al. (2017a) conducted an in vitro study evaluating the effects of three WSA, compared with a cool-season perennial grass, on ruminal fermentation and methane output. The diets consisted of (DM basis): 1) 100% orchardgrass; 2) 50% orchardgrass + 50% Japanese millet; 3) 50% orchardgrass + 50% sorghum × sudangrass; or 4) 50% orchardgrass + a mixture of 25% millet + 25% sorghum × sudangrass. Although orchardgrass had slightly greater nutrient digestibility than the WSA, the WSA showed benefits in ruminal bacterial protein efficiency. Results were mixed for CH_4 output (mg/d), with millet having the greatest CH_4 output and sorghum × sudangrass (and the mix of the two WSA species) having the lowest CH_4 output. It is important to note that forage quality of perennial cool-season grass pastures would likely be lower than that used in this study due to mid-summer heat and drought stress. This would make WSA even more valuable in grazing-based dairy systems as an alternative mid-summer forage. Additional research is needed to fully assess the environmental impact of grazing WSA.

SUMMARY AND CONCLUSIONS

Cool-season annual forages show strong potential and WSA forages show some potential for use in environmentally efficient, pasture-based livestock systems. Advances in plant breeding over the last two decades have increased biomass production and forage quality of annual forages, making them a viable option for forage-based livestock systems. Strategic use of annual forages in livestock production has the opportunity to increase BW gain compared with traditional perennial forage systems. Moreover, the coupling of annual grazing systems with row cropping systems decreases both economic and environmental risk associated with the intensification and specialization of modern agriculture. However, more research is needed not only in individual seasonal systems, but also in year-round, integrated-crop livestock systems in order to determine possible economic and environmental benefits of such a system.

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