Published November 1, 2018

Alternatives to Conventional Nitrogen Fertilization on Tall Fescue and Bermudagrass

M. D. Corbin, R. L. G. Nave,* G. E. Bates, D. M. Butler, and S. A. Hawkins

ABSTRACT

Alternatives to conventional N fertilization on tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons. cv. Kentucky-31] and bermudagrass [*Cynadon dactylon* (L.) Pers. cv. Vaughn's #1] were studied at the University of Tennessee Plateau Research and Education Center in Crossville, TN. The experimental period occurred from April to September 2016 and 2017, and the experimental design for each experiment was a completely randomized block design with six treatments and four replications (n = 24). For both species, treatments were: control (CN) without N fertilization; grass and white clover (WC) [*Trifolium repens* (L.) cv. Ladino-Will]; grass and red clover (RC) [*Trifolium pretense* (L.) cv. Cinnamon Plus]; grass and cowpea (CW) [*Vigna unguiculata* (L.) cv. 'Iron & Clay']; broiler litter (BL); and ammonium nitrate (AN). Legume percentage of CW in tall fescue was comparable to RC in tall fescue (P = 0.646) in 2016 but differed in 2017 (P = 0.0002). Also in tall fescue, RC treatments resulted in the greatest total herbage mass (HM) in 2017, which was 1986 kg ha^{-1} more than other treatments. In 2017, RC and WC treatments in tall fescue were greater in (ADF) for most of the growing season. For bermudagrass, RC treatments resulted in the greatest HM in 2016, with 4526 kg ha^{-1} more than other treatments, and in 2017 with 4289 kg ha^{-1} more than other treatments. Treatments containing a single application of BL or AN in spring each year showed no differences for total HM and crude protein (CP) in both species.

Core Ideas

- Comparing sources of N applied to grasses can help lead to decisions N application.
- This information assists southeastern producers with guidelines on N fertilization.
- With conventional N fertilizer increasing prices, it is important to explore different alternatives.

In the southeastern United States, managing grazing pastures can come with challenges. Some challenges arise due to climatic conditions, which involve changes in temperature and precipitation from season to season, and which can have an impact on the growth rate of desired forages through the seasons (Ball et al., 2007). The humid transition zone of the Southeast is characterized by a mixture of tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons. cv. Kentucky-31] and bermudagrass [*Cynadon dactylon* (L.) Pers. cv. Vaughn's #1] pastures (Hoveland et al., 1997). In the Southeast, tall fescue serves as an excellent forage crop due to its persistency, high nutritive value, and high herbage mass (HM) potential (Nave et al., 2016). Also, as a cool-season (C3) perennial grass, it reaches its maximum productivity during the spring and early summer months of March through June (Ball et al., 2007). During the reduced growth rate of the tall fescue, i.e., warmer months, other forages such as bermudagrass, a warm-season (C4) perennial grass, can be integrated to complement tall fescue and fill in the gap with the potential to increase forage production in the summer (Fribourg et al., 1979).

When it comes to grazing pastures, management is key to maximizing forage potential. The optimum N application can be determined by completing forage management practices, which consist of adequate soil testing and understanding and comparing relative growth rates of cool- and warm-season grasses and timing of N application (Anderson and Shapiro, 1978). Based on soil recommendations, liming and fertilizing have the potential to improve certain forage nutritive values and HM (Ball et al., 2007). Utilizing the information on the plants' N status, HM, and nutritive value is useful in forage management (Starks et al., 2006).

There are different methods of N application, as well as different sources of N. The relative prices of synthetic N fertilizers have varied, and the amount of research that compares the different N sources relative to economic advantage is scarce (Poore and Drewnoski, 2010). With prices increasing for N fertilizer, it is important to evaluate different N application alternatives. Additionally, comparing alternative sources of N and their

M.D. Corbin, R.L.G. Nave, G.E. Bates, and D.M. Butler, Dep. of Plant Sciences, Univ. of Tennessee, Knoxville, TN 37996; and S.A. Hawkins, Dep. of Biosystems Engineering and Soil Science, Univ. of Tennessee, Knoxville, TN 37996. Received 21 Mar. 2018. Accepted 4 Sept. 2018. *Corresponding author (rnave@utk.edu).

Abbreviations: ADF, acid detergent fiber; AN, ammonium nitrate; BL, broiler litter; CN, control treatment; CP, crude protein, CW, cowpea; DM, dry matter; HM, herbage mass; NDF, neutral detergent fiber; NIRS, near-infrared spectroscopy; PREC, Plateau Research and Education Center; RC, red clover; WC, white clover.

Published in Agron. J. 111:275–286 (2019)
doi:10.2134/agronj2018.03.0190

Copyright © 2019 by the American Society of Agronomy
5585 Guilford Road, Madison, WI 53711 USA
All rights reserved

effect on cool- and warm-season perennial grasses commonly grown in the Southeast can help lead to decisions on renewable and affordable N sources.

The objective of this study was to evaluate the effect of different sources of N, to include two perennial and one annual legume species, on HM and forage nutritive value of tall fescue and bermudagrass pastures. Our hypothesis was that alternative sources of N, when compared with conventional methods, would introduce new, efficient methods of N applications associated with forage production. If significant relationships are observed between forage nutritive value and HM when using different N sources, this information could allow us to make recommendations on effectiveness and management of alternative N sources.

MATERIALS AND METHODS

This study was conducted at the University of Tennessee Plateau Research and Education Center (PREC) in Crossville, TN (36°0′ N, 85°7′ W, 580 m elevation). Two experiments were established, one with tall fescue cv. Kentucky-31, and the other with bermudagrass cv. Vaughn's #1 (Vaughn, 1994). Experimental period occurred from April to September 2016 and 2017. The experimental design for each experiment was a completely randomized block design with six treatments and four replications per treatment ($n = 24$). For both experiments, treatments were as follows: (i) no N source; (ii) grass and white clover (WC, *Trifolium repens* L.) cv. Will; (iii) grass and red clover (RC, *Trifolium pretense* L.) cv. Cinnamon Plus; (iv) grass and cowpea (CW, *Vigna unguiculata* L.) cv. Iron & Clay; (v) fertilization with broiler litter (BL); and (vi) fertilization with ammonium nitrate (AN). Individual plots for both species measured 6.09 × 1.54 m with the exception of four replicate plots containing grass and CW mixture measuring 6.09 × 3.04 m to accommodate the planting width of the no-till drill (Great Plains, Salina, KS).

Soil types in both experiments were 85% Lily, 5% Gilpin, 5% Lonewood, and 5% Ramsey. Initial soil samples for both sites were collected at a 15-cm depth in 2015 and 2016 and sent to the University of Tennessee Soil, Plant, and Pest Center laboratory for analysis (Hanlon and Savoy, 2007). Prior to treatment applications of BL in 2016 and 2017, composite samples were collected from a broiler producing farm in Cleveland, TN, and sent to the University of Arkansas Agriculture Diagnostic Laboratory (Fayetteville) for analysis (Peters et al., 2003). The same BL source was used in both experiments. Ammonium nitrate was applied to its designated plots at a rate of 67.2 kg ha^{-1} once for the entire growing season.

Tall Fescue

Soil characteristics for 2015 were: pH, 6.0; P, 59 kg ha^{-1} High; K, 135 kg ha^{-1} Medium; Ca, 1928 kg ha^{-1} Sufficient; Mg, 65 kg ha^{-1} Sufficient. Soil characteristics for 2016 were: pH, 6.2; P, 47 kg ha^{-1} High; K, 147 kg ha^{-1} Medium; Ca, 2048 kg ha^{-1} Sufficient; and Mg, 149 kg ha^{-1} Sufficient.

Broiler litter nutrient concentration for 2016 (dry matter [DM] basis) were: pH, 7.1; moisture, 26.6%; NO_3–N, 240 mg kg^{-1}; NH_4–N, 4319 mg kg^{-1}; total N, 41.5 g kg^{-1}; total P, 16.3 g kg^{-1}; total K, 32.8 g kg^{-1}; and total Ca, 29.1 g kg^{-1}. Broiler litter nutrient concentration for 2017 (DM basis) were: pH, 7.9; moisture, 30.7%; NO_3–N, 95.0 mg kg^{-1}; NH_4–N, 7823 mg kg^{-1}; total N, 54.3 g kg^{-1}; total P, 14.1 g kg^{-1}; total K, 39.8 g kg^{-1}; and total Ca, 28.0 g kg^{-1}.

On 9 Oct. 2014, tall fescue, cv. Kentucky 31, was drilled at seeding rate of 17 kg ha^{-1} utilizing the no-till drill model (Great Plains, Salina, KS) into existing tall fescue cv. Kentucky 31 area to ensure tall fescue coverage. On 5 Oct. 2015 both inoculated RC and WC were drilled into existent tall fescue plots utilizing a Hege seed drill (Hege Company, Waldenburg, Germany) with 18-cm spacing. Following soil recommendations, lime was broadcasted to the soil surface at a rate of 4500 kg ha^{-1} on 26 Oct. 2015. To ensure proper establishment, white clover was seeded again on 1 Mar. 2016, after a visual observation suggested an establishment failure from initial seeding in October. Total seeding rate was 8.9 kg ha^{-1} for RC and 4.5 kg ha^{-1} for WC. Plots in the BL treatment received 4.4 Mg BL ha^{-1}. An average of 50% of the total N content from the as-is basis is available for plant uptake (He and Zhang, 2014). Application occurring on 5 Apr. 2016 contained an N amount of 174 kg N ha^{-1}, which corresponds to an N plant availability rate of 87 kg N ha^{-1}. Application occurring on 5 Apr. 2017 contained an amount of 168 kg N ha^{-1}; therefore, 84 kg N ha^{-1} was available to the plant. These small differences in N content were expected coming from a waste-based product. On 5 Apr. 2016 and 2017, plots in the AN treatment received 67.2 kg N ha^{-1}, respectively. On 10 Apr. 2016, 33.6 kg ha^{-1} of potash (K_2O) was applied following recommendations from soil test analysis. On 23 Feb. 2017, Shredder 2,4-D LV4 (2,4-dichlorophenoxyacetic acid, 2-ethylhexyl ester) herbicide was applied to plots that did not include legume mixtures, to control broadleaf weeds, such as buckhorn plantain (*Plantago lanceolata* L.), dandelion (*Taraxacum officinale*), and buttercup (*Ranunculus repens* L.). Prior to planting on 2 June 2016 and 30 May 2017, CW seeds were inoculated with NDURE premium peanut inoculant at a rate of 140 g of inoculant per 45 kg of seeds, and then no-till drilled into plots at a rate of 56 kg ha^{-1}.

Bermudagrass

Soil characteristics for 2015 were: pH, 5.8, P, 38 kg ha^{-1} High; K, 141 kg ha^{-1} Medium; Ca, 1701 kg ha^{-1} Sufficient; and Mg, 63 kg ha^{-1} Sufficient. Soil characteristics for 2016 were: pH, 5.9; P, 71 kg ha^{-1} High; K, 239 kg ha^{-1} High; Ca, 1808 kg ha^{-1} Sufficient; and Mg, 146 kg ha Sufficient.

Broiler litter nutrient concentration for 2016 (DM basis) were: pH, 7.1; moisture, 26.6%; NO_3–N, 240 mg kg^{-1}; NH_4–N, 4319 mg kg^{-1}; total N, 41.5 g kg^{-1}; total P, 16.3 g kg^{-1}; total K, 32.8 g kg^{-1}; and total Ca, 29.1 g kg^{-1}. Broiler litter nutrient concentration for 2017 (DM basis) were: pH, 7.9; moisture, 30.7%; NO_3–N, 95.0 mg kg^{-1}; NH_4–N, 7823 mg kg^{-1}; total N, 54.3 g kg^{-1}; total P, 14.1 g kg^{-1}; total K, 39.8 g kg^{-1}; and total Ca, 28.0 g kg^{-1}.

In preparation for tilling ground for bermudagrass establishment, Cornerstone Plus herbicide was applied to the experimental area on 27 May 2015 at a rate of 4.5 L ha^{-1} and 41% or 1.8 L ha^{-1} of that amount contained the active ingredient glyphosate, (*N*-(phosphonomethyl) glycine). On 14 July 2015, plots were tilled and fertilized with 13–13–13 (N–P_2O_5–K_2O) at a rate of 560 kg ha^{-1} followed by establishment of bermudagrass via vegetative propagation with small bales of bermudagrass cuttings at a rate of 14 bales ha^{-1}. Following soil recommendations, lime was applied at a rate of 4500 kg ha^{-1} on 26 Oct. 2015. Both

RC and WC were drilled on the same dates and with same drill as used in the tall fescue experiment. On 28 Apr. 2016 and 2 May 2017, BL and AN treatments were applied at the same rates used in the tall fescue experiment to desired plots. On 4 May 2016 and 23 Feb. 2017, a 2,4-D herbicide (Shredder 2,4-D LV4) application was applied to plots that did not include legume mixtures. Based on recommendations from soil analysis, 33.6 kg ha^{-1} of potash was applied to bermudagrass on the same dates as tall fescue, and on 31 May 2016 a second application of 33.6 kg ha^{-1} of potash was applied to bermudagrass following first harvest, based on soil test recommendations. Cowpea planting and establishment followed the same dates and procedures as those described in the tall fescue experiment.

Measurements

A center strip in each experimental plot was harvested utilizing a 0.91 m wide Carter forage harvester (Carter, Brookston, IN) at a stubble height of 15 cm. Border material of each plot was cleaned off after each harvest. Plots in the tall fescue experiment were harvested on 26 April, 31 May, 28 June, 26 July, and 31 August in 2016, and 28 April, 26 May, 10 July, 14 August, and 6 September in 2017. Plots in the bermudagrass experiment were harvested on 31 May, 28 June, 26 July, 31 August, and 28 September in 2016 and 26 May, 10 July, 14 August, and 6 September in 2017.

Plot weights were recorded during each harvest. A subsample was then collected from the harvested material and wet weights of the subsamples were recorded. Herbage samples were dried at 60°C to a constant weight (~72 h) and dry weights recorded to determine HM. Samples were ground to pass through a 1-mm sieve with a Wiley Mill Grinder (Thomas Scientific, Swedesboro, NJ) in preparation for near-infrared spectroscopy (NIRS) analysis. Three forage nutritive value parameters (ADF, NDF, and CP) were predicted using a Unity SpectraStar XT NIRS instrument (Unity Scientific, Milford, MA). Equations for the forage nutritive analyses were standardized and checked for accuracy with the 2014 Grass Hay Equation developed by the NIRS Forage and Feed Consortium (NIRSC, Hillsboro, WI). Software used for NIRS analysis was Win ISI II supplied by Infrasoft International (State College, PA). The Global H statistical test compared the samples against the model and samples from distinct data sets within the database for accurate results, in which all forage samples fit the equation, (H < 3.0), and are reported accordingly (Murray and Cowe, 2004).

A single forage sample to characterize botanical composition was collected from a 0.1-m^2 area at a 12.7-cm stubble height, and selected at random with in each legume–grass mixture experimental unit. Sampling dates were 26 Aug. and 9 Sept. 2016, and 10 Aug. and 6 Sept. 2017. Sampling dates were chosen to guarantee all legume species were developed. Samples were separated by species, dried at 60°C to constant weight (~72 h), and separately weighed.

Statistical Analyses

Differences between least square means by treatment for HM, all nutritive value variables, and all species were evaluated using the PROC MIXED procedures, adjusted for Tukey's method for least square means separation of SAS (SAS for Windows V 9.4, SAS Institute, Cary, NC). Response variables (HM, CP, ADF, and NDF) were considered dependent, year and treatment (N source) × harvest date were considered fixed effects, and replicates were considered random effect. There were significant year × treatment interactions ($P < 0.0001$) for all dependent variables. Therefore, results of each experiment are displayed separately by year for all variables. Differences between least squares means by treatments for botanical composition variables of legume and grass were tested for each species using the PROC MIXED procedures adjusted for Tukey's method for least square means separation of SAS. Treatment was a fixed effect and replication was a random effect.

RESULTS AND DISCUSSION

Weather

In April through September 2015, mean air temperature was 0.1° below the 30-yr average and precipitation was 55% above the 30-yr average (722 mm). In April through September 2016, mean air temperature was 0.4°C above the 30-yr average and precipitation was 39% below the 30-yr average. In April through September 2017, mean air temperature was 0.7°C above the 30-yr average and precipitation was 30% above the 30-yr average (Fig. 1). With the exception of 39% below normal rainfall in 2016, seasonal precipitation and air temperature in other stated years were considered adequate for forage growth during the study period (Fig. 1).

Tall Fescue

Results from a type 3 test performed by the PROC MIXED procedure for the tall fescue experiment of 2016 and 2017 are presented in Table 1.

Botanical Composition

Knowledge of botanical composition is key in managing mixed pastures. Botanical composition analysis showed that percentage WC was lower than that of CW when mixed to existent tall fescue plots in 2016 and lower than both CW and RC in 2017 (Table 2). Many studies suggest that planting WC in a mixture with tall fescue increases production (Dobson et al., 1976), improves forage quality, and can serve as an N supply (Watson and Watson, 1989). However, our results do not agree with past research. One of the reasons for the lack of WC effect on response variables may be its low percentage in the mixture with tall fescue, which may be due to poor establishment that resulted from our use of a Hege seed drill (Hege Company, Waldenburg, Germany). This drill is primarily intended for cultivated ground instead of drilling WC in already established tall fescue pasture. However, RC was drilled with the same Hege seed drill and its establishment did not seem to be a major concern.

Percentage of RC was greater than the other legumes in 2017 (Table 2). This may be due to RC having a longer growing season (April–October) since it is a cool-season legume vs. CW, a warm-season legume, with a shorter growing season (June–August) (Ball et al., 2007). Although RC is a cool-season legume, it is also fairly tolerant to drought conditions (Ball et al., 2007). Also, RC is considered a cool-season, short lived perennial vs. CW being a warm season–annual (Ball et al., 2007). Climatic conditions for the area, such as favorable temperatures from our Zone B location, allowed RC to grow and perform well over a longer period throughout the season when compared with CW.

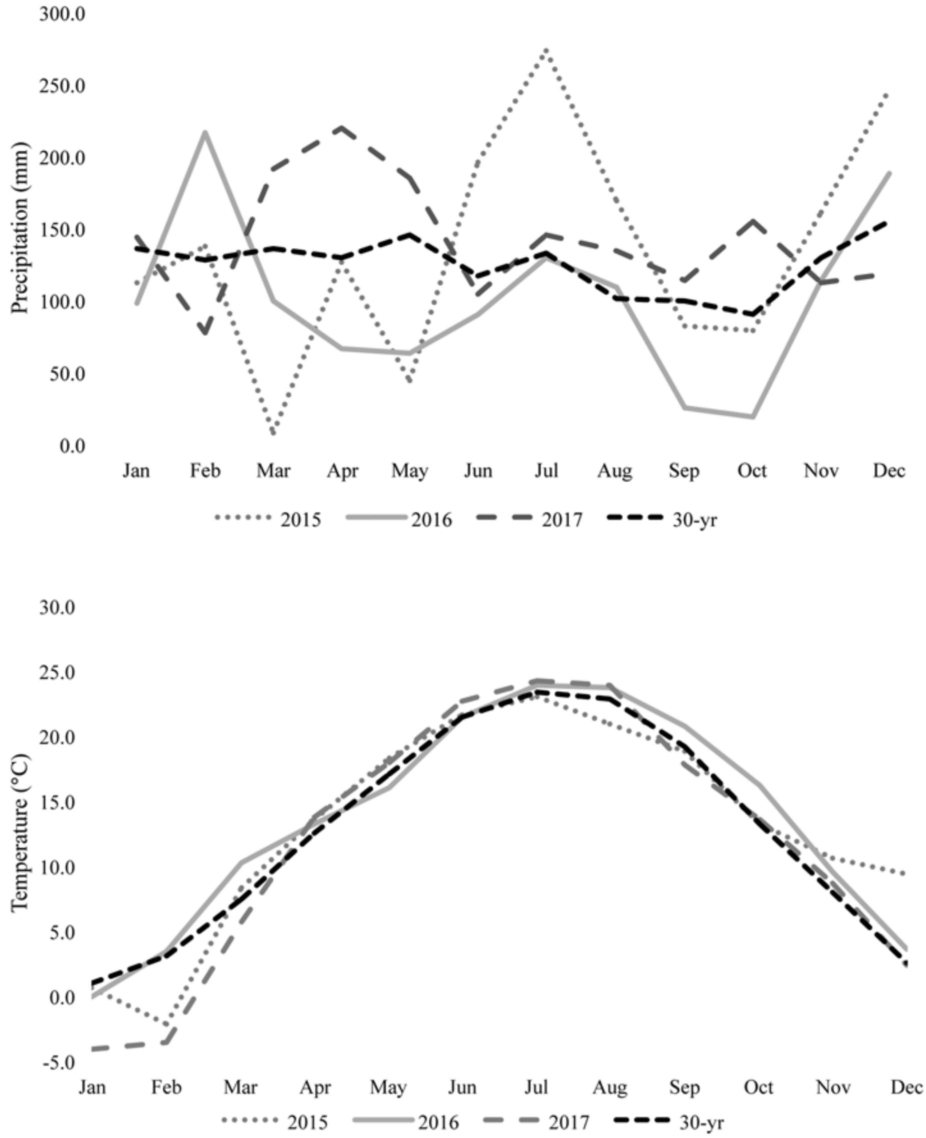

Fig. 1. Weather for Crossville, TN, reported as monthly averages based on daily records including 30-yr average for 2015, 2016, and 2017.

Legume percentage of CW was comparable to RC ($P = 0.646$) in 2016 but differed in 2017 ($P = 0.0002$) (Table 2). Considering CW is drought-tolerant (Ehlers and Hall, 1997), CW grown in a mixture with tall fescue performs better when tall fescue is more stressed by drought conditions. This also suggests CW may serve as an alternative source of N in existent tall fescue plots during the warmer months when tall fescue is not thriving and stressed due to unfavorable weather conditions.

Herbage Mass

In 2016, treatments containing AN and BL had greater HM than CN and legume mixtures (with the exception of RC) (Fig. 2). In 2017, treatments containing RC had the greatest total HM, followed by AN and BL. This may be due to larger amounts of precipitation recorded for 2017, promoting more growth vs. 2016 (Fig. 1), and possibly due to the fact that RC is a short-lived perennial, usually 2 yr in the south, and its ability to fix N (Kallenbach and Bishop-Hurley, 2004; Ball et al., 2007). A study showed that the annual uptake of transferred N from RC to tall fescue cv. Tacuabe was greater in the second year after establishment (Mallarino et al., 1990), suggesting RC may be a good alternative source to synthetic N in existent tall fescue plots. Similarly, results of the present study suggest BL and RC both served as a good alternative source to synthetic N in tall fescue swards. Control treatment had the lowest total HM and did not differ from treatments containing CW and WC in both years (Fig. 2). Our results are in agreement with past research conducted in Georgia that showed RC varieties combined with fescue more than doubled HM relative to fescue monoculture; fescue mixed with RC and fescue monoculture averaged 10,000 and 4,500 kg ha^{-1} dry forage, respectively, over a 3-yr period (Dobson et al., 1976).

The BL treatment had the greatest HM at the first harvest in 2016. For the remaining harvests of 2016 and 2017, BL and AN did not differ in the amount of HM produced during each harvest period. During both years, HM values for all treatments containing a forage legume (CW, RC, and WC) did not differ during the first harvest period. However, as the season progressed, plots containing RC showed greater HM among mixtures (Table 2). In 2017, the RC and tall fescue mixture had the highest HM among all treatments during the third harvest (Table 2). This may be due to climatic conditions being

Table 1. Results of the "type 3 test of fixed effects" in tall fescue and legume–tall fescue mixed sward across five harvesting dates during the growing season of 2016 and 2017.

Effect	Num DF	Den DF	*F* value	*Pr > F*	Effect	Num DF	Den DF	*F* value	*Pr > F*
	HM† kg DM ha^{-1} 2016					HM kg DM ha^{-1} 2017			
Treatment	5	14.4	13.54	<0.0001	Treatment	5	29.1	48.60	<0.0001
Date (Treatment)	24	52.5	17.51	<0.0001	Date (Treatment)	24	68.8	34.01	<0.0001
	CP† g kg^{-1} 2016					CP g kg^{-1} 2017			
Treatment	5	15	21.93	<0.0001	Treatment	5	16.2	23.68	<0.0001
Date (Treatment)	24	55.6	15.61	<0.0001	Date (Treatment)	24	54.3	14.65	<0.0001
	ADF† g kg^{-1} 2016					ADF g kg^{-1} 2017			
Treatment	5	14.8	6.37	0.0024	Treatment	5	15	61.86	<0.0001
Date (Treatment)	24	55.4	7.78	<0.0001	Date (Treatment)	24	53.8	31.13	<0.0001
	NDF† g kg^{-1} 2016					NDF g kg^{-1} 2017			
Treatment	5	18.2	9.06	0.0002	Treatment	5	14.9	32.67	<0.0001
Date (Treatment)	24	57.2	6.73	<0.0001	Date (Treatment)	24	55.6	15.19	<0.0001

† HM, herbage mass; CP, crude protein; ADF, acid detergent fiber; NDF, neutral detergent fiber.

Table 2. Average herbage mass of tall fescue and legume–tall fescue mixed sward per harvesting period for 2016 and 2017 and botanical composition of the three mixed swards averaged across Harvests 4 and 5 combined in 2016 and 2017.

		Harvest 1	Harvest 2	Harvest 3	Harvest 4	Harvest 5	Botanical composition‡	
Year	Treatment†	Herbage mass, kg DM ha^{-1}					% Legume	% Grass
2016	AN	1021b§	2153a	363ab	324b	567ab		
	BL	1695a	1988ab	339ab	336b	555ab		
	CN	370c	1058bc	283b	325b	440b		
	CW	370c	1058bc	263b	743a	497b	27a	73b
	RC	452c	1248abc	546a	678a	825a	24ab	76ab
	WC	296c	897c	289b	282b	489b	10b	90a
	P-value	<0.0001	0.0047	0.0061	0.0001	0.0162	0.0370	0.0370
2017	AN	921ab	800a	861b	629b	179ab		
	BL	1191a	881a	1182b	901ab	248a		
	CN	212d	214b	583b	506b	195ab		
	CW	444bcd	292b	608b	499b	146ab	20b	80b
	RC	778abc	966a	3374a	1112a	158ab	38a	62c
	WC	406cd	250b	645b	497b	73b	4c	96a
	P-value	<0.0001	<0.0001	<0.0001	0.0003	0.0255	<0.0001	<0.0001

† AN, ammonium nitrate; BL, broiler litter; CN, control; CW, cowpea; RC, red clover; WC, white clover.

‡ Percent values are the means from botanical samples collected, dried, and weighed during Harvest 4 and 5 periods.

§ Means within a column per year without a common superscript letter differ ($P \leq 0.05$), based on Tukey's test.

favorable for RC mixed with tall fescue during the experimental period at the experimental site. Red clover is known to perform best from March to June as long as soil drains properly and adequate grazing management is practiced (Ball et al., 2007). Also, in 2016, CW showed its largest HM results of the season during the fourth harvest, which occurred in July (Table 2). Cowpea is a warm-season annual legume, normally established in late May, also considered a drought-tolerant legume (Ball et al., 2007; Ehlers and Hall, 1997). Foster et al. (2009) showed that cowpea grown alone in Florida had a linear increase in HM when precipitation was adequate and peaked around 10 wk after planting. The authors also observed that cowpea monoculture performed favorably during drought conditions, with HM peaking around 7 wk after planting. Studies have shown perennial grass–legume mixtures typically increase in total biomass and RC mixed with orchardgrass (*Dactylis glomerata* L.) resulted in greater biomass and greater soil N uptake compared with orchardgrass alone (Schipanski and Drinkwater, 2012). Treatments with RC and CW during summer months provided additional N input, which likely was responsible for increasing HM production during a period of reduced growth rate (Nave et al., 2013, 2014). Red clover–tall fescue mixtures showed approximately 40% more HM in 2017 (6390 kg ha^{-1}) than 2016 (3750 kg ha^{-1}) (Fig. 2), which can also be observed on individual HM per harvesting period of 2017 compared with 2016 (Table 2). This may be due to RC being a short-lived forage legume with generally greater production during the second year after establishment (Wiersma et al., 1998). In addition, although RC is drought tolerant, no drought occurred for the growing season of 2017 (Fig. 1), favorably benefiting the RC and tall fescue mixture. The WC treatment was comparable to CN treatments, due to poor establishment (Table 2).

Forage Nutritive Value

Crude protein can be affected by the amount of available N in the soil (Minson, 1990). In 2016, average CP for treatments containing AN, BL, and RC were significantly greater than CW, WC, and CN treatments (Table 3). In 2017, RC and BL treatments showed the highest CP content. Red clover, as a legume, will generally have greater CP content than grasses, with a study showing that mean concentrations of CP in legumes was 55 g kg^{-1} DM greater than temperate grasses (Minson, 1990). Broiler litter results may be explained due to BL containing organic matter, which aids in nutrient holding capacity (Evers, 1998),

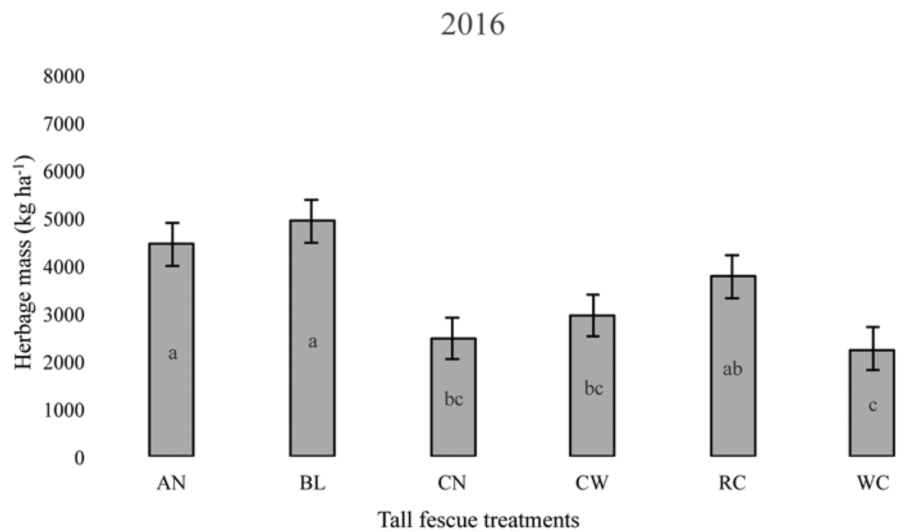

Fig. 2. Total herbage mass of tall fescue swards under six different treatments (AN, ammonium nitrate; BL, broiler litter; CN, control; CW, cowpea; RC, red clover; and WC, white clover) across five harvesting dates during the growing in 2016 and 2017 ($P \leq 0.0001$).

allowing tall fescue to retain the available N and increase CP. Based on these results, RC and BL are not only good alternative sources of N in existent tall fescue plots, but also enhancing CP content. Average CP for CW treatment was comparable to CN and WC treatments in 2016 (Table 3). However, CW was only comparable to CN in 2017, once that WC treatment had the lowest CP concentration among treatments. It was expected to observe CP content of tall fescue mixed with CW to be low, once that CW is known to have a shorter growing season, June–August (Ball et al., 2007). However, WC had contrary results from what was expected. This may be due to poor establishment of WC in 2015. Also, the fact that tall fescue plots mixed with WC had lower CP content than CN may be due to mixed plots being under stress and competition. In 2017, RC and WC were significantly greater in ADF content (Table 3). Cool-season legumes are known to have a high amount of indigestible fiber, especially when mature, and in many instances these values are superior to those of cool-season grasses, especially for stem digestibility vs. leaf digestibility (Buxton, 1996). Nitrogen fertilization of tall fescue plots may contribute to production of young leaves, prolonging immature status of these plants, increasing forage nutritive value (Buxton, 1996). Neutral detergent fiber levels for CW and RC treatments were lower than all other treatments in 2016 growing season and RC treatments were lower than all other treatments in 2017 (Table 3). Our research is in agreement with other studies (Kleen et al., 2011) showing that CP was associated with legume percentages (Table 2). Also, under grazing, CP values for RC + Grass were greater than that of WC + Grass (184 vs. 154 g kg^{-1}, respectively) (Kleen et al., 2011).

Average CP values for RC treatments were significantly greater than the other treatments in the fourth and fifth harvest period of 2017 (Table 4). Red clover, even though it is a cool-season legume, performs well under drought conditions and high temperatures (Ball et al., 2007); therefore, it had an advantage over other legume mixtures. In addition, its ability to fix N increases CP content and may serve well in aiding tall fescue nutritional values during warmer months, especially because CP levels are expected to be decreasing as the cool-season grass matures reducing the leaf/stem ratio (Buxton, 1996). Tall fescue plots fertilized with AN showed greater CP than all other treatments for the first harvest of 2016 (Table 4). However, AN showed no CP differences to BL for the remaining of 2016, and earlier in the 2017 season (Table 4). We suspect this may be due to the amount

Table 3. Concentration of crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) of tall fescue and legume–tall fescue mixed swards averaged across five harvesting dates during the growing season of 2016 and 2017.

	2016			2017		
Treatment†	CP	ADF	NDF	CP	ADF	NDF
	g kg^{-1}					
AN	138a‡	329c	574ab	149bc	308bc	585a
BL	135a	332bc	585a	159ab	299c	581a
CN	114b	353a	570ab	140c	313b	587a
CW	119b	341abc	543bc	142c	306bc	573a
RC	138a	343abc	521c	166a	339a	492b
WC	114b	349ab	569ab	122d	348a	573a
P-value	<0.0001	0.0024	0.0002	<0.0001	<0.0001	<0.0001

† AN, ammonium nitrate (34–0–0); BL, broiler litter; CN, control; CW, cowpea; RC, red clover; WC, white clover.

‡ Means within a column per year without a common superscript letter differ ($P \leq 0.05$), based on Tukey's test.

of nutrient carry over rate associated with BL and its ability to retain nutrients well (Evers, 1998). Also, studies have shown that in the beginning of the growing season, not all total N from BL was readily available (Teutsch et al., 2005; Bitzer and Sims, 1988).

There were only a few differences among treatments for ADF content in 2016, which occurred mostly during the second and third harvest period (Table 4). All legume mixed treatments showed consistently greater ADF content throughout the season in 2016, and that is consistent with findings showing legumes under high maturity tend to show greater amounts of indigestible fiber (Buxton and Hornstein, 1986; Buxton et al., 1985). Acid detergent fiber is directly correlated to digestibility (Buxton, 1996). In 2017, RC and WC treatments were greater in ADF for most of the growing season (Table 4). This may be due to accelerated rate of maturity of cool-season legumes under warmer temperatures that could have increased ADF values. Also RC treatments were significantly less than all other treatments in NDF for four out of five harvest periods of 2017 (Table 4). This may be due to the maturity level and aggressiveness of the RC legume in 2017.

Bermudagrass

Results from a type 3 test performed by the PROC MIXED procedure for the bermudagrass experiment of 2016 and 2017 are located in Table 5.

Botanical Composition

Botanical composition analysis showed that percentage of legumes in a bermudagrass mixed sward was greater for treatments containing RC in both years (Table 6). Percentage of cool-season legumes was expected to be high once that bermudagrass is a warm-season grass, therefore allowing the cool-season legume to get a head start and have less competition in the beginning of the growing season. However, WC treatments did not seem to have the vigorous growth early in the season as suggested by RC treatments. This may be due to drought conditions in 2016 (Fig. 1) where growth and legume N fixation, especially of non-drought tolerant species such as WC, can be reduced undergoing stress associated with drought or water depletion (Engin and Sprent, 1973). Red clover is considered a short-lived perennial legume, which may grow more vigorous and quickly with a tendency to produce the most HM in the year after establishment (Wiersma et al., 1998). Also, RC is drought tolerant and the fact that there was a severe drought in 2016 could have given RC an advantage when compared with WC. Amount of precipitation affects the persistence of legumes, more so to WC due to it being shallow rooted compared with RC being deep rooted (Ledgard and Steele, 1992).

Table 4. Concentrations of crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) of tall fescue and legume–tall fescue mixed sward averaged per harvesting date in 2016 and 2017.

Year	Treatment†	Harvest 1	Harvest 2	Harvest 3	Harvest 4	Harvest 5
		CP, g kg^{-1}				
2016	AN	178a‡	115ab	133ab	138b	125bc
	BL	149b	118a	131ab	145ab	133ab
	CN	125c	100bc	105b	126b	113c
	CW	125c	100bc	124ab	129b	115c
	RC	126c	111abc	145a	161a	146a
	WC	120c	99c	108b	129b	113c
	P-value	<0.0001	0.0015	0.0021	0.0005	<0.0001
2017	AN	176ab	161bc	124a	130b	153bc
	BL	191a	171ab	136a	137b	162b
	CN	147bc	147c	134a	131b	140c
	CW	148bc	152c	137a	130b	141c
	RC	152bc	183a	139a	170a	183a
	WC	125c	122d	93b	123b	147bc
	P-value	0.0005	<0.0001	<0.0001	<0.0001	<0.0001
		ADF, g kg^{-1}				
2016	AN	295b	333b	332b	346	338
	BL	320a	347ab	333ab	337	325
	CN	315a	366a	368a	367	350
	CW	315a	366a	342ab	335	346
	RC	319a	354ab	356ab	350	339
	WC	321a	362a	362ab	357	346
	P-value	0.0118	0.0020	0.0188	0.2087	0.1332
2017	AN	282b	289bc	319b	345bc	305ab
	BL	273b	277c	308b	340c	295ab
	CN	291b	303b	314b	346bc	311ab
	CW	292b	300bc	282c	340c	314a
	RC	328a	328a	385a	359ab	293b
	WC	324a	352a	382a	370a	314a
	P-value	<0.0001	<0.0001	<0.0001	<0.0001	0.0061
		NDF, g kg^{-1}				
2016	AN	530	550	587a	591a	611a
	BL	545	567	594a	606a	611a
	CN	537	563	576ab	579a	595a
	CW	537	563	545bc	472b	598a
	RC	522	550	513c	495b	524b
	WC	539	591	564ab	548ab	605a
	P-value	0.6506	0.5216	<0.0001	<0.0001	0.0003
2017	AN	574a	557b	588a	623a	581a
	BL	566a	552c	591a	621a	576a
	CN	580a	593a	564a	608a	589a
	CW	586a	590ab	497b	602a	591a
	RC	508b	458d	500b	502b	490b
	WC	558a	565abc	575a	605a	562a
	P-value	0.0004	<0.0001	<0.0001	<0.0001	<0.0001

† AN, ammonium nitrate; BL, broiler litter; CN, control; CW, cowpea; RC, red clover; WC, white clover.

‡ Means within a column per year without a common superscript letter differ ($P \leq 0.05$), based on Tukey's test.

Table 5. Results of the "type 3 test of fixed effects" in bermudagrass and legume–bermudagrass mixed sward across five harvesting dates during the growing season of 2016 and 2017.

Effect	Num DF	Den DF	*F* value	*Pr* > *F*	Effect	Num DF	Den DF	*F* value	*Pr* > *F*
	HM† kg DM ha^{-1} 2016					HM kg DM ha^{-1} 2017			
Treatment	5	14.7	44.25	<0.0001	Treatment	5	17.7	20.76	<0.0001
Date (Treatment)	24	55.6	19.58	<0.0001	Date (Treatment)	18	38.9	23.19	<0.0001
	CP g kg^{-1} 2016					CP g kg^{-1} 2017			
Treatment	5	15	119.22	<0.0001	Treatment	5	15.8	56.30	<0.0001
Date (Treatment)	24	55.8	21.36	<0.0001	Date (Treatment)	18	49.3	8.47	<0.0001
	ADF g kg^{-1} 2016					ADF g kg^{-1} 2017			
Treatment	5	17.9	8.72	0.0002	Treatment	5	21.5	1.93	0.1310
Date (Treatment)	24	56.7	14.71	<0.0001	Date (Treatment)	18	49.9	9.06	<0.0001
	NDF g kg^{-1} 2016					NDF g kg^{-1} 2017			
Treatment	5	14.3	153.83	<0.0001	Treatment	5	22.1	65.15	<0.0001
Date (Treatment)	24	54.9	36.71	<0.0001	Date (Treatment)	18	51	6.76	<0.0001

† HM, herbage mass; CP, crude protein; ADF, acid detergent fiber; NDF, neutral detergent fiber.

Table 6. Average herbage mass of bermudagrass and legume–bermudagrass mixed sward per harvesting period in 2016 and 2017 and botanical composition means of bermudagrass and legume mixed swards for Harvest 4 and 5 combined in 2016 and 2017.

		Harvest 1	Harvest 2	Harvest 3	Harvest 4	Harvest 5	Botanical composition§	
Year	Treatment†	Herbage mass, kg DM‡ ha^{-1}					% Legume	% Grass
2016	AN	719bc¶	1282bc	996bc	1695	326		
	BL	765bc	1334bc	1171abc	2145	456		
	CN	409c	347d	679c	1562	561		
	CW	409c	548cd	2123a	1730	525	9b	91a
	RC	3317a	2876a	2018ab	1979	207	33a	67b
	WC	1192b	1682b	1918ab	1357	185	18b	82a
	P-value	<0.0001	<0.0001	0.0010	0.1338	0.0786	0.0020	0.0020
2017	AN	1198bc	1412bcd	305b	364			
	BL	1541bc	2427b	775ab	509			
	CN	521c	1183cd	483b	311			
	CW	493c	1006d	381b	345		13b	87a
	RC	2822a	4736a	1104a	879		67a	33b
	WC	1795ab	2026bc	490b	319		16b	84a
	P-value	<0.0001	<0.0001	0.0025	0.5208		<0.0001	<0.0001

† AN, ammonium nitrate; BL, broiler litter; CN, control; CW, cowpea; RC, red clover; WC, white clover.

‡ DM, dry matter.

§ Percent values are the means from botanical samples collected, dried, and weighed during Harvest 4 and 5 periods.

¶ Means within a column per year without a common superscript letter differ ($P \leq 0.05$), based on Tukey's test.

Cowpea showed lower percentage in bermudagrass mixed swards in both years compared with WC and RC (Table 6). Since CW and bermudagrass are both warm-season species, competition was expected to be a factor. Legume growth and amount of fixed N is decreased when grown in grass species that are aggressive and already established (Ledgard and Steele, 1992). Even though CW is known for being drought tolerant (Ehlers and Hall, 1997), bermudagrass thrives in warm temperatures and is known to be invasive owning to a lateral spread by both rhizomes and stolons (Ball et al., 2007). Bermudagrass may have been highly competitive, impeding CW to thrive in mixture. Perhaps increasing the seeding rates of CW in bermudagrass swards may benefit the warm-season legume growth in these mixtures.

Herbage Mass

Overall, RC treatments had greater total HM than all other treatments for both 2016 and 2017 growing seasons (Fig. 3). As previously mentioned, this may be due to RC growth pattern, of being a short-lived perennial and resilience, allowing the species to have an advantage throughout the season (Wiersma et al., 1998; Ball et al., 2007). Based on total HM of bermudagrass sward mixed with RC suggests that the legume may be a viable option to increase productivity of bermudagrass during the growing season. Treatments containing CW did not differ from AN, BL, and WC in 2016 (Fig. 3). However, CW was lower than AN, BL, and WC in 2017 (Fig. 3). This may be due to more precipitation in 2017 compared with 2016 (Fig. 1), implying bermudagrass is thriving and being more productive, therefore more aggressive resulting in decreased CW growth (Ledgard and Steele, 1992). Broiler litter and WC were comparable to AN for average HM in 2016 and 2017 (Fig. 3), which is in agreement with findings from Evers (1998). These results suggest that BL and WC may serve as good sources of N in bermudagrass pastures. Our results of RC treatments showing greater HM than CN treatments are in agreement with past research done in Southeastern Texas, which showed subterranean clover (*Trifolium subterraneum* L.) and arrowleaf clover (*Trifolium vesiculosum* Savi) mixed with bermudagrass had greater average HM compared with bermudagrass alone for 2 yr (Evers, 1985).

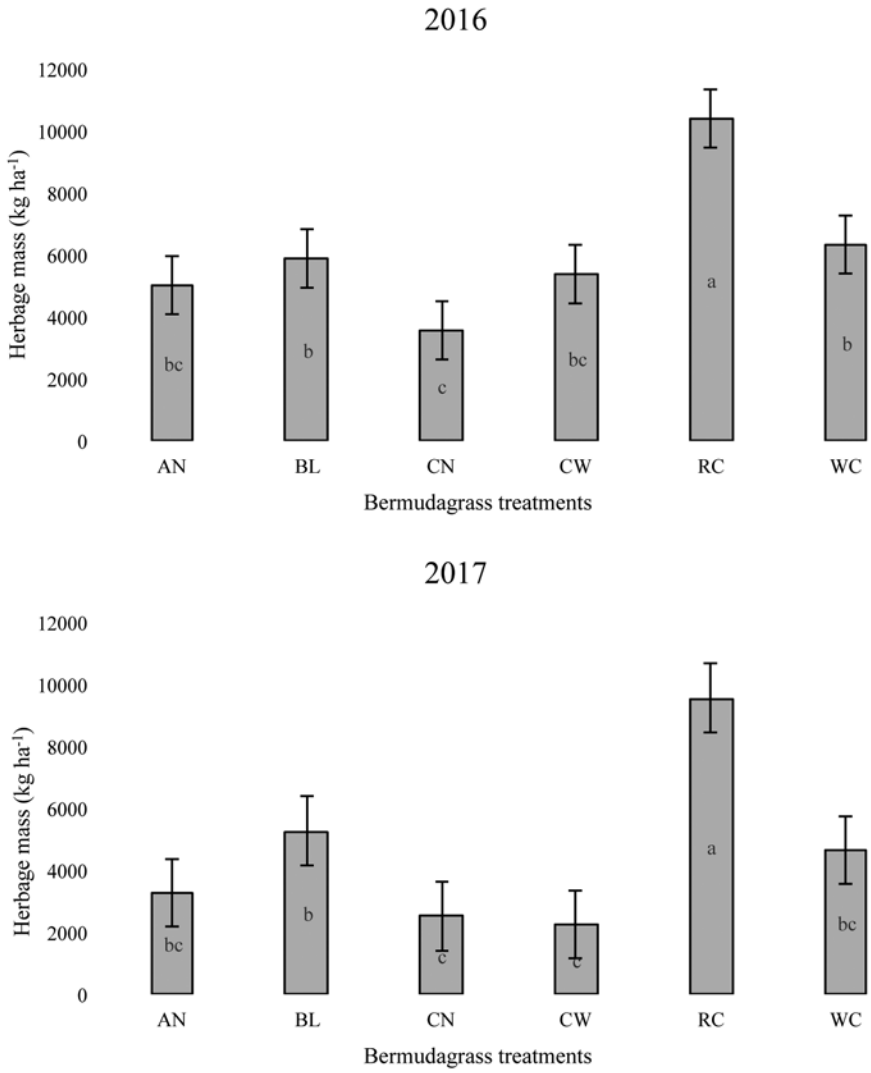

Fig. 3. Total herbage mass of bermudagrass swards under six different treatments (AN, ammonium nitrate; BL, broiler litter; CN, control; CW, cowpea; RC, red clover; and WC, white clover) across five harvesting dates during the growing season in 2016 and four harvesting dates during the growing season in 2017 ($P \leq 0.0001$).

These results can potentially allow grazing to begin earlier in the late spring due to cool-season legume forage availability and biological N fixation (Evers, 1985).

The number of harvests in 2016 was greater than the number of harvests in 2017 due to unfavorable weather conditions through the summer, delaying desired harvest dates in 2017. This delay eliminated the desired last harvest due to the warm season coming to an end, resulting in bermudagrass declining in growth and production. Based on the results presented in Table 4, treatments did not differ for the last two harvests in 2016 and the last harvest in 2017. This may be due to bermudagrass approaching the end of its growing season during this time, which occurred late August and September. Based on results from Evers (1985), coastal bermudagrass grown in southeastern Texas showed decreased percentage of DM by about 20% from June to September. Because productivity of bermudagrass is declining, it is no longer responding to the N sources applied. Therefore, HM showed less variance at the end of the season, resulting in no differences among treatments. Treatments containing RC were significantly greater than all treatments for the first and second harvest of 2016 and second harvest of 2017 (Table 6). This may be due to RC being a cool-season legume and lacking competition for growth from the warm-season companion bermudagrass during the cool temperatures in the early spring (Ball et al., 2007). Herbage mass results for CW treatments showed its highest recordings for the third harvest of 2016 (Table 6). This may be due to the drought that occurred in 2016 (Fig. 1). This is in agreement with the study, of cowpea performing well in Florida, 7 wk after planting, during drought conditions (Foster et al., 2009). Cowpea, being a warm-season legume with a drought-tolerant characteristic, may serve as an excellent source of additional HM and N in bermudagrass swards under drought conditions. However, in 2017, drought conditions were not present and CW treatments usually showed the lowest HM values. Bermudagrass plots containing AN also showed low in comparison with RC treatments (Table 6), and this may be due to the fact that AN quickly releases N into the soil, and when applied to a warm-season grass under rapid growth rate (Gelley et al., 2016), the amount of N available from AN may be reduced during the growing season when compared with slower release of N provided by legumes, and manures due to the organic matter, which holds nutrients (Ledgard and Steele, 1992; Evers, 1998). In addition,

Table 7. Concentration of crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) of bermudagrass and legume–bermudagrass mixed swards averaged across five harvesting dates during the growing season of 2016 and four harvesting dates in 2017.

	2016			2017		
Treatment†	CP	ADF	NDF	CP	ADF	NDF
	g kg^{-1}					
AN	120c‡	338a	636a	115c	322	644a
BL	119cd	342a	640a	124c	319	646a
CN	118cd	338a	613b	117c	319	634a
CW	109d	343a	598b	117c	313	615a
RC	174a	342a	493d	190a	329	474c
WC	147b	321b	532c	144b	320	545b
P-value	<0.0001	0.0002	<0.0001	<0.0001	0.1310	<0.0001

† AN, ammonium nitrate (34–0–0); BL, broiler litter; CN, control; CW, cowpea; RC, red clover; WC, white clover.

‡ Means within a column per year without a common superscript letter differ ($P \leq 0.05$), based on Tukey's test.

split applications of synthetic N fertilizer may be ideal in this situation to increase efficiency (Alley, 2001). Also, most soil test recommendations suggest to split applications of N due to bermudagrass growth habit of spreading by stolons and rhizomes and ability to quickly retain and respond to N. Bermudagrass production has been known to increase as fertilizer rate increased (Evers, 1998).

Forage Nutritive Value

Bermudagrass has been known to respond well to N application (Evers, 1998). Crude protein content is highly influenced by the amount of N the plant uptakes from the soil (Minson, 1990). Legumes, with their ability to fix N, have usually greater CP content compared with most grasses (Buxton, 1996). Based on the results from this study, RC had greater CP content during both 2016 and 2017 growing seasons (Table 7), which suggests that among all treatments, RC highly improves forage nutritive value of bermudagrass in a mixed sward. In addition, based on results from total HM (Fig. 3), RC appears to improve overall productivity as well, and could be considered as a viable option as a sustainable N source to bermudagrass swards. Again, this may be due to RC growth pattern, of being a short-lived, cool-season perennial and resilient to drought, allowing the species to have an advantage throughout the entire growing season (Wiersma et al., 1998; Ball et al., 2007). Cowpea treatment was significantly lower than RC and WC for CP content in 2016 (Table 7). Even though legumes tend to have high CP content, CW had lower values than RC and WC, possibly due to their different growing seasons. Also, CW is considered a warm-season annual legume and may have been outcompeted by bermudagrass in a mixed sward. The vigorous and invasive spreading of rhizomes and stolons from the established and actively growing bermudagrass did not provide desirable conditions for CW to reach proper performance (Ledgard and Steele, 1992).

For the variable ADF analyzed, WC treatment had lower values than all other treatments in 2016 (Table 7), but no differences occurred among treatments for ADF in 2017 (Table 7). A recent study showed mixtures containing more erect growing legumes such as RC had greater ADF values compared to grass–legume mixtures with low growing legumes such as WC (Kleen et al., 2011). Red clover treatments were lower than all other treatments for NDF in 2016 and 2017. This may also be due to the growth habit of RC.

Table 8. Concentrations of crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) of bermudagrass and legume–bermudagrass mixed sward per harvesting date in 2016 and 2017.

Year	Treatment†	Harvest 1	Harvest 2	Harvest 3	Harvest 4	Harvest 5
		CP				
		g kg^{-1}				
2016	AN	161ab‡	118b	120c	98c	100bc
	BL	149bc	123b	130c	95c	97bc
	CN	129c	131b	130c	97c	100bc
	CW	129c	126b	113c	91c	85c
	RC	170a	198a	197a	159a	146a
	WC	157ab	177a	164b	123b	113b
	P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
2017	AN	132c	98b	126b	102b	.
	BL	140bc	107b	132b	116b	.
	CN	145bc	103b	117b	102b	.
	CW	137c	101b	126b	104b	.
	RC	212a	171a	187a	192a	.
	WC	168b	144a	134b	132b	.
	P-value	<0.0001	<0.0001	0.0002	<0.0001	.
		ADF				
2016	AN	307ab	321ab	344	354a	362
	BL	315ab	324ab	335	358a	379
	CN	326a	315b	337	347ab	364
	CW	326a	309b	340	357a	383
	RC	325a	343a	341	340ab	361
	WC	295b	300b	321	328b	361
	P-value	0.0050	0.0013	0.3018	0.0018	0.0899
2017	AN	308ab	314b	334ab	333	.
	BL	308ab	311b	331b	326	.
	CN	299ab	310b	336ab	333	.
	CW	303ab	295b	319b	335	.
	RC	323a	349a	340ab	304	.
	WC	282b	304b	360a	333	.
	P-value	0.0214	<0.0001	0.0069	0.0781	.
		NDF				
2016	AN	556a	637a	649a	651a	688ab
	BL	554ab	627a	650a	663a	705a
	CN	518b	606ab	614ab	641a	687ab
	CW	518b	551b	561bc	653a	709a
	RC	426c	462c	479c	495c	603c
	WC	434c	466c	513c	577b	668b
	P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
2017	AN	632a	646a	638ab	660a	.
	BL	617a	651a	658a	660a	.
	CN	612a	632ab	637ab	654a	.
	CW	623a	584b	586b	668a	.
	RC	433b	470c	498c	495b	.
	WC	456b	513c	603ab	609a	.
	P-value	<0.0001	<0.0001	<0.0001	<0.0001	.

† AN, ammonium nitrate; BL, broiler litter; CN, control; CW, cowpea; RC, red clover; WC, white clover.

‡ Means within a column per year without a common superscript letter differ ($P \leq 0.05$), based on Tukey's test.

In both years, concentration of CP was consistently greater for treatments containing RC throughout the whole growing season (Table 8). Earlier in the season, as WC developed, it showed an increase for CP content, being comparable to RC at times; however, once temperatures were increased, N release from WC may have decreased. As mentioned, legume growth and N fixation can be reduced undergoing stress associated with drought or water depletion (Engin and Sprent, 1973). As expected and similarly to HM and botanical composition results, CW treatments seemed to have been outcompeted by bermudagrass, maintaining low CP content comparable to bermudagrass monoculture treatments during all harvesting periods in both years (Table 8). This suggests that CW may not be suitable as a mixture to improve bermudagrass productivity and nutritive value. Contrary to CW, our results suggest that RC ability to fix N and tolerate warm temperatures and droughty conditions (Ball et al., 2007) may serve well in aiding bermudagrass nutritive value throughout summer.

There were no differences in ADF values late in the growing season for both 2016 and 2017 (Table 8). Very few differences occurred for ADF content in 2016, with WC and legume absent plots being for the most part lower in NDF content for most of the harvesting periods. This suggests that legumes may have increased total fiber content to the bermudagrass mixture, potentially decreasing digestibility. As for NDF values, RC and WC were lower than all other treatments for the first and second harvest in 2016 and 2017 (Table 8). Red clover treatments were lower than all other treatments in NDF for the fourth and fifth harvest of 2016 and third and fourth harvest of 2017 (Table 8).

SUMMARY

Based on CP content from all treatments tested in this study, mixtures containing bermudagrass with RC were highest in both years. Our results suggest that RC is considered a good alternative source of N for both a cool-season or a warm-season grass, even in drought conditions as it was observed in 2016. In addition, RC appears to improve overall productivity and should be considered as a viable option for a sustainable N source to tall fescue and bermudagrass. Our results showed WC perform poorly in mixture with tall fescue and adequate in mixture with bermudagrass, which suggests adequate establishment of WC into these grasses, especially tall fescue, is needed to ensure successful productivity. Treatments containing CW resulted most of the time in the lowest HM and nutritive value. Future studies should consider different seeding rates and dates for planting CW in mixture with these forage grasses. As for the mixture of CW with bermudagrass, our results indicate that since both are warm-season species, there may be too much competitiveness and CW was not suitable to improve productivity and nutritive value in the mixed bermudagrass sward. Even though BL has potential to negatively impact the environment when not managed properly, it still serves as a renewable, alternative source of N; the BL treatment in many instances had greater productivity than AN in both experiments. Utilizing these results in combination with the cost for each N source could assist forage producers in choosing a sustainable and profitable source of N fertilization.

REFERENCES

Alley, M. 2001. Fertilizers for forages. Crop and Soil Environmental News. Virginia Tech, Blacksburg, VA. https://www.sites.ext.vt.edu/newsletter-archive/cses/2001-03/forages.html (accessed 3 Oct. 2018).

Anderson, B., and C.A. Shapiro. 1978. G78-406 Fertilizing grass pastures and haylands G78-406. Historical Materials from University of Nebraska-Lincoln Extension. 1300. https://digitalcommons.unl.edu/extensionhist/1300 (accessed 3 Oct. 2018).

Ball, D.M., C.S. Hoveland, and G.D. Lacefield. 2007. Southern forages: Modern concepts for forage crop management. 4th ed. Potash and Phosphate Institute and the Foundation for Agronomic Research, Norcross, GA.

Bitzer, C.C., and J.T. Sims. 1988. Estimating the availability of nitrogen in poultry manure through laboratory and field studies. J. Environ. Qual. 17:47–54. doi:10.2134/jeq1988.00472425001700010007x

Buxton, D.R. 1996. Quality-related characteristics of forages as influenced by plant environment and agronomic factors. Field Crops Res. 59:37–49.

Buxton, D.R., and J.S. Hornstein. 1986. Cell-wall concentration and components in stratified canopies of alfalfa, birdsfoot trefoil, and red clover. Crop Sci. 26:180–184. doi:10.2135/cropsci1986.0011183X002600010043x

Buxton, D.R., J.S. Hornstein, W.F. Wedin, and G.C. Marten. 1985. Forage quality in stratified canopies of alfalfa, birdsfoot trefoil, and red clover. Crop Sci. 25:273–279. doi:10.2135/cropsci1985.0011183X002500020016x

Dobson, J.W., C.D. Fisher, and E.R. Beaty. 1976. Yield and persistence of several legumes growing in tall fescue. Agron. J. 68:123–125. doi:10.2134/agronj1976.00021962006800010032x

Ehlers, J.D., and A.E. Hall. 1997. Cowpea (*Vigna unguiculata* L. Walp). Field Crops Res. 53:187–204. doi:10.1016/S0378-4290(97)00031-2

Engin, M., and J.I. Sprent. 1973. Effects of water stress on growth and nitrogen-fixing activity of *Trifolium repens*. New Phytol. 72:117–126.

Evers, G.W. 1985. Forage and nitrogen contributions of arrowleaf and subterranean clovers overseeded on bermudagrass and bahiagrass. Agron. J. 77:960–963. doi:10.2134/agronj1985.00021962007700060030x

Evers, G.W. 1998. Comparison of broiler poultry litter and commercial fertilizer for coastal bermudagrass production in the Southeastern US. J. Sustain. Agric. 12:55–77. doi:10.1300/J064v12n04_06

Foster, J.L., A.T. Adesogan, J.N. Carter, L.E. Sollenberger, A.R. Blount, R.O. Myer, S.C. Phatak, and M.K. Maddox. 2009. Annual legumes for forage systems in the United States Gulf Coast Region. Agron. J. 101:415–421. doi:10.2134/agronj2008.0083x

Fribourg, H.A., J.B. McLaren, K.M. Barth, J.M. Bryan, and J.T. Connel. 1979. Productivity and quality of bermudagrass and orchardgrass-ladino clover pastures for beef steers. Agron. J. 71:315–320. doi:10.2134/agronj1979.00021962007100020023x

Gelley, C., R.L.G. Nave, and G. Bates. 2016. Forage nutritive value and herbage mass relationship of four warm-season grasses. Agron. J. 108:1603–1613. doi:10.2134/agronj2016.01.0018

Hanlon, E.A., and H.J. Savoy. 2007. Procedures used by state soil testing laboratories in the southern region of the United States. Southern Coop. Series Bull. 190-D. Clemson Exp. Stn., Clemson, SC.

He, Z., and H. Zhang, editors. 2014. Applied manure and nutrient chemistry for sustainable agriculture and environment. Springer, Dordrecht. doi:10.1007/978-94-017-8807-6

Hoveland, C.S., M.A. Mccann, and N.S. Hill. 1997. Rotational vs. continuous stocking of beef cows and calves on mixed endophyte-free tall fescue-bermudagrass pasture. J. Prod. Agric. 10:245–250. doi:10.2134/jpa1997.0245

Kallenbach, R.L., and G.J. Bishop-Hurley. 2004. A guide to the common forages and weeds of pastures. Univ. of Missouri Extension, Columbia.

Kleen, J., F. Taube, and M. Gierus. 2011. Agronomic performance and nutritive value of forage legumes in binary mixtures with perennial ryegrass under different defoliation systems. J. Agric. Sci. 149:73–84. doi:10.1017/S0021859610000456

Ledgard, S.F., and K.W. Steele. 1992. Biological nitrogen fixation in mixed legume/grass pastures. Plant Soil 141:137–153. doi:10.1007/BF00011314

Mallarino, A.P., W.F. Wedin, C.H. Perdomo, R.S. Goyenola, and C.P. West. 1990. Nitrogen transfer from white clover, red clover, and birdsfoot trefoil to associated grass. Agron. J. 82:790–795. doi:10.2134/agronj1990.00021962008200040027x

Minson, D.J. 1990. Forage in ruminant nutrition. Academic Press, San Diego, CA.

Murray, I., and I. Cowe. 2004. Sample preparation. In: C.A. Roberts, J. Workman Jr., and J.B. Reeves III, editors, Near infrared spectroscopy in agriculture. Agron. Monogr. 44. ASA, CSSA, and SSSA, Madison, WI. p. 75–112. doi:10.2134/agronmonogr44.c5

Nave, R.L.G., R.P. Barbero, C.N. Boyer, M.D. Corbin, and G.E. Bates. 2016. Nitrogen rate and initiation date effects on stockpiled tall fescue during fall grazing in Tennessee. Crop Forage Turf. Manage. 2:2015-0174. doi:10.2134/cftm2015.0174

Nave, R.L.G., M.R. Sulc, and D.J. Barker. 2013. Relationships of forage nutritive value to cool-season grass canopy characteristics. Crop Sci. 53:341–348. doi:10.2135/cropsci2012.04.0236

Nave, R.L.G., M.R. Sulc, D.J. Barker, and N. St-Pierre. 2014. Changes in forage nutritive value among vertical strata of a cool-season grass canopy. Crop Sci. 54:2837–2845. doi:10.2135/cropsci2014.01.0018

Peters, J., S.M. Combs, B. Hoskins, J. Jarman, J.L. Kovar, M.E. Watson, A.M. Wolf, and N. Wolf. 2003. Recommended methods of manure analysis. Univ. of Wisconsin Coop. Ext., Madison.

Poore, M.H., and M.E. Drewnoski. 2010. Utilization of stockpiled tall fescue in winter grazing systems for beef cattle. Prof. Anim. Sci. 26:142–149.

Schipanski, M.E., and L.E. Drinkwater. 2012. Nitrogen fixation in annual and perennial legume-grass mixtures across a fertility gradient. Plant Soil 357:147–159. doi:10.1007/s11104-012-1137-3

Starks, P.J., D. Zhao, W.A. Phillips, and S.W. Coleman. 2006. Herbage mass, nutritive value and canopy spectral reflectance of bermudagrass pastures. Grass Forage Sci. 61:101–111. doi:10.1111/j.1365-2494.2006.00514.x

Teutsch, C.D., J.H. Fike, G.E. Groover, and S. Aref. 2005. Nitrogen rate and source effects on the yield and nutritive value of tall fescue stockpiled for winter grazing. Forage and Grazinglands 3. doi:10.1094/FG-2005-1220-01-RS

Vaughn, T. 1994. Bermudagrass Vaughn's #1. US Patent PP8, 963. Date issued: 25 October.

Watson, C.E., Jr., and V.H. Watson. 1989. Comparison of white clover and ammonium nitrate as nitrogen sources for tall fescue. Fert. Res. 21:109–111. doi:10.1007/BF01080535

Wiersma, D.W., R.R. Smith, D.K. Sharpee, M.J. Mlynarek, R.E. Rand, and D.J. Undersander. 1998. Harvest management effects on red clover forage yield, quality, and persistence. J. Prod. Agric. 11:309–313. doi:10.2134/jpa1998.0309