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Abstract

Forage legumes provide an alternative N source in grazing systems. The objective was to evaluate plant and animal responses in N-fertilized or grass-legume-based systems under continuous stocking during winter and summer, from 2016-2019. The three treatments consisted of year-round forage systems including winter and summer forage components. The first system (Grass+N) included N-fertilized (112 kg N ha^{-1} yr^{-1}) 'Argentine' bahiagrass (*Paspalum notatum*) pastures during the summer, overseeded with a mixture (56 kg ha^{-1} of each) of 'FL 401' cereal rye (*Secale cereale*) and 'RAM' oat (*Avena sativa*) during winter with a second application of 112 kg N ha^{-1} yr^{-1}. Total annual fertilization for this treatment was 224 kg N ha^{-1} yr^{-1}. System 2 (Grass + clover) included unfertilized Argentine bahiagrass during summer, overseeded with a similar rye-oat mixture, plus a mixture of clovers [17 kg ha^{-1} of 'Dixie' crimson (*Trifolium incarnatum*), 6.7 kg ha^{-1} of 'Southern Belle' red clover (*Trifolium pratense*), and 3.4 kg ha^{-1} ball clover (*Trifolium nigrescens*), fertilized with 34 kg N ha^{-1} during winter. System 3 (Grass+CL+RP) included the germplasm Ecoturf rhizoma peanut (*Arachis glabrata*; RP) and Argentine bahiagrass during the summer, overseeded with the same a similar rye-oat-clover mixture used in System 2 and fertilized with 34 kg N ha^{-1} during winter. Pastures were continuously stocked using variable stocking rates. Results indicate that clover inclusion during winter improved herbage distribution along the grazing season. Integrating RP during summer increased steer ADG by nearly 80% compared with Grass+N or Grass+Clover (bahiagrass monocultures during summer). While N fertilizer allowed for greater stocking rates, it did not improve animal performance throughout the year. Overall, similar gain per area was achieved in Grass+CL+RP than Grass+N, with lesser N-fertilizer inputs.

Introduction

Perennial, warm-season grasses comprise the backbone of most beef cattle operations in the southeastern U.S. They are generally the primary feed source for these operations because they are adapted to the environment and typical producer management. Bahiagrass (*Paspalum notatum* Fluggé) is among the predominant warm-season perennial grasses in this region. It provides most of its herbage from spring through early autumn, with a shortage in herbage productivity during winter dormancy (Gates et al., 2001). Herbage shortages can be alleviated by overseeding cool-season annual grasses into bahiagrass. This practice can reduce feeding costs and enhance animal performance (Dubeux et al., 2016). In subtropical regions, individual animal performance is generally greater during the cool season, due to greater cool-season forage nutritive value, reduced heat stress, and increased animal intake (Dubeux et al., 2016).

Developing sustainable forage-based, beef cattle production systems is imperative for minimizing the environmental impact of food production systems. The hypothesis of this study was that replacement of N fertilizer by forage legumes would maintain forage and animal productivity over time without increasing water use. The objectives were to evaluate plant and animal responses for N-fertilized grass and grass-legume mixtures under continuous stocking, during the cool and warm seasons across four years.

Methods and Study Site

A four-year grazing experiment was conducted from January-October of 2016-2019 at University of Florida, North Florida Research and Education Center (NFREC), located in Marianna, FL (30°52'N, 85°11' W, 35 m MSL). Annual rainfall was 1378, 1271, 1889, and 1220 mm during 2016, 2017, 2018, and 2019.

Treatments consisted of three year-round grazing systems, including warm-season perennial forages in the summer overseeded with cool-season annual species in the winter. Treatment Grass+N consisted of N-fertilized 'Argentine' bahiagrass during the summer, overseeded with an N-fertilized mixture of 'FL401' cereal rye and 'RAM' oat, each planted at a seeding rate of 56 kg ha^{-1} in the fall for winter forage production. Total annual N fertilization was 224 kg N ha^{-1} for the Grass+N system, split equally in warm and cool seasons. Treatment Grass+Clover consisted of bahiagrass receiving no N during the summer that was overseeded in fall with an N-fertilized (34 kg N ha^{-1}) rye-oat-clover mixture consisting of 'Dixie' crimson (*T. incarnatum*

L.), 'Southern Belle' red (*T. pretense* L.), and ball (*T. nigrescens* Viv.) clovers seeded at rates of 16.8, 6.7, and 3.4 kg ha^{-1}, respectively. Treatment Grass+Clover+RP included Ecoturf rhizoma peanut, strip-planted with bahiagrass (50% of pasture area in each species allocated in alternating strips). No N fertilizer was applied to Grass+Clover+RP during the summer. In fall, pastures were seeded to a similar oat-rye and clover mixture and the winter N-fertilizer scheme was the same as for Grass+Clover. Each pasture (experimental unit) measured 0.85 ha, and treatments were replicated three times in a randomized complete block design. Pastures were continuously stocked using a variable stocking rate, and put-and-take animals were used to adjust herbage allowance every 14 days (Sollenberger et al., 2005). Two tester Angus crossbred steers remained on each pasture throughout the entire experiment each year.

Herbage mass was quantified every 14 d using the double sampling method (Wilm et al., 1944). Herbage allowance was estimated every 14 d, with the method described by Sollenberger et al. (2005). Put-and-take animals were used throughout the experimental period to maintain similar herbage allowance among treatments within each block. Target herbage allowance was 1.0 kg DM kg^{-1} BW during the cool season, and 1.5 kg DM kg^{-1} BW during the warm season.

Forage hand-plucked samples were collected every 14 d for each functional group (i.e., grass and legume) present in the sward and analysed for nutritive value [crude protein and in vitro digestible (IVDOM) concentrations]. The methodologies to assess livestock performance were similar for both cool and warm seasons. The body weight (BW) of the tester steers was measured every 21 d after 16 h withdrawal from feed and water. Initial BW of tester steers was 224 ± 27, 311 ± 31, 277 ± 17, and 230 ± 29, for 2016, 2017, 2018, and 2019, respectively. The same animals remained on their corresponding pastures during the 10 months of grazing each year, encompassing both cool and warm seasons. Average daily gain (ADG) was calculated for each 21-d period by dividing the average weight gain of the two testers per pasture by the number of days (kg hd^{-1} d^{-1}). The ADG over the entire year (cool + warm season) was estimated as a weighted average based on ADG per given season and year and the length of the season per given year.

All response variables were analysed using SAS PROC GLIMMIX (SAS/STAT 15.1; SAS Institute, Cary, NC). Pastures were considered experimental units for all output variables. For responses including ADG, gain per area, and stocking rate, the model included treatment, evaluation period, and their interactions as fixed effects. Block, year, and block × treatment were considered random effects. All other herbage responses were repeated measures. Least squares treatment means were compared through pairwise t-test using the PDIFF option of the LSMEANS statement in the aforementioned procedure.

Results

Cool-season herbage responses

Herbage accumulation rates during the cool season showed a treatment × evaluation date interaction ($P = 0.01$). Grass+N peaked earlier in the season (March), than Grass+Clover+RP and Grass+Clover, and Grass+N also showed a second peak after N-fertilizer application in early April. Herbage accumulation rate in Grass+N was 40 kg DM ha^{-1} d^{-1} at both peaks, and declined after early April, whereas Grass+Clover (70 kg DM ha^{-1} d^{-1}) and Grass+Clover+RP (50 kg DM ha^{-1} d^{-1}) had their greatest herbage accumulation rates in late April. As expected, a similar pattern was observed in herbage mass over time. However, there were no treatment differences in total seasonal herbage mass among the three treatments during the cool season ($P = 0.75$), where herbage averaged 700 kg DM ha^{-1} in each system.

Crude protein concentrations in the grass component did not differ among treatments ($P = 0.23$), but it differed across evaluation periods through the cool season ($P < 0.001$). The greatest grass CP concentrations were observed in early and late January, with values of 251 g kg^{-1}. Grass CP concentrations decreased as the cool season progressed, reaching their lowest levels by late April (150 g kg^{-1}). Clover CP concentrations (Grass+Clover and Grass+Clover+RP) did not differ between treatments ($P = 0.22$), but they differed across evaluation dates ($P < 0.001$), with lowest CP concentrations observed in early May (208 g kg^{-1}) and greatest in late March (271 g kg^{-1}). Clover IVDOM concentration also differed among evaluation periods ($P <0.001$) and were above 750 g kg^{-1} from January through March, decreasing to 675 g kg^{-1} by the end of the cool season. Grass IVDOM concentrations also differed by evaluation period, having similar concentrations in January and February (~750 g kg^{-1}), decreasing to 650 g kg^{-1} by April.

Warm-Season Herbage Responses

Herbage accumulation rate (kg DM ha^{-1} d^{-1}) was affected by treatment × evaluation interaction ($P = 0.01$). Throughout most of the evaluation periods, Grass+Clover+RP had the least herbage accumulation rate, and on average this treatment produced 24 kg DM ha^{-1} d^{-1}. Grass+N had greater rates of herbage accumulation from

May through late July, where it remained constant around 60 kg DM ha^{-1} d^{-1}. Grass+Clover pastures, lacking N-fertilizer application during the warm season, showed lower herbage accumulation rates the first half of the season but then peaked in late August (80 kg DM ha^{-1} d^{-1}) before decreasing thereafter. Similarly, herbage mass also showed a treatment × evaluation interaction (P = 0.007). Grass+N and Grass+Clover had consistently greater herbage mass than Grass+Clover+RP (P = 0.002). The least herbage mass was observed across the three treatments during the beginning of the warm season (late May - late June), averaging 850 kg DM ha^{-1}.

Grass CP concentration differed among treatments (P = 0.002), where Grass+N had the greatest average CP concentration (120 g kg^{-1}) compared with Grass+Clover and Grass+Clover+RP treatments at 111 g kg^{-1}. There was also an evaluation date effect ($P < 0.001$) on grass CP concentration. Overall, there was a decreasing trend in CP from May through October, with concentrations greatest in early June and least by early October (162 and 75 g kg^{-1}, respectively). There was also an evaluation date effect ($P < 0.001$) on grass IVDOM concentration, where IVDOM was above 480 g kg^{-1} from May through July. By September, the grass component IVDOM concentration reached its lowest at 380 g kg^{-1}. For the rhizoma peanut component of Grass+Clover+RP pastures, the CP and IVDOM concentrations did not differ along the evaluation periods (P = 0.13, SEM= 10 and 0.79, respectively), and averaged 187 g CP kg^{-1}, and 668 g DOM kg^{-1} OM, respectively.

Animal performance

Average daily gain did not differ (P = 0.47) among treatments during the cool season across the 4 years and averaged 0.85 kg d^{-1}. Additionally, gain per area during the cool season did not differ among treatments (P = 0.90) and averaged 282 kg BW ha^{-1}. Stocking rate average 2.9 AU ha^{-1} and was not affected by treatment (P =0.59), and herbage allowance also did not differ among treatments during the cool season (P = 0.73), averaging 0.7 kg DM kg^{-1} BW.

Average daily gain during the warm season was different among the three across treatments (P = 0.01), with Grass+Clover+RP having greatest ADG (0.61 kg d^{-1}) than Grass+N and Grass+Clover (did not differ, and averaged 0.34 kg d^{-1}). Within Grass+Clover+RP, there was no effect of sampling date (P = 0.11) on proportion of RP in the consumption (44% of diet). Gain per area during the warm season was also greatest in Grass+Clover+RP (P = 0.04; 397 kg ha^{-1}), while Grass+Clover was least with 278 kg ha^{-1}. There were treatment differences in stocking rates (P = 0.003), where Grass+N allowed for overall the greatest stocking rates, Grass+Clover+RP the least, and Grass+Clover was intermediate (6.3, 5.6, and 4.3 AU ha^{-1}, respectively). Herbage allowance did not differ among all treatments during the warm season (P = 0.96) and averaged 1.2 kg DM kg^{-1} BW.

The annual (cool + warm season) ADG did not differ among treatments (P = 0.18), where the ADG was 0.61 kg d^{-1}. Gain per unit land area (P = 0.46) also did not differ among treatments and averaged 618 kg BW ha^{-1}. Stocking rates were greater for Grass+N and Grass+Clover across the year (P = 0.01), averaging 4.3 AU ha^{-1}, while the stocking rate for Grass+Clover+RP was least (3.7 AU ha^{-1}).

Table 1. Average daily gain (ADG), gain per area (GPA), and stocking rate (AU ha^{-1}) in Grass+Clover, Grass+N, and Grass+Clover+RP pastures during cool and warm seasons from 2016-2019, and the whole-year average.

	Treatment[a]				
	Grass+Clover	Grass+N	Grass+Clover+RP	SEM	P
Cool Season					
ADG, kg	0.91	0.83	0.80	0.08	0.47
GPA, kg ha^{-1}	288	285	273	39.5	0.90
Stocking rate, AU[b] ha^{-1}	2.8	3.0	2.9	0.30	0.59
Warm Season					
ADG, kg d^{-1}	0.33 B[C]	0.36 B	0.61 A	0.05	0.01
GPA, kg ha^{-1}	278 B	335 AB	397 A	67.8	0.04
Stocking rate, AU ha^{-1}	5.6 B	6.3 A	4.3 C	0.48	0.003
Cool + Warm Season					

ADG, kg d^{-1}	0.56	0.58	0.69	0.07	0.18
GPA, kg ha^{-1}	565	620	669	103	0.46
Stocking rate, AU ha^{-1}	4.4 A	4.9 A	3.7 B	0.34	0.01

[a]Grass+N: bahiagrass, overseeded with rye and oat during the cool season; Grass+Clover: bahiagrass, overseeded with rye-oat-clover during the cool season; Grass+Clover+RP: bahiagrass-rhizoma peanut mixture overseeded with rye-oat-clover during the cool season. [b]Animal unit (AU); 1 AU=350 kg bodyweight. [c]Means followed by the same letter do not differ ($P \geq 0.05$) according to LSD.

Discussion and Implications

Mixing forage species of complementary seasonality of plant growth is an effective strategy for ensuring adequate forage mass throughout an extended grazing season (McCormick et al., 2006). In this study, herbage accumulation rate and herbage mass differed, based on the sward components during the cool season. Small grains provide earlier growth compared with clovers (Dubeux et al., 2016), and N fertilization resulted in greater herbage mass and accumulation rate of Grass-N earlier in the cool season. Herbage accumulation rate and herbage mass began to decline in early March for Grass+N, at which time Grass+Clover and Grass+Clover+RP productivity increased, due to increasing clover productivity. Thus, the benefits of including clovers are highlighted, especially since herbage mass was sustained for Grass+Clover and Grass+Clover+RP pastures well into late spring, while the Grass+N (no legume) was in decline. Herbage accumulation rates and herbage mass were less in Grass+Clover+RP during peak growth (August) than the other treatments. The herbage accumulation rates observed in this study were less than previously reported for Ecoturf rhizoma peanut (Shepard et al., 2018).

Animal gains during the cool season were similar to those reported by Dubeux et al. (2016), for steers grazing various cool-season forage mixtures. The benefit of clover inclusion was also evident, especially since gains did not differ among forage treatments, despite clover treatments receiving 78 kg ha-1 less N fertilizer during the cool-season. Although stocking rates were greater in Grass+N, the GPA was similar across all treatments during the cool season, which indicates the value of clover inclusion in cool-season grazing systems.

Nitrogen fertilization did not improve steer performance during the warm season, while ADG values were similar to what has been reported for continuously stocked bahiagrass pastures (Sollenberger et al., 1989). In contrast, inclusion of rhizoma peanut (Grass+Clover+RP) improved ADG and GPA. On an annual basis, N-fertilizer inputs were reduced from 224 (Grass+N) to 34 kg N ha^{-1} yr^{-1} (Grass+Clover+RP) yet animal performance was sustained or sometimes increased.

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