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Evaluation of five bermudagrass cultivars fertigated with swine lagoon effluent

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Abstract

Bermudagrass [*Cynodon dactylon* (L.) Pers.] hay is an important output from land receiving swine (*Sus scrofa*) effluent application (also known as spray fields); however, there is limited information about cultivar differences in the upper Southeast United States. Herbage accumulation, nutritive value, tissue nitrate concentration, and stem maggot damage were evaluated for five bermudagrass cultivars (‘Coastal’, ‘Midland 99’, ‘Ozark’, ‘Tifton 44’, and ‘Tifton 85’) fertigated with swine effluent throughout three growing seasons (2016, 2017, and 2018). All cultivars achieved canopy height ≥35 cm by July and cover of 100% by August of year of planting. Based on 3-yr averages, Tifton 85 (9.3 Mg ha^{-1}) had greater herbage accumulation than cultivars Coastal, Ozark, and Tifton 44 (≈7.9 Mg ha^{-1}), and Midland 99 was intermediate (8.5 Mg ha^{-1}). Bermudagrass stem maggot (*Atherigona reversura*) damage was consistently lower for Tifton 85 and resulted in larger differences in herbage accumulation in 2017 (11.2 vs. 8.4 Mg ha^{-1} for Tifton 85 and the other cultivars, respectively). There were moderate differences in crude protein concentration (ranged from 179 to 212 g kg^{-1}) and no difference in total digestible nutrients (622 g kg^{-1}). Tissue nitrate concentrations ranged from 3,433 to 16,168 mg NO_3^- kg^{-1}. Differences in productivity and nutritive value were moderate among cultivars; however, in areas with potentially high bermudagrass stem maggot damage, greater utilization of Tifton 85, if adapted, is warranted. Hay production from spray fields results in high yields and high nutritive value forage. Frequent nitrate testing, if possible by harvested hay lot, is advised.

1 | INTRODUCTION

Bermudagrass [*Cynodon dactylon* (L.) Pers.] is a widely grown forage species in land receiving swine effluent application (also known as spray fields) in the Coastal Plains of North Carolina. In this region, most swine farms rely on lagoons for waste storage and application of stored waste on permitted land is the means of waste disposal (Spearman et al., 2016). Two criteria that justify best fit of bermudagrass-based cropping systems in spray fields are (a) bermudagrass’ greater yield and nutrient removal compared to other warm-season crop species grown in the region (Burns et al., 1990; Heitman et al., 2017; McLaughlin et al., 2004; Woodhouse, 1969), and (b) the opportunity to increase the timeframe for effluent application by overseeding cool-season annual crops into established bermudagrass (Conrad-Acuña et al., no date) and

Abbreviations: ADF, acid detergent fiber; BSM, bermudagrass stem maggot; CP, crude protein; HA, herbage accumulation; HM, herbage mass; NCDA&CS, North Carolina Department of Agriculture and Consumer Services; NIRS, near infrared spectroscopy; TDN, total digestible nutrient.

where frequent irrigation is required to prevent lagoon overflow (Burns et al., 1990). As of 2014, there were about 50,000 hectares permitted for application of swine effluent in the Coastal Plains in North Carolina (NC-DWR, 2016, as cited by Heitman et al., 2017).

Production of hay from bermudagrass grown in spray fields is a strategy to capture and remove nutrients applied from swine effluent. Bermudagrass hay is readily consumed by livestock (Burns & Fisher, 2007). Total digestible nutrient and crude protein concentration values for bermudagrass hay grown in North Carolina can range from 530 to 700 and from 60 to 230 g kg^{-1}, respectively (Castillo & Romero, 2016). Effluent application rates have significant effects on dry matter yield, nutritive value, and nitrate concentration (Burns et al., 1985; Burns et al., 1990; Harvey et al., 1996). In addition, high effluent application rates can result in higher nitrate concentration levels potentially toxic to livestock (Burns et al., 1990). The accumulation of nitrate in plants implies that the rate of assimilation has not kept pace with the rate of uptake (Wright & Davison, 1964). Brink et al. (2003) reported small differences in nutrient uptake, particularly for P, among seven bermudagrass cultivars fertigated with swine effluent.

Several cultivars of bermudagrass are readily available in the Southeast United States and to land managers of spray fields in the Coastal Plains of North Carolina. In addition to high dry matter yield and nutrient removal, desirable attributes for selection of bermudagrass cultivars to be grown in spray fields include rapid establishment, high nutritive value, and low tissue nitrate concentration. Further, in light of increasing reports of bermudagrass stem maggot (*Atherigona reversura*) damage, Baxter et al. (2015) indicated that using cultivars that are not as often or extensively damaged may be a useful integrated pest management (IPM) strategy for forage bermudagrass producers. There is limited data, however, that compares vegetatively propagated bermudagrass cultivar responses in spray field conditions in the upper Southeast United States. Therefore, the objectives of this experiment were to determine the effects of fertigated swine effluent on herbage accumulation, nutritive value, tissue nitrate concentration, and observed stem maggot damage of five vegetatively propagated bermudagrass cultivars.

2 | MATERIALS AND METHODS

2.1 | Experimental site, plot establishment, and management

The experiment was conducted on-farm at a producer's field located in Tar Heel, NC (34°44′42.9′′ N; 78°49′30.4″ W) throughout three growing seasons (2016, 2017, and 2018). The farm is a commercial, integrated swine operation that utilized lagoon waste storage and associated spray fields for effluent disposal. The soils at the site are classified as Foreston loamy sand (coarse-loamy siliceous, semiactive, thermic Aquic Paleudult) and Leon sand (sandy, siliceous, thermic Aeric Alaquod) according to the USDA soil taxonomy system (2020). Soil samples to a 20-cm depth were collected on April 2016 and analyzed at the Agronomic Division of the North Carolina Department of Agriculture and Consumer Services (NCDA&CS). The soil test results indicated pH of 6.0 and concentrations (mg kg^{-1}) of 290 for P, 710 for K, 9,600 for Ca, 1,216 for Mg, 14.8 for S, 7.2 for Mn, 34.8 for Zn, and 3.5 for Cu. According to the NCDA&CS guidelines, the aforementioned soil nutrient concentrations were in the category of very high in the soil test index system (Hardy & Stokes, 2014) and therefore soil amendments were not recommended.

Core Ideas

- Five vegetatively propagated bermudagrass cultivars were evaluated for 3 yr in spray fields.
- Hay production from spray fields results in high yielding and high nutritive value forage.
- There were moderate differences in herbage responses, except for stem maggot damage.
- Because of the high variability, frequent testing for nitrate tissue concentration is advised.

Sprigs of five bermudagrass cultivars were harvested the day before planting and were planted on 6 Apr. 2016 to 5-cm depth using a sprig planter (Bermuda King). Each plot (experimental unit) was 21 by 30 m (630 m^2). The plots were fertigated with swine lagoon effluent using a permanent sprinkler irrigation system installed at the farm. Specific dates of effluent application are provided in Table 1. Samples of the liquid waste were collected directly from the lagoon throughout the growing season and sampling followed the protocol described by Crouse and Hicks (2015). Nutrient concentrations in the effluent samples were analyzed by the NCDA&CS laboratory. Nitrogen concentration was determined as total Kjeldahl nitrogen (TKN) by modified USEPA Method 351.2 using an auto-flow spectro-photometric analyzer (Skalar Analytical, 1995; USEPA, 2001). Analysis of P and K was conducted using inductively coupled plasma-optical emission spectrometry (ICP-OES) following closed-vessel nitric acid microwave digestion (Donohue & Aho, 1992; Campbell & Plank, 1992). Nutrient loadings per application event were calculated by multiplying the total volume of effluent discharged of the sprinkler irrigation system times the nutrient concentration. Total nutrient loadings were the cumulative summation of the loadings for each application event throughout the calendar year. The target N loading rate according to the site-specific's Waste Utilization Plan/Nutrient

TABLE 1 Dates of effluent application and herbage sampling in a spray field located in Tar Heel, NC (34°44′42.9“N; 78°49′30.4″E)

Year	Swine effluent application date	Harvest date
2016	18 Apr., 10 May, 26 May, 14 June, 17 July, 27 July, 1 Sept., 17 Sept., 27 Sept., 28 Sept., 10 Oct., 21 Oct., 24 Oct., 26 Oct.	8 July, 4 Aug., 18 Sept., 3 Oct.
2017	8 May, 4 July, 14 July, 26 July, 1 Aug., 4 Sept., 26 Sept.	7 June, 3 July, 11 Aug., 18 Sept.
2018	8 Mar., 5 Apr., 18 Apr., 14 May, 11 June, 2 July, 9 July, 19 July, 27 July, 22 Aug., 28 Aug., 5 Sept.	31 May, 2 July, 6 Aug., 25 Sept.

TABLE 2 Total annual irrigation, total water inputs (precipitation + irrigation) and total N, P, and K loadings from swine effluent application

Year	Irrigation	Total water inputs	N	P	K
	mm		kg ha^{-1}		
2016	166	1,714.0	249	42	563
2017	83	1,151.4	116	29	481
2018	141	1,939.5	310	58	945

Management (WUP/NM) was 309 kg N ha^{-1} yr^{-1}. Total nutrient loadings per year, total irrigation, and total water inputs are presented in Table 2. During the winter season of 2016–2017, the plots were overseeded with rye (*Secale cereale* L.) and the rye was clipped to 10-cm stubble height and removed from the bermudagrass plots in April 2017. Rainfall was measured using an in-field precipitation gauge located at the farm and temperature data were obtained from the closest weather station in Elizabethtown, NC (located approximately 24 km away from the research site). Rainfall and temperatures are presented in Figure 1. Extreme weather events that brought excess rainfall were tropical storm Julia and hurricane Mathew in September and October 2016, respectively, and hurricane Florence in September 2018 (Figure 1).

Herbicides were applied in 2016 and 2018, and insecticide in 2018. Diuron [3-(3,4-dichlorophenyl)−1,1-dimethylurea; Direx (ADAMA); 1.46 kg a.i. ha^{-1}] was applied on 13 Apr. 2016. Metsulfuron methyl + chlorsulfuron [Methyl 2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2yl)amino]carbonyl] amino]sulfonyl]benzoate + 2-Chloro-N-[(4- v methoxy-6-methyl-1,3,5-triazin-2-yl)aminocarbonyl] benzenesulfonamide; Cimarron Plus (Bayer); 21.0 + 6.6 g a.i. ha^{-1}] and 2,4-D amine (Dimethylamine Salt of 2,4-Dichlorophenoxyacetic acid; Shredder [Southern Ag.]; 1.07 kg a.i. ha^{-1}), mixed with nonionic surfactant and humectant (80% Branched alkyl phenol ethoxylate, 1,2,3-Propanetriol, 1,2 dihydroxypropane; Top Surf [Winfield Solutions, LLC]) were applied on 4 June 2016. Pendimethalin (N-(1-ethylpropyl)−3,4-dimethyl-2,6-dinitrobenzenamin; Framework 3.3 EC; 0.32 kg a.i. ha^{-1} [Agrisolutions]) was applied on 24 Feb. 2018; Pendimethalin (0.36 kg a.i. ha^{-1}) and metsulfuron methyl + chlorsulfuron (12.4 + 3.9 g a.i. ha^{-1}) were applied on 9 June 2018. Insecticides β-cyfluthrin [Cyano(4-fluoro-3-phenoxyphenyl)methyl-3-(2,2-dichloro-ethenyl)−2,2-dimethyl-cyclopropanecarboxylate; Baythroid XL (Bayer); 0.02 kg a.i. ha^{-1}] and bifenthrin [(2 methyl[1,1-biphenyl]−3-yl)methyl 3-(2-chloro-3,3,3- trifluoro-1-propenyl)−2,2-dimethyl-cyclopropanecarboxylate; Bifen 25% EC; 0.11 kg a.i. ha^{-1}] were applied on 28 July and 6 Aug. 2018 to control armyworms (*Spodoptera* spp.).

2.2 | Treatments and experimental design

Treatments were the five bermudagrass cultivars ‘Coastal’, ‘Midland 99’, ‘Ozark’, ‘Tifton 44’, and ‘Tifton 85’. The cultivars are readily available to producers in Southeast North Carolina that use them for production of hay, grazing, and as a nutrient receiver crop for spray field areas. For more information about the aforementioned cultivars and other cultivars of bermudagrass, we direct the reader to Hanna and Anderson (2008), Taliaferro et al. (2016), and Jennings et al. (2016) as a starting point. Treatments were randomly assigned to experimental units and the experimental design was a randomized complete block design replicated three times.

2.3 | Response variables

2.3.1 | Herbage mass and accumulation

Herbage samples were collected by clipping an area of 2.7-m^2 (3 by 0.9 m) to 8-cm stubble height using a

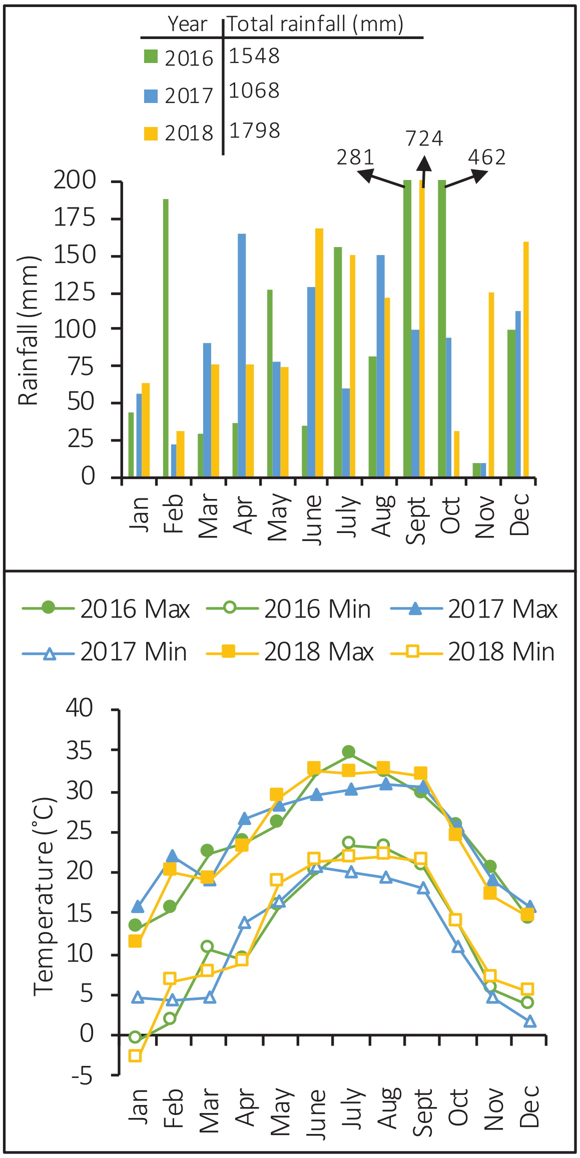

FIGURE 1 Monthly rainfall and average maximum and minimum daily temperatures during the 2016 to 2018 period in Tar Heel, NC (34˚44′42.9″ N; 78˚49′30.4″ W)

walk-behind sickle bar mower. The sampling area was randomly located for each defoliation event. The harvested forage was weighed fresh in the field; then, a representative subsample (0.5–1 kg) was weighed fresh and subsequently dried at 60 ˚C until constant weight to determine dry matter concentration and to calculate herbage mass (HM). There were four defoliation events per year (Table 1). After collecting the herbage samples, the whole plots were immediately clipped to the target stubble height and the clipped material was removed from the plots.

The harvest schedule was based on a compromise between the producer cooperator's schedule and our request to allow the canopy height of the bermudagrass to be at least ≈35 cm before harvest. Consequently, forage regrowth intervals ranged from 26 to 45 d. The HM samples were used to estimate total annual herbage accumulation (HA). Total annual HA was defined as the cumulative summation of HM values in the corresponding year and it was estimated for each year as well as an overall 3-yr mean. The HM values from the last collection date in 2018 were not included in the calculation of HA because sampling was delayed due to hurricane Florence and there was variable defoliation from beef livestock intrusion that grazed the plots before we were able to collect samples.

2.3.2 | Canopy height and canopy cover

During the establishment year, canopy height and cover were measured four times before harvesting (1 June, 1 July, 4 August, and 6 Sept. 2016). In 2017 and 2018, canopy height was measured before each harvest event. Canopy height was defined as the distance from the soil level to the average nonextended and noncompressed height of the canopy. Canopy height was measured using a ruler at 10 randomly located sampling points in each plot. The average height of the 10 sampling points provided an estimate of canopy height per experimental unit.

Canopy cover was defined as the percentage of the ground covered by bermudagrass (Allen et al., 2011) and it was estimated using a 1-m^2 quadrat (1 by 1 m) that was placed at two randomly located sampling points in each plot. The quadrat was divided in 25 20- by 20-cm squares (five rows of five). Canopy cover was estimated visually by the same observer in 10 randomly selected 20- by 20-cm squares per quadrat and averaged to obtain an overall cover estimate per quadrat-location. The average of the two quadrats provided an estimate of canopy cover per experimental unit.

2.3.3 | Stem maggot damage and botanical composition

Visual symptoms of bermudagrass stem maggot (BSM) damage were observed during summer 2016 and 2017, but not in 2018. The BSM damage was determined on the day of the August herbage sampling events in 2016 and 2017 (Table 1). In 2016, one person visually ranked bermudagrass plots in the field for BSM damage using a scale from 1 to 5 (1 being "no BSM damage" and 5 being "severe BSM damage"). In 2017, we anticipated potential BSM damage and we used an approach to quantify it. Three 31- by 31-cm quadrats were randomly located in each plot and all the tillers inside the quadrats were clipped to ground level. The total number of tillers and the number of tillers that showed visual BSM damage were determined soon after harvest and using the fresh samples. The BSM damage was defined as the percentage of the total number of harvested tillers that showed visual symptoms of

TABLE 3 Fit statistics of near infrared spectroscopy models for prediction of crude protein (CP) and acid detergent fiber (ADF) of five bermudagrass [*Cynodon dactylon* (L.) Pers] forage cultivars

Constituent	R^2_c	SEC	R^2_cv	SECV
		g kg^{-1}		g kg^{-1}
CP	.99	0.36	.99	0.48
ADF	.99	0.20	.88	1.00

BSM. The average of the three quadrats provided an estimate for BSM damage for each experimental unit.

Botanical composition by weight was determined for each harvest in 2017 and 2018. Botanical composition was determined because of observed regrowth of the 2016–2017 winter-planted rye after its defoliation on April 2017, and due to the potential temporarily effects of overseeded cool-season forages to hinder bermudagrass regrowth early in the summer (Aiken, 2014). A subsample (0.5–1 kg) was collected from the whole plot harvested herbage; the samples were hand-separated fresh in two components, bermudagrass and others. The two components were then dried in a forced-air drier at 60 ˚C to constant weight. Bermudagrass presence was estimated by dividing the weight of the bermudagrass component by the total weight of the harvested herbage (bermudagrass + others) and multiplying it by 100 to express it as a percentage.

2.3.4 | Crude protein, tissue nitrate, and total digestible nutrient concentrations

Dried samples were ground using a Wiley mill (A. H. Thomas) to <1-mm particle size in preparation for analysis of crude protein (CP), acid detergent fiber (ADF), and nitrate ion (NO_3^-) concentrations. The ADF values were used to calculate total digestible nutrient (TDN) concentration following the equation for bermudagrass used by the NCDA&CS Feed and Forage Laboratory [$\text{TDN} = 73.7 - (0.595 \times \text{ADF}) + (0.463 \times \text{CP})$]. Estimates of TDN are the preferred method to balance forage-based rations for beef cattle in North Carolina (Freeman et al., 2016; Poore, 2014; Kunkle et al., 2000).

Concentrations of CP and ADF were determined using near infrared spectroscopy (NIRS) models developed for this experiment. Samples were scanned with a Foss NIRS Model 6500 (Foss North America) and NIRS model development was performed using a data analysis pipeline written in R environment (R Core Team, 2016). The pipeline was previously used in the successful development of NIRS models to determine forage nutritive value of native warm-season grasses and bermudagrass (Bekewe et al., 2019; Castillo et al., 2020), and to compare predictions among benchtop and hand-held NIRS devices (Acosta et al., 2020). To obtain a calibration for CP and ADF, a total of 147 samples (72 samples selected from this trial + 75 samples from bermudagrass trials previously conducted across North Carolina) were assembled into a library, in which both laboratory analyses and NIRS scans were available. The 72 samples from this trial included in the NIRS model development were selected using a stratified random sampling approach to ensure inclusion of at least one sample from each cultivar-sampling date–year combination and corresponded to 40% of the total number of samples for this trial. Fit statistics for the NIRS model are provided in Table 3.

Wet chemistry analyses for CP, ADF, and NO_3^- concentrations were performed by the Dairy One Forage Laboratory. In summary from the laboratory analytical procedures of Dairy One Laboratory (2015), CP concentration was calculated by multiplying the concentration of total N (determined by dry combustion using a LECO CN628) by 6.25, and ADF concentration was determined using Method 12 of the Ankom fiber analyzer (Ankom). The NO_3^- concentration was determined using the RQflex reflectometer method (Relectoquant). Concentrations of CP, TDN, and NO_3^- are presented as weighed averages across harvests within a year.

2.4 | Statistical analyses

Effects were considered significant when $P \leq .05$. For canopy height, ground cover, and herbage mass in 2016, data were analyzed by collection date. Analyses of variance for the 2016 responses included treatment as fixed effect and block as random effect. For herbage accumulation (2016, 2017, and 2018), an analysis of variance was set up with cultivar and year as fixed effects, and block as a random effect. For botanical composition (2017 and 2018), the statistical model included cultivar, year, and collection date as fixed effects, and block as a random effect. Collection date was set up as a repeated measure with an unstructured covariance structure based on the lowest Akaike Information Criterion value. For BSM damage (2016 and 2017), the data were analyzed by year because the methodology used to estimate BSM damage was different in 2016 and 2017. For BSM damage, treatment set up as fixed effect and block as random effect. For concentrations of CP, TDN, and tissue NO_3^-, the statistical model included cultivar and year as fixed effects and block as random effect. When an interaction effect was declared, simple effects were analyzed using the SLICE procedure of SAS (SAS

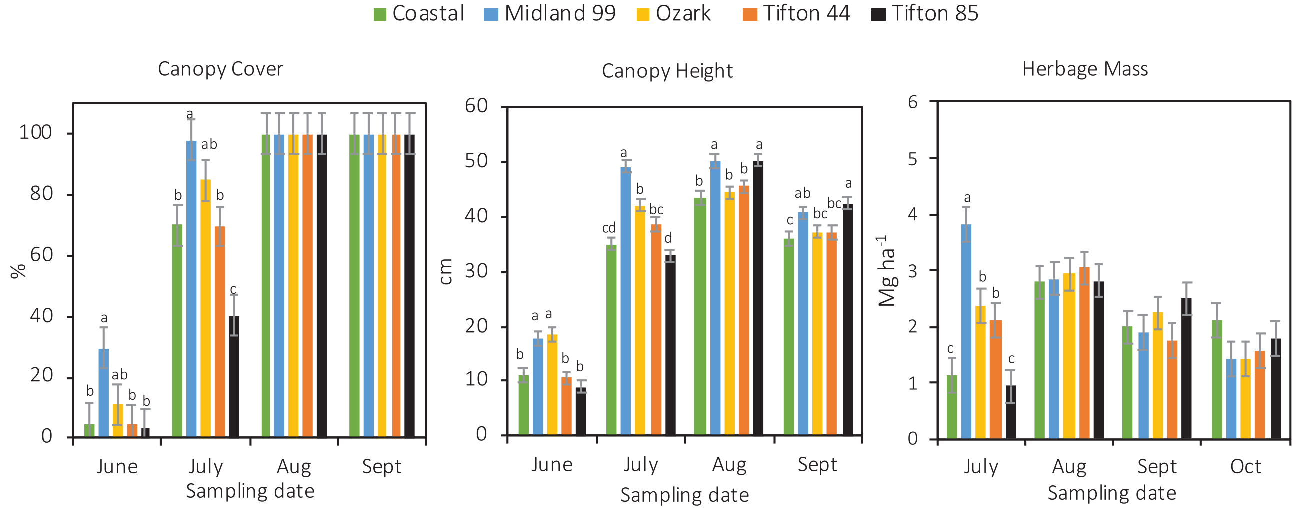

FIGURE 2 Year-of-establishment (2016) responses of five bermudagrass [*Cynodon dactylon* (L.) Pers] cultivars fertigated with swine effluent in Tar Heel, NC (34°44′42.9″ N; 78°49′30.4″ W). Bars represent means ± 1 SE

Institute, 2010). Separation of least squares means was done using the LINES option of the GLIMMIX procedure in SAS.

3 | RESULTS AND DISCUSSION

Tropical Storm Julia, Hurricane Matthew, and Hurricane Florence (September 2016, October 2016, and September 2018, respectively) contributed to greater than normal rainfall for the study area (Figure 1).

3.1 | Year-of-establishment responses

For the year of establishment responses, the discussion of canopy cover, canopy height, and HM responses is focused on describing the general response patterns of the cultivars as a group. In July (3 mo after planting), canopy cover ranged from 40 to 98% and canopy height of all cultivars was ≥35 cm tall (Figure 2). The producer cooperator decided to start harvesting the plots at that point and consequently sampling for HM was initiated. With the exception of Midland 99 for which HM was 3.8 Mg ha^{-1} in the July harvest, the HM values for all cultivars and across sampling dates in 2016 ranged from 1.4 to 3.0 Mg ha^{-1} (Figure 2). By the second harvest on August, and thereafter, canopy cover for all the cultivars was 100% prior to each harvest and canopy height differences among cultivars were <8 cm. Herbage mass difference among cultivars occurred in July only (Figure 2); however, total annual herbage accumulation was not different in 2016 (Figure 3).

Under the spray field conditions of this study, the five bermudagrass cultivars successfully established in the year of planting and were clipped as early as 3 mo after planting with no apparent deleterious effects as observed by its productivity during the 2 yr after the year of establishment. The majority of reports in the literature for bermudagrass receiving animal manure are for established bermudagrass swards (≥2-yr-old swards), with most reports considering a single cultivar (Burns et al., 1990; Lund et al., 1975; Woodard & Sollenberger, 2011; Woodhouse, 1969), and fewer reports comparing established cultivars (Brink et al., 2003). Spray fields receiving swine manure from storage lagoons are characterized by frequent fertigation events that provide significant amounts of water and nutrients (Table 2); therefore, a cultivar with rapid establishment is desirable and may be able to better compete with potential weeds, thereby reducing the need

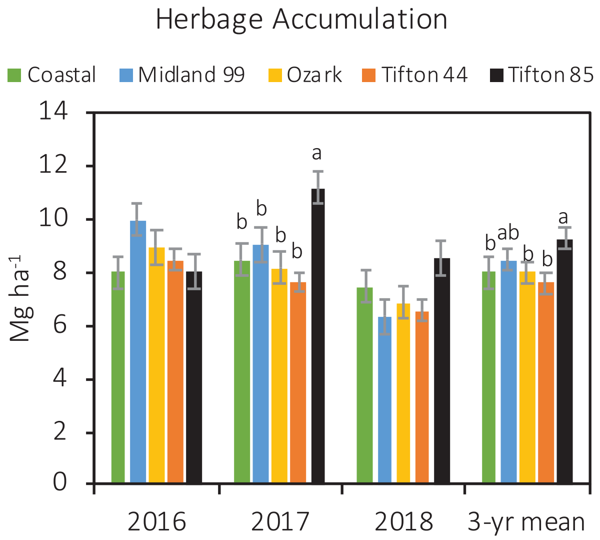

FIGURE 3 Herbage accumulation of five bermudagrass cultivars [*Cynodon dactylon* (L.) Pers] fertigated with swine effluent in spray field conditions in Tar Heel, NC (34°44′42.9″ N; 78°49′30.4″ W). Bars represent means ± 1 SE

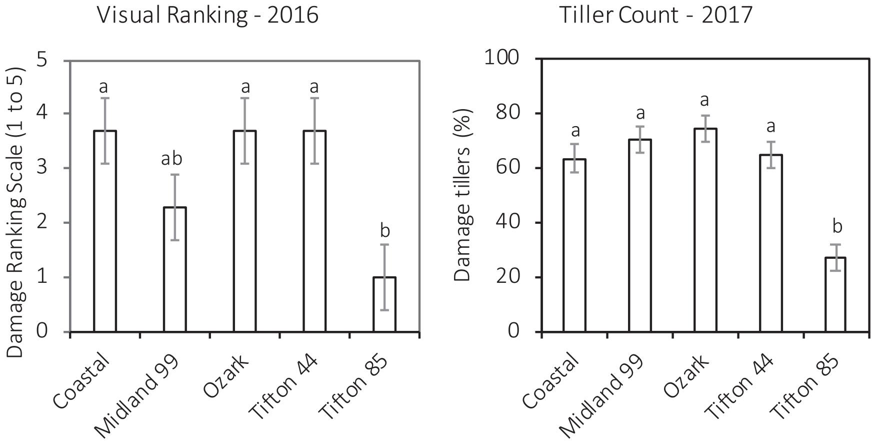

FIGURE 4 Bermudagrass stem maggot (*Atherigona reversura*; BSM) damage in Tar Heel, NC (34°44′42.9″ N; 78°49′30.4″ W). Scale of measurement in 2016 is 1 to 5, where 1 = no damage and 5 = severe damage. Estimates in 2017 are the percent of damaged tillers. Bars are means ± 1 SE

for herbicide applications. Mueller et al. (1992) provided evidence of differential responses during the establishment phase for Coastal and Tifton 44 bermudagrasses.

3.2 | Herbage responses

Averaged across the 3 yr, Tifton 85 HA was greater than Coastal, Ozark, and Tifton 44 (Figure 3). These results were similar in 2017; however, there were no differences among cultivars in 2016 and 2018 (Figure 3). Burton et al. (1993) reported 26% greater dry matter yield for Tifton 85 compared to Coastal in two 3-yr trials. Total annual HA values averaged across cultivars were 8.7, 8.9, and 7.2 Mg ha^{-1} in 2016, 2017, and 2018, respectively. It is worth noting the high HA values in the year of establishment (2016). Lower HA values in 2018 are most likely the result of only including three sampling events for the reasons previously explained.

Greater HA for Tifton 85 in 2017 is attributed to lower BSM damage (Figure 4). Consistently, Tifton 85 had lower BSM damage compared to the other cultivars based on the BSM assessments conducted in 2016 and 2017 (Figure 4). There was no observed BSM damage in 2018. From a study conducted in the greenhouse, Baxter et al. (2015) indicated that *C. nlemfuensis* 'Tifton 68' and 'PI 316507' and *C. nlemfuensis*-influenced 'Tifton 85' and 'Coastcross-II' cultivars had lesser BSM damage than fine-textured bermudagrass *C. dactylon* cultivars [common cultivar (ecotype: Tifton, GA), Coastal, 'Alicia', and 'Russell']. The same authors suggested that actual damage in uncontrolled conditions in situ is likely to be substantially greater because greater populations and multiple generations of BSM may be present and the susceptibility of the fine-textured cultivars would be accentuated. The aforementioned results and implications from the greenhouse study are consistent with our findings in this field trial (Figure 4).

Herbage accumulation values in our study were about twice as great as those reported for bermudagrass cultivars and trials conducted in non-spray field areas in North Carolina. Under grazing conditions and non-spray field areas, Burns and Fisher (2008) reported no difference in HA for Coastal and Tifton 44 (which averaged 4.0 Mg ha^{-1}); Burns et al. (2009) reported slightly greater HA for Coastal than for Tifton 44 (3.5 and 3.0 Mg ha^{-1}, respectively). Under one- or two-clippings per year in North Carolina, Wang, Smyth, Crozier, Gehl, and Heitman (2018) reported yields of Coastal bermudagrass ranged from 4.1 to 8.0 Mg ha^{-1} over a 4-yr period. In the Wang et al. (2018) study, the bermudagrass yields consistently decreased as time progressed; no rationale was provided by the authors for such response, although the defoliation management schedule was changed to multiple harvests per year in the last year of the trial with the expectation of greater yields. Herbage accumulation values under spray field conditions in North Carolina are more similar to those reported from non-spray fields in States located South of North Carolina where there is a longer growth season for warm-season grasses. Herbage accumulation of Coastal bermudagrass in a Southern Piedmont location in Georgia was reported as 7.5 (± 0.7) and 8.3 (± 1.0) Mg ha^{-1} under hay and grazing conditions, respectively (Franzluebbers, Wilkinson, & Stuedemann, 2001). Alderman et al. (2011), reported Tifton 85 dry matter yield in Florida up to ≈11 Mg ha^{-1} under clipping conditions and N fertilizer applied at 135 kg N ha^{-1}.

There was a year x cultivar interaction effect for botanical composition ($P < .05$), so data were analyzed by year. Differences among cultivars were significant in 2017 only. Averaged across sampling dates in 2017, Tifton 85 had greater proportion of bermudagrass in the total harvested herbage (95%) than Tifton 44 and Midland 99 (similar and averaged 85%), and Ozark (68%) (data not shown). The proportion of bermudagrass in Coastal (88%) was similar to all other cultivars except Ozark. There were no differences in botanical composition among cultivars in 2018, and the proportion of bermudagrass in the harvested herbage averaged 98%.

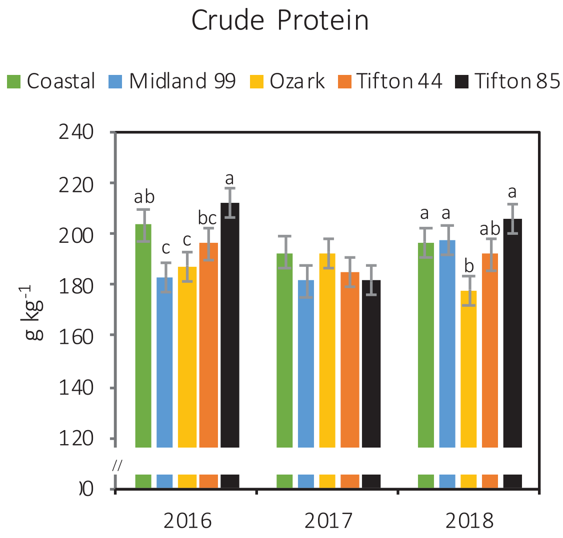

FIGURE 5 Concentration of crude protein (seasonal weighed average) of five bermudagrass cultivars grown in spray fields in Tar Heel, NC (34˚44′42.9″ N; 78˚49′30.4″ W). Data are means ± 1 SE

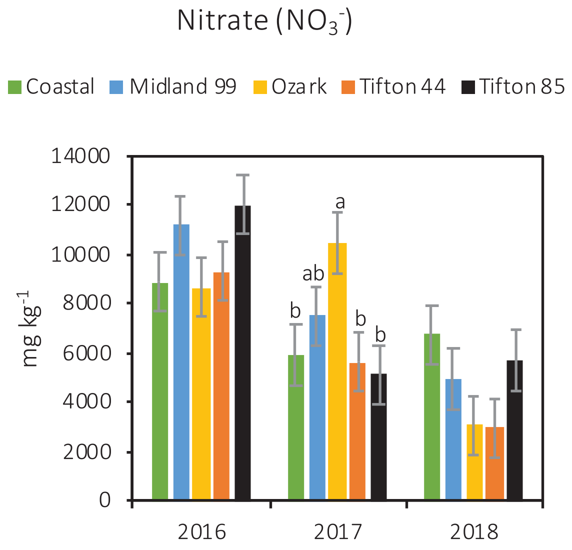

FIGURE 6 Tissue nitrate Ion (NO_3^-) concentration (seasonal weighed averages) of five bermudagrass cultivars grown in spray fields in Tar Heel, NC (34˚44′42.9″ N; 78˚49′30.4″ W). Data are means ± 1 SE

3.3 | Crude protein, tissue nitrate, and total digestible nutrient concentrations

There was a cultivar x year interaction ($P = .01$) for CP, so the data were analyzed by year. There were no differences in CP concentration among cultivars in 2017. With the exception of CP concentration for Ozark in 2018 which was 179 g kg^{-1}, the CP concentration values among cultivars and years ranged from 182 to 212 g kg^{-1} with moderate differences among cultivars in 2016 and 2018 (Figure 5). The CP concentrations of the cultivars in this study would be adequate for most ruminant requirements, and they were almost twofold greater than the recommended CP concentration of ≈105 g kg^{-1} which is suitable to meet the CP dietary needs of a lactating beef cow in the first 90 d after calving (NRC, 1996). The CP values in our study were similar to those reported for Coastal bermudagrass under spray field conditions in North Carolina based on the tissue N concentration values reported by Burns et al. (1990).

Averaged across cultivars, seasonal NO_3^- concentration values were 11,967, 5,100, and 4,680 mg NO_3^- kg^{-1} in 2016, 2017, and 2018, respectively, with corresponding N loadings of 249, 116, and 310 kg N ha^{-1} (Table 2). There was a cultivar × year interaction ($P = .02$), so data were analyzed by year (Figure 6). Differences among cultivars for NO_3^- concentration occurred in 2017 only, in which Ozark had greater NO_3^- concentration than all cultivars except Midland (Figure 6). Burns et al. (1990) reported that nutrient loadings from swine effluent altered seasonal NO_3^- concentration of Coastal bermudagrass ranging from 2,924 mg NO_3 kg^{-1} with a loading of 420 kg N ha^{-1} to 10,410 mg NO_3^- kg^{-1} with a loading 1,290 kg N ha^{-1}. Although the N loadings were greater in the aforementioned study, the range in NO_3^- concentration is similar to the range of NO_3^- values in our study. The proportion of NO_3^- relative to CP concentration ranged from 42 to 50 g kg^{-1} across cultivars (data not shown). In an experiment that evaluated four seeded-type bermudagrass cultivars fertigated with swine effluent in NC, Spearman et al. (2016) reported that forage NO_3^- concentration values ranged from 2,400 to 9,900 mg kg^{-1} with N loading ranging from 54 to 305 kg ha^{-1}. High NO_3^- concentration values may in part be explained by the relatively short time (≤14 d for four harvesting events) between effluent application and harvest dates for several dates (Table 1). In contrast, Harvey et al. (1996) reported much lower NO_3^- concentration values (≤2,600 mg NO_3^- kg^{-1}) for a mixed bermudagrass field composed of Tifton 44, ‘Guymon’, and common bermudagrass at N loading of 873 kg N ha^{-1}.

Considering that the harvested forage could serve as the sole ration for ruminants, the safety of tissue NO_3^- concentration was also examined by harvest date in each year, in addition to the seasonal weighed averages previously presented. Tissue NO_3^- concentrations ranged from 5,067 to 15,600 mg kg^{-1} in 2016, 3,433 to 14,633 mg kg^{-1} in 2017, and 5,000 to 16,167 mg kg^{-1} in 2018 (Figure 7). The generally considered safe threshold for all kinds of livestock if forage is the sole source of feed is ≤5,000 mg NO_3^- kg^{-1}; however, this threshold can range between 2,500 and 5,000 mg NO_3^- kg^{-1} as reported in several extension publications (Anderson, 2016; Burns, 2019; Garner, 1958; Hancock, 2013; Poore et al., 2000; Strickland et al., 1996). The variation in the NO_3^- threshold may be explained, in part, because no single level of nitrate is toxic under all conditions and due to the wide

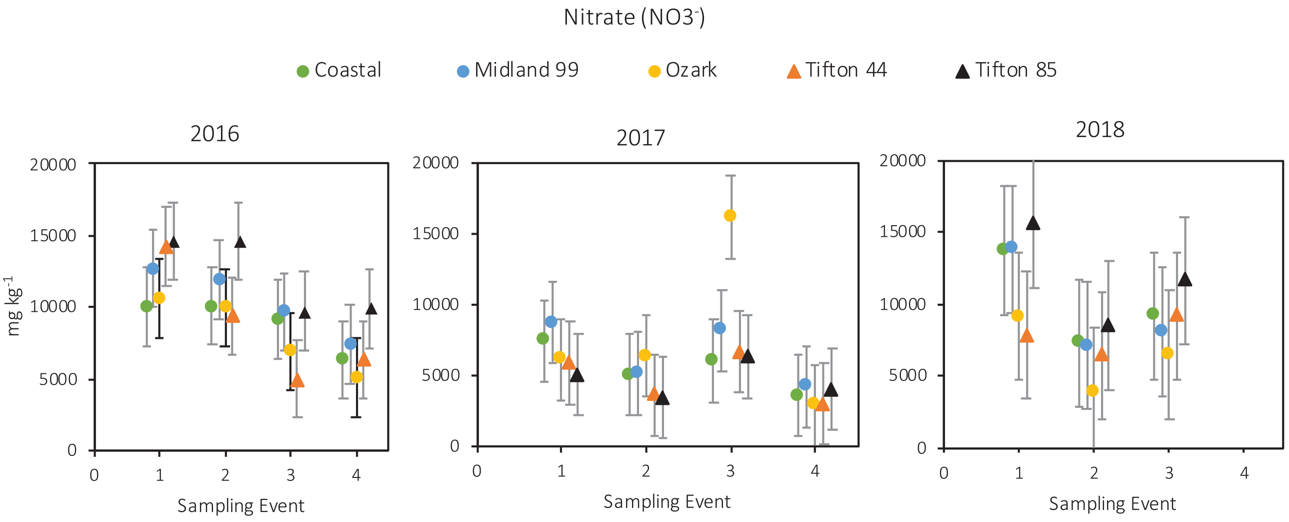

FIGURE 7 Tissue nitrate ion (NO_3^-) concentration of five bermudagrass cultivars grown in spray fields in Tar Heel, NC (34°44′42.9″ N; 78°49′30.4″ W). Data are means ± 95% confidence interval

variation in the degree of tolerance to nitrates among animal species (Hanway et al., 1963). Forage NO_3^- concentration >5,000 mg kg^{-1} can be fed as a proportion of the ration, and there are several categories proposed in the literature (Hancock, 2013; Poore et al., 2000). Concentration of NO_3^- was generally lesser for the mid- to late-season clippings in all years (sampling events 3 and 4) (Figure 7). Out of 55 bermudagrass hay lots harvested in this experiment, there were nine lots with NO_3^- concentration ≤5,000 mg kg^{-1}; seven out those nine lots were from 2017, which had the least N loading per year (Table 2), and there was one each in 2016 and 2018.

Herbage TDN concentration was affected by year ($P = .0002$). The TDN concentration was greatest in 2016 and 2018 (average 628.4 g kg^{-1}) and least in 2017 (615.6 g kg^{-1}). The TDN values for bermudagrass hay in our study met the TDN diet requirement (≈600 g kg^{-1}) of a lactating beef cow in the first 90 d after calving if forage was the sole source of feed (NRC, 1996; Poore, 2014; Hall et al., 2009). Under grazing conditions in the Piedmont of North Carolina, Burns, Wagger, and Fisher (2009) reported average daily gains of 0.63 kg and weight gains of 884 kg ha^{-1} for Angus steers grazing Tifton 44 bermudagrass with CP and in vitro true organic matter disappearance values of 134 and 644 g kg^{-1}, respectively. The TDN/CP ratio values for all cultivars were <8 (data not shown), indicating there was adequate protein to match the energy in the forage and there is no need for supplemental protein in the diet (Moore et al., 1991). Using animal response data, Burns and Fisher (2007) reported little advantage of Tifton 44 in comparison to Coastal; however, Tifton 85 had greater digestible fiber and offered potentially greater dry matter digestion and digestible intake compared to Coastal. Based on the animal response data reported by Burns and Fisher (2007), the tissue NO_3^- concentration presented by Burns et al. (1990), the BSM damage data presented by Baxter et al. (2015), and the data collected in our study, greater utilization of Tifton 85 in the upper Southeast United States is warranted where Tifton 85 is adapted. However, Anderson and Wu (2011) indicated that Tifton 85 is more susceptible to low-temperature injury than Midland 99, Ozark, Tifton 44, and Coastal.

4 | CONCLUSIONS

The five vegetatively propagated bermudagrass cultivars used in this study successfully established in the year of planting. Under the spray field conditions, defoliation events started 3 mo after planting and there were no deleterious effects as observed in the subsequent 2 yr of this experiment. Overall, there were moderate differences in herbage responses among cultivars, with Tifton 85 having greater 3-yr mean HA than all cultivars except Midland 99. The concentrations of CP and TDN across cultivars were ≥179 and 616 g kg^{-1}, respectively, which meet the nutritional demands for most ruminants. Tissue nitrate concentrations were lesser for mid- to late-season clippings and for lower N loading amounts. However, there was a wide range in tissue NO_3^- concentration (from 3,433 to 16,168 mg NO_3^- kg^{-1}) and therefore the safety of tissue NO_3^- concentration needs to be examined for each hay harvest lot. Based on the results of this study, and previously reported data in other studies, greater utilization of Tifton 85 in the upper Southeast United States is warranted, especially in southern locations with milder cold temperatures as well as it being less susceptible to bermudagrass stem maggot damage than cultivars that are not *C. nlemfuensis* hybrids. Hay production from spray fields results in high-yielding and high nutritive value forage. Because of the high variability in nitrate tissue concentration, frequent testing, if possible by harvested hay lot, is advised.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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