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Poultry litter and nitrogen fertilizer effects on productivity and nutritive value of crabgrass

Stephanie Sosinski | **Miguel S. Castillo** | **Stephanie Kulesza** | **Ramon Leon**

Crop and Soil Sciences Dep., North Carolina State Univ., Raleigh, NC 27695, USA

Correspondence
Miguel S. Castillo, Crop and Soil Sciences Dep., North Carolina State Univ., Raleigh, NC 27695, USA.
Email: mscastil@ncsu.edu

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Abstract

Crabgrass (*Digitaria* spp.) is deemed as a productive and nutritious warm-season annual forage for livestock in the U.S. transition zone. However, there is limited information about nitrogen (N) source and rate effects on productivity and nutritive value of crabgrass in North Carolina. Herbage accumulation (HA), N removal, crude protein (CP), total digestible nutrients (TDN), and tissue nitrate (NO_3^-) concentrations were evaluated for 2 yr (2020 and 2021) in two physiographic regions (Piedmont and Coastal Plain). Treatments were five rates of chemical N fertilizer (up to 480 kg N ha^{-1}), five rates of plant-available N from broiler poultry litter (up to 472 and 399 kg N ha^{-1} in 2020 and 2021, respectively), and one control (zero N). Overall crabgrass responses were not different between N sources. At Coastal Plain, HA increased from 4,990 kg dry matter (DM) ha^{-1} and plateaued at 7,136 kg DM ha^{-1} at an agronomic optimum N rate (AONR) of 198 (SE = 49) kg N ha^{-1}. At Piedmont, HA responses were erratic, estimation of an AONR was not possible, and HA values were approximately half or less to those at Coastal Plain. Removal of N was linearly associated with HA. Increasing N rate had a marginal positive effect on CP (ranged from 126 to 154 g kg^{-1}) and no effect on TDN (averaged 626 g kg^{-1}). Tissue NO_3^- values were below the toxic threshold for feeding livestock. Poultry litter is an effective N source for crabgrass. Nitrogen rate effects were more apparent on crabgrass' productivity; nutritive value was generally high regardless of N rate and source.

1 | INTRODUCTION

Pasture-based livestock systems in the U.S. transition zone, the area between the temperate northeast and subtropical southeast, rely primarily on cool-season forages. However, forage availability from cool-season forages is limited during the summer season when temperatures are high, a phenomenon known as 'summer slump'. Consequently, warm-season forages represent a component for year-round forage production systems in this region (Boyer et al., 2019). Crabgrass [*Digitaria ciliaris* (Retz.) Koeler] is a C4 warm-season annual grass of high nutritive value and productivity with potential to complement traditional tall fescue [*Lolium arundinaceum* (Schreb.) Darbysh]-based forage systems in the United States (Beck et al., 2007; Teutsch et al., 2005).

Managers of land and livestock have typically recognized crabgrass as a volunteer reoccurring species in grazing and hay systems. In some cases, common crabgrass has been

Abbreviations: ADF, acid detergent fiber; AONR, agronomic optimum N rate; CP, crude protein; DM, dry matter; HA, herbage accumulation; NCDA&CS, North Carolina Department of Agriculture and Consumer Services; NIRS, near infrared spectroscopy; TDN, total digestible nutrient; TDN, total digestible nutrients.

deemed desirable as a primary or secondary (fallback) forage component (Burns et al., 2004; Dalrymple et al., 1996; Ogden et al., 2006); in other cases, an undesirable weed interfering with the establishment of row crops (Ball et al., 2015; Kim et al., 2002). Research efforts have brought to market improved forage cultivars of crabgrass such as 'Red River' (Dalrymple, 2001), 'Quick-N-Big' (Dalrymple, 2010), and 'Impact' (Bouton et al., 2019). A limited number of publications have reported on the effects of defoliation and N management on productivity and nutritive value of crabgrass. Results from research conducted in other states of the southeast United States support the use of crabgrass as a productive and nutritious forage as well as the use of organic N sources such as broiler litter as an alternative to chemical fertilizers (Gelley et al., 2016, 2017; Teutsch et al., 2005). Working with Red River crabgrass fertilized with ammonium nitrate and poultry litter in Virginia, Teutsch et al. (2005) reported that N source had no effect on dry matter (DM) yield, no clear effect on forage digestibility and fiber concentration, and tissue nitrate (NO_3^-) concentrations were consistently lower for poultry litter treatments. There is limited information, and none in North Carolina specifically, that reports on the effects of N fertilizer source and rate on crabgrass responses in contrasting physiographic regions.

Poultry litter, as well as swine manure, are readily available in North Carolina as byproducts of the animal husbandry industry and can be used as inexpensive fertilizers to support biomass and forage production (Heitman et al., 2017; Spearman et al., 2021). North Carolina ranks top five in the nation for broiler and swine production (National Agriculture Statistics Service, 2021). According to North Carolina's administrative code, animal feeding operations with ≥250 swine or ≥30,000 confined poultry with a liquid waste management system must apply for a permit to collect, store, treat, and apply animal waste. Although animal feeding operations with dry litter management systems are exempt from requiring a permit, they are also subject to regulations regarding waste storage and application. These rules include applying waste at agronomic rates, which requires a current soil test, waste analysis, and estimates of the N requirement of the crops to be grown (General Assembly of North Carolina, 2018a, 2018b).

High concentrations of NO_3^- in the forage can be potentially toxic to livestock (Burns et al., 1990). Symptoms of livestock poisoned by NO_3^- include depressed feed intake, reproductive failure, respiratory distress, cyanosis, and even death (Lee & Beauchemin, 2014). Information on productivity, nutritive value, N removal, and tissue NO_3^- concentration is needed if crabgrass is to be used as a forage and included as a receiver crop and potentially sold as hay as part of animal waste nutrient management plans in North Carolina. Therefore, the objective of this experiment was to determine the effects of fertilizer N source and N rate on productivity, N removal, nutritive value, and tissue NO_3^- concentration when crabgrass is managed as a hay crop in the Coastal Plain and Piedmont.

Core Ideas

- Poultry litter is an effective N source for crabgrass production.
- At Coastal Plain herbage accumulation plateaued at 7,136 kg DM ha^{-1} at an agronomic optimum N rate of 198 (SE = 49) kg N ha^{-1}.
- Herbage accumulation at Piedmont was erratic and approximately half or less than Coastal Plain.
- Concentrations of crude protein ranged from 126 to 154 g kg^{-1} and calculated total digestible nutrients averaged 626 g kg^{-1}.
- Tissue NO_3^- values were mostly below the toxic threshold for feeding livestock.

TABLE 1 Initial soil characterization of the experimental areas

Location (year)	pH	P	K	Ca	Mg
		mg kg^{-1}			
Coastal Plain (2020)	6.0	529	55	12,400	2,310
Coastal Plain (2021)	5.9	469	100	12,600	2,067
Piedmont (2020)	6.3	28	125	12,400	2,797
Piedmont (2021)	6.3	149	121	12,200	2,918

2 | MATERIALS AND METHODS

2.1 | Experimental site, plot establishment, and management

The experiment was conducted in two physiographic regions of North Carolina, USA (Piedmont and Coastal Plain), for 2 yr (2020 and 2021). The experimental plots in the Piedmont were located at the Piedmont Research Station in Salisbury, NC (35˚42′ N, 80˚37′ W, 200 m asl) and in the Coastal Plain at the Cherry Research Farm in Goldsboro, NC (35˚23′ N, 78˚02′ W, 19 m asl); hereafter the sites will be referred to as Piedmont and Coastal Plain. The soils in the study areas were Lloyd clay loam (fine, kaolinitic, thermic Rhodic Kanhapludult) at Piedmont and Kenansville loamy sand (loamy, siliceous, subactive, thermic Arenic Hapludult) at Coastal Plain. Soil test results from samples collected each year in late winter and prior to establishment of crabgrass are presented in Table 1. Soil amendments, except for N, were applied before planting to all plots following the recommendations for warm-season annual grasses set by the North Carolina Department of Agriculture and Consumer Services (NCDA&CS) Agronomic

Division. Specifically, at Piedmont, 43 and 81 kg ha^{-1} of P and K, respectively, were applied on 9 Apr. 2020, and 37 and 70 kg ha^{-1} of P and K, respectively, were applied on 7 Apr. 2021 using a fertilizer blend of single and triple super phosphate and muriate of potash. At Coastal Plain, K was applied at 120 kg ha^{-1} on 24 Apr. 2020 using potassium sulfate and 83 kg ha^{-1} on 14 Apr. 2021 using muriate of potash.

In the years prior to the study, the sites at Piedmont were planted to sorghum [*Sorghum bicolor* (L.) Moench] in 2019 and corn (*Zea mays* L.) in 2020 as summer crops and followed by rye (*Secale cereale* L.) as cover crop planted in the fall. At Coastal Plain, pearl millet [*Cenchrus americanus* (L.) Morrone] was planted in summer 2019 and 2020 followed by annual ryegrass (*Lolium multiflorum* L.) as a cover crop planted in the fall. For all site–year combinations, the fall cover crop was terminated by spraying herbicide glyphosate, N-(phosphonomethyl) glycine in the form of its potassium salt (RoundUp PowerMax) at a rate of 1.56 kg a.i. ha^{-1}. Two weeks after herbicide application, the residual biomass was mowed and removed. The field was tilled and cultipacked within 2 d prior to the planting date of crabgrass each year. Planting dates were 4 and 11 May 2020 and 30 and 29 Apr. 2021 for Piedmont and Coastal Plain, respectively.

Quick-N-Big crabgrass [*Digitaria sanguinalis* subsp. *aegyptiaca* (Willd.) Henrard] was established by hand broadcasting seed at a pure-live-seed rate of 5.6 kg ha^{-1}. The seed for each experimental unit was mixed with ∼1 kg of sand to help achieve uniform seed dispersion during establishment. Because of excessive rainfall shortly after the planting date at Piedmont 2020 (Figure 1), successful stand establishment did not occur. Consequently, the plots were sprayed again with herbicide glyphosate and replanted 1 wk after herbicide application on 22 June 2020.

Herbicides carfentrazone-ethyl {ethyl 2-chloro-3-[2-chloro-5-[4-(difluoromethyl)−3-methyl-5-oxo-1,2,4-triazol-1-yl]−4-fluorophenyl]propanoate} (AimEC) at the rate of 0.035 kg a.i. ha^{-1} and sodium salt of bentazon' {3-{1-melhylethyl)−1H-2,1,3-benzothiadiazin-4 (3H)-one 2.2-dioxide} (Basagran) at the rate of 1.12 kg a.i. ha^{-1} were sprayed during early establishment of crabgrass at Coastal Plain on 10 June 2020 and 8 June 2021 to control yellow nutsedge (*Cyperus esculentus* L.) and broadleaf weeds. Weather data (monthly rainfall, long-term reference average monthly rainfall, and average daily maximum and minimum temperatures) were retrieved from the weather stations located at the research stations, and the data are presented in Figure 1.

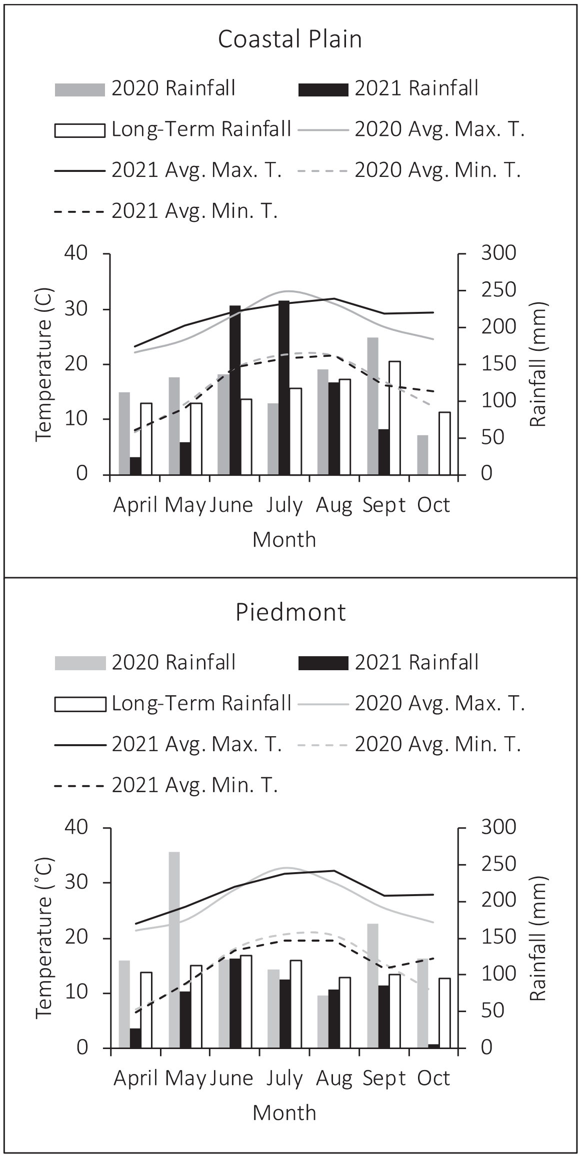

FIGURE 1 Long-term (21-yr; 1990 to 2020) monthly rainfall, monthly rainfall, and average maximum and minimum temperatures. Total accumulated rainfall values during May through October were 980 mm for Piedmont 2020, 491 mm for Piedmont 2021, 863 mm for Coastal Plain 2020, and 723 for Coastal Plain 2021

2.2 | Treatments and experimental design

The treatment design was a dose-response design with 11 treatments resulting from five N rates of chemical fertilizer, five N rates of broiler poultry litter, and one control treatment (no N applied). Chemical fertilizer (340 g N kg^{-1}; 26% polymer coated urea plus 8% ammonium sulfate) was applied at total N rates of 30, 60, 120, 240, and 480 kg ha^{-1}. Poultry litter was at applied at rates of 2.2, 6.7, 13.6, 20.2, and 26.9 Mg ha^{-1} on a fresh weight basis in both years. The DM concentrations of the broiler poultry litter determined at 105 °C were 733 and 772 g kg^{-1} in 2020 and 2021, respectively (Table 2). Plant-available N was estimated to be 100% for chemical fertilizer and 50% for poultry litter (Kulesza, 2022). Hence, the resulting plant-available N rates applied for the broiler poultry litter treatments were 39, 118, 236, 354, and 472 kg N ha^{-1} in

TABLE 2 Initial characterization of broiler litter

Year	DM[a]	Total C	Total N	NH_4–N	NO_3–N	Organic N	P	K	Ca	Mg	Na	S	Fe	Mn	Zn	Cu	B
	g kg^{-1}												mg kg^{-1}				
2020	733	393.0	47.8	3.0	0.6	44.3	14.9	30.3	30.4	6.1	11.1	10.1	817	424	488	589	329
2021	772	396.5	38.5	2.9	0.2	35.4	14.2	25.9	25.8	6.1	7.4	10.0	580	662	622	616	0

[a]DM, dry matter concentration determined at 105 °C.

2020 and 33, 100, 199, 299, and 399 kg N ha^{-1} in 2021. The N mineralization process is a microbially mediated process and it has been reported, including in North Carolina (Savala et al., 2016), that plant-available N coefficients from organic sources vary as functions of environmental and cultural practices (Castillo et al., 2010; Castillo et al., 2011). However, current standard nutrient management planning guidelines for broiler poultry litter in North Carolina assume availability coefficient values of 50% if broadcast and left on the surface (like in this study) and 60% if incorporated (Kulesza, 2022). Because broiler litter contains several plant nutrients (Table 2), applying broiler litter at a N-rate basis resulted in additional amounts of P, K, and other nutrients applied to plots that received the broiler litter treatments.

The treatments were applied to experimental units arranged in a randomized complete block design replicated four times. The experimental unit size was 3 m wide by 8 m long with 1.5-m alleys between experimental units. A new site, adjacent to the site used in Year 1, was used to set up the experimental plots in Year 2. A cultipacker was driven over all experimental units the day of and day after planting to ensure optimum seed-to-soil contact. For the chemical N fertilizer, half of the total N rate was broadcasted at planting time and the other half was applied after the first harvest. The full rate of broiler poultry litter was broadcasted by hand 1 wk prior to planting crabgrass.

Broiler poultry litter from a whole-house cleanout was collected from two farm cooperators in Rockingham and Randolph counties, NC, in 2020 and 2021, respectively. Five samples were taken from the poultry litter pile on the day of application and the samples were thoroughly mixed into a single composited sample, which was immediately sent for nutrient analysis to the NCDA&CS Agronomic Division Laboratory (Raleigh, NC). Initial characterization of the poultry litter is presented in Table 2. Total N and C concentrations were determined by oxygen combustion gas chromatography with an elemental analyzer (NA1500; CE Elantech Instruments) (AOAC, 1990; Campbell & Plank, 1992). Total concentrations of P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, B, and Na were determined with an inductively coupled plasma spectrophotometer (Optima 3300 DV ICP emission spectrophotometer; Perkin Elmer Corporation) (Donohue & Aho, 1992; adapted USEPA, 2001), after open-vessel HNO_3 digestion in a microwave digestion system (MARS & MDS2100 microwaves; CEM Corp.) (Campbell & Plank, 1992).

2.3 | Response variables

2.3.1 | Herbage accumulation and N removal

Herbage mass samples were collected using a forage plot-harvester (RCI Engineering LLC) equipped with a flail mower and a weigh-bin collection system. Samples were collected by clipping a 0.91-m wide by 6-m long strip to 10-cm stubble height running through the center of each plot. The target sampling date to harvest plots was when crabgrass reached late boot to early flowering stage maturity. There were four sampling events for each site–year combination except for Piedmont 2020 where there were only two sampling events due to the issues during the establishment phase previously described. At Piedmont, herbage mass sampling occurred on 7 Aug. and 4 Sept. 2020 and on 17 June, 7 July, 30 July, and 30 Aug. 2021. At Coastal Plain, herbage mass sampling occurred on 2 July, 23 July, 12 Aug., and 3 Sept. 2020 and 23 June, 14 July, 5 Aug., and 26 Aug. 2021. The clipped forage was weighed fresh in the field, and a subsample (approximately 0.5–1.0 kg) was oven dried at 60 ˚C to constant weight to determine DM concentration and to calculate herbage mass on a DM basis. Herbage accumulation was calculated by adding the herbage mass values of all sampling events within a year and corresponding treatment. After collecting the samples in the field, the remainder of the plot was mowed to the 10-cm target stubble height and the clipped material was removed from the plots. The dried herbage samples were ground using a Wiley mill with four rotating and six stationary knives that produce a shearing action (A. H. Thomas Co.) to pass through a 1-mm screen and subsequently stored in Whirl-Pak bags in preparation for nutritive value, tissue total N, and NO_3^- analyses. Removal of N was estimated by multiplying herbage accumulation (HA) by N concentration values.

2.3.2 | Nutritive value and tissue nitrate concentrations

Estimates of nutritive value were crude protein (CP), acid detergent fiber (ADF), and ADF-based calculated total digestible nutrient (TDN) concentrations. Concentrations of CP and ADF were estimated using near infrared spectroscopy (NIRS) models developed for this experiment. Samples were scanned with a Perten DA 7250 NIRS analyzer (PerkinElmer) and NIRS model development was performed using a data analysis pipeline written in R environment (Acosta et al., 2020; R Core Team, 2016). To obtain a calibration for CP and ADF, a total of 169 samples were selected (28% of total samples) for calibration based on their spectral information to represent the population of samples collected in this trial. Another set of 63 samples, which was not part of the calibration set, were used as the validation set. The selected samples were sent to a commercial laboratory for wet chemistry analysis of CP and ADF. In summary, from the laboratory analytical procedures manual (Dairy One, 2015), concentration of CP was calculated by multiplying the concentration of total N (determined by dry combustion using a LECO CN628, LECO) by 6.25. The ADF concentration was determined using Method 12 of the ANKOM Fiber Analyzer (ANKOM Technology). Fit statistics for NIRS model validation were r^2 values of .98 and .67, and standard errors (g kg^{-1}) of 5 and 20, for CP and ADF, respectively. Although Van Soest et al. (1991) stated that ADF is not a valid fiber fraction for predicting digestibility, ADF values were used to calculate TDN concentration following the 'Forage grass' equation used by the NCDA&CS Feed and Forage Laboratory [$TDN = 92.5 - (0.80ADF)$]. Calculation of TDN from ADF, rather than a summative equation (Van Soest et al., 1991), is, to date, the preferred method to balance energy requirements for forage-based rations in North Carolina (Freeman et al., 2016; Kunkle et al., 2000; Poore, 2014).

Values for CP and TDN concentrations were reported as a weighted average across sampling dates within a year. Tissue NO_3^- concentrations were extracted with a 2% acetic acid solution according to QuikChem Method 13-107-04-1-A (Sechtig, 2003) and analyzed using a Lachat Quikchem 8500 flow injection colorimetric analyzer (Hach USA). Because the herbage harvested from a single clipping event could serve as the sole ration for ruminant animals, the safety of tissue NO_3^- concentration was examined by sampling date.

2.4 | Statistical analysis

Data were analyzed by region. We evaluated the effects of year, N source and N rate on HA, N removal, nutritive value, and tissue NO_3^- using mixed models for analysis of variance as a first step and to assess whether years could be combined. These models included year, N source, and N rate as fixed effects and block and block within year as random effects.

The nature of the responses to N rate treatments was evaluated using regression. For HA data, response to N rate treatments were examined by fitting linear and linear-plateau models. The joint point of the linear-plateau model was considered to be the N rate at which further addition of N fertilizer does not result in a measurable increase in HA, also known as the agronomic optimum N rate (AONR). Although fitting other curve models, such as a quadratic-plateau, may provide less bias (Cerrato & Blackmer, 1990), the linear-plateau model was selected a priori because it is considered a more conservative test (greatest yield for the least amount of N applied) (Rajkovich et al., 2015) and because of its historical use in North Carolina (Anderson & Nelson, 1987) for identification of the AONR to be used in the North Carolina Realistic Yield Expectation database tool (Osmond et al., 2020). When fitting a linear-plateau model was not possible, then a quadratic model was fit as an additional step and to compare its fit statistics to a linear model. The N rate response data were visually inspected, and the selected model reported was statistically significant with the lowest error residual. The

TABLE 3 Linear-plateau regression coefficients for herbage accumulation (HA) response as a function of N source from 2020 to 2021 at Coastal Plain in North Carolina. Values in parentheses represent one SE. *P* value is for the pairwise comparison of regression coefficients between fertilizer and poultry litter models

N source	Intercept	Slope	AONR	HM at AONR
	kg HA^{-1}	kg HA kg^{-1} N	kg N ha^{-1}	kg HA ha^{-1}
Fertilizer (F)	5,009 (236)	6.4 (1.9)	334 (95)	7,153 (363)
Poultry litter (PL)	4,979 (305)	15.5 (4.6)	138 (33)	7,130 (209)
P value (F – PL)	0.93	0.07	0.06	0.96
Combined model (F & PL)	4,990 (211)	10.0 (3.1)	198 (49)	7,136 (179)

Note. AONR, agronomic optimum N rate, which is the joint point of the linear-plateau function.

association between N removal data and HA was assessed using regression analysis.

Analyses of variance were performed using the GLIMMIX procedure of SAS (SAS 9.4, SAS Institute, 2010). Linear and quadratic models were fitted using the REG procedure. Linear-plateau models were fitted using the NLIN procedure. Comparison of overall linear-plateau model trends was performed by setting up a sum of squares reduction test using the NLIN procedure. The ESTIMATE function was used for pairwise means comparison of linear-plateau model regression coefficients. We considered $P \leq .05$ to be statistically significant.

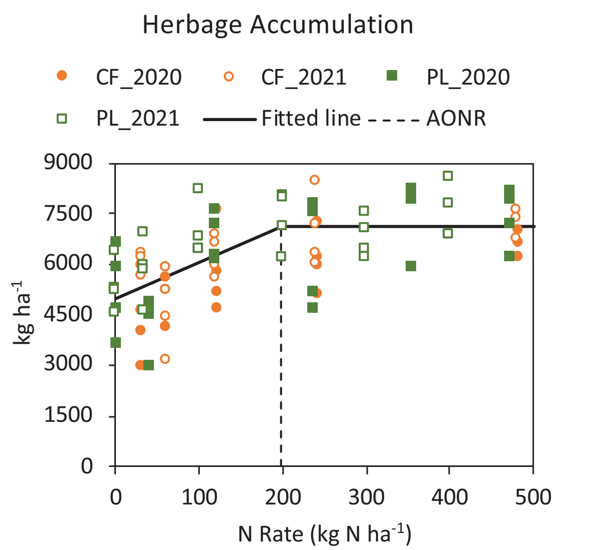

FIGURE 2 Herbage accumulation of 'Quick-N-Big' crabgrass as a function of N source (CF, chemical fertilizer; PL, poultry litter) and N rate at the Coastal Plain of North Carolina for 2 yr (2020 and 2021). Regression coefficients of the fitted model and agronomic optimum N rate (AONR) are presented in Table 3

3 | RESULTS AND DISCUSSION

3.1 | Herbage accumulation and N removal

At Coastal Plain, the main effect of year and the interaction effects of year with N source and with N rate were not significant; therefore, data were combined across years and linear-plateau models were fit by N source (Table 3). Based on the sum of squares reduction test ($P = .09$) and pairwise comparisons of the model's regression coefficients (Table 3), apparent HA was not different between chemical N fertilizer and broiler poultry litter. Hence, a single linear-plateau model adequately fit the data (Table 3; Figure 2). Herbage accumulation increased from 4,990 kg ha^{-1} at 0 kg N ha^{-1}and plateaued at 7,136 kg ha^{-1} at an AONR of 198 kg N ha^{-1} (with 95% confidence intervals of 100 and 295 kg N ha^{-1}) (Figure 2).

Several studies have validated poultry litter as an alternative N source for forage and grain production (Lin et al., 2018; Savala et al., 2016; Singh et al., 2021; Wood et al., 1993). Possible concerns from hay producers about potential deleterious effects associated with low nutrient availability and high weed infestation when using poultry litter have been mentioned (Woodard & Sollenberger, 2011). There is no evidence in our results, or to the best of our knowledge that has been reported in the literature, that field application of poultry litter rates as high as 26.9 Mg ha^{-1} on a fresh weight basis (equivalent to 20.1 Mg ha^{-1} on a DM basis), like in our study, would have deleterious effects on HA, or that yields from poultry litter would be lower than those from chemical N fertilizer when adequately accounting for N availability from the poultry litter. In fact, the results of a meta-analysis from 90 datasets comparing poultry litter and chemical fertilizer concluded that the greatest benefits were observed when poultry litter was applied at the highest rates (up to 30 Mg ha^{-1}) (Lin et al., 2018). Long-term application of poultry litter increases levels of soil nutrients (Mitchell & Tu, 2006); therefore, proper nutrient management using agronomic rates of N and P should be implemented to avoid adverse impacts resulting from land application of poultry litter (Moore et al., 1995).

Working with Red River crabgrass fertilized with ammonium nitrate and poultry litter near Blackstone, VA, Teutsch et al. (2005) also reported no differences between N sources for HA in two out of three years of experimentation. Although the authors did not attempt to fit models to find a joint point to determine the AONR, they suggested that AONR for crabgrass would likely lie between 150 to 250 kg ha^{-1}, which agrees with the AONR of 198 (SE = 49) kg N ha^{-1} estimated in our study. Greater yields for poultry litter vs. chemical fertilizer have been associated with wetter years where excessive rainfall early in the growing season likely leached plant-available N from the rooting zone (Teutsch et al., 2005) coupled with greater yields later in the growing season from poultry litter treatments as mineralization of organic N accrued (Bitzer & Sims, 1988; Reddy et al., 1979). Not only N is added when using poultry litter, but P, K, Ca, S, Mg, and other essential nutrients are also added to soil potentially improving plant growth, which may lead to higher crop yield (Lin et al., 2018).

At Piedmont, there was a three-way interaction of year by N rate by N source; therefore, the data were analyzed by year. For both years, there was a two-way interaction of N rate by N source; therefore, data were subsequently analyzed by N source. It was not possible to fit linear-plateau models to HA data at Piedmont. For three out of four year–location–N source combinations at Piedmont, there was a linear or quadratic response to fertilizer N or broiler litter; Piedmont 2020 was the exception. Overall, HA at Piedmont was ≤4,256 kg DM ha^{-1}. At Piedmont 2020, there was no chemical fertilizer N rate effect on HA (averaged 1,852 kg DM ha^{-1}; SE = 143); however, for poultry litter, HA increased quadratically up to a maximum of 2,707 kg DM ha^{-1} (r^2 = .48; $Y = 1{,}383 + 3.98X - 0.003X^2$) as plant-available N rates increased from 0 to 472 kg ha^{-1}. At Piedmont 2021 for chemical N fertilizer, HA increased quadratically up to 3,153 kg DM ha^{-1} (r^2 = .36; $Y = 1928 + 7.0X - 0.01X^2$) as N rates increased from 0 to 480 kg ha^{-1}. For poultry litter at Piedmont 2021, HA increased linearly from 1,821 to 4,256 kg DM ha^{-1} as plant-available N rate increased from 0 to 399 kg N ha^{-1} ($r^2 = 0.87$, $Y = 1{,}982 + 2.48X$).

Crabgrass seasonal HA values can vary widely from year to year, and its productivity is especially influenced by rainfall and temperature. Bouton et al. (2019) reported total seasonal HA values for Quick-N-Big crabgrass ranging from 5,459 to 15,680 kg DM ha^{-1} across three locations during 2010–2014 in Oklahoma. Working with Red River crabgrass in Virginia, Teutsch et al. (2005) reported maximum HA values of 7,000; 9,800; and 6,500 kg DM ha^{-1} in 2001, 2002, and 2003, respectively. Also working with Red River crabgrass fertigated with swine manure in Mississippi, McLaughlin et al. (2004) reported total HA values of 10,000; 1,600; and 8,100 kg DM ha^{-1} in 1999, 2000, and 2001, respectively.

Overall, HA responses to N treatments were erratic at Piedmont, and values were about half or less than Coastal Plain. These responses are attributed to a shorter growing season for Piedmont 2020 and lower rainfall for Piedmont 2021. There were only two sampling events for HA at Piedmont 2020 due to the issues during the establishment phase previously described, rendering a shorter growing season. Also, rainfall during May through October at Piedmont 2021 was about half compared with both years at Coastal Plain and about 294 mm lower than the 21-yr (1999 to 2020) long-term average of 785 mm for the May through October timeframe at this location. Total accumulated rainfall values during May through October were 980 mm for Piedmont 2020, 491 mm for Piedmont 2021, 863 mm for Coastal Plain 2020, and 723 mm for Coastal Plain 2021.

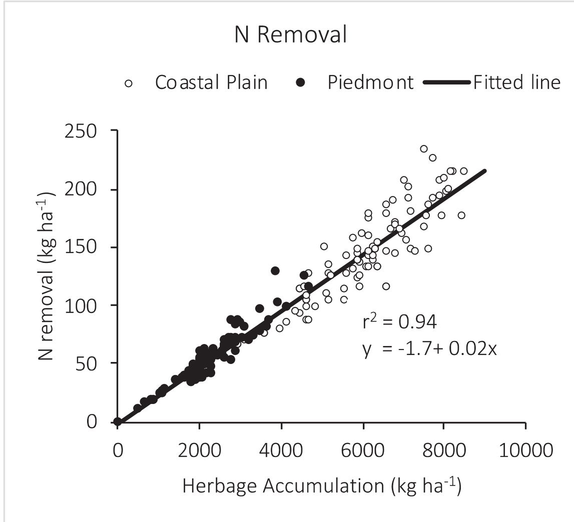

FIGURE 3 Removal of N as a function of herbage accumulation of 'Quick-N-Big' crabgrass. Each data point (n = 192) represents an experimental unit as a function of two N sources (poultry litter and chemical fertilizer), 2 yr (2020 and 2021), and N rate treatments ranging from 0 to 480 kg N ha^{-1}

Nitrogen removal in the harvested forage was linearly associated (r^2 = .94, $Y = -1.7 + 0.02X$) with HA (Figure 3). This regression approach for N removal data enables producers to estimate the nutrient removals with the harvested herbage and will assist in developing nutrient management guidelines to avoid applying amounts of N fertilizer that may exceed the N removal capacity of crabgrass.

3.2 | Crude protein and total digestible nutrients

Overall, CP concentration in this experiment ranged from 126 to 154 g kg^{-1}. At Coastal Plain, there were significant effects of N rate and N rate by year; therefore, data were pooled across N sources and the N rate effects were analyzed by year. At Coastal Plain 2020, concentration of CP increased quadratically (r^2 =.56; $Y = 126 + 0.1X + 5.8\text{e}{-5}X^2$) from 126 g kg^{-1} at 0 kg N ha^{-1} to 158 g kg^{-1} at 480 kg N ha^{-1}. At Coastal Plain 2021, there were no significant treatment effects and CP concentration averaged 149 g kg^{-1}.

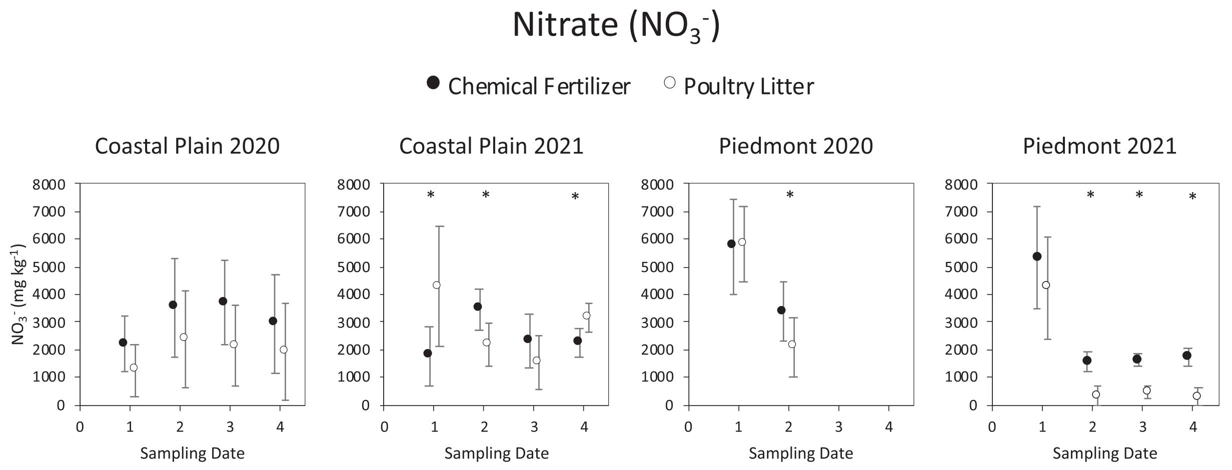

FIGURE 4 Tissue nitrate (NO_3^-) concentration of 'Quick-N-Big' crabgrass. Data are means ± 95% confidence intervals of the mean. * = significant difference between poultry litter and chemical fertilizer at the corresponding sampling date

At Piedmont, there was a significant N rate effect on CP concentration; therefore, data were pooled across years and N sources to estimate the effect of N rate on CP concentration. Increasing N fertilization from 0 to 480 kg N ha^{-1} increased CP concentration linearly from 144 to 154 g kg^{-1} (r^2 = .1; $Y = 144 + 0.02X$). Across several harvest events within season and for a 3-yr experiment, Teutsch et al. (2005) reported that CP concentration increased, for the most part, as N rate increased from 0 to 336 kg ha^{-1} for Red River crabgrass; however, the range of CP values reported by those authors was rather wide (from 53 to 185 g kg^{-1}) compared with a narrower range in our experiment (126–154 g kg^{-1}). McLaughlin et al. (2004) reported CP ranged from 90 to 140 g kg^{-1} for Red River crabgrass fertilized with 371 kg N ha^{-1} yr^{-1} from swine manure. Beck et al. (2007) reported that CP concentration values decreased linearly from 141 to 106 g kg^{-1} as harvest interval increased from 21 to 49 d.

There were no effects of N treatments on TDN concentration values across the experiment. Overall, TDN concentration values ranged from 596 to 650 g kg^{-1}. Beck et al (2007) reported that TDN values for crabgrass decreased linearly from 626 to 548 g kg^{-1} as harvest interval increased from 21 to 49 d of regrowth. Although the same regrowth interval was targeted for every crabgrass harvest event in our experiment, this was not always possible, and regrowth intervals ranged from 20 to 31 d. It is likely that TDN concentration values in our study may have been influenced by different harvest intervals among site-years. It is worth noting that even at the fertilization rate of 0 kg N ha^{-1}, the concentrations of CP (≥126 g kg^{-1}) and TDN (≥596) of crabgrass would meet the CP (≈104 g kg^{-1}) and TDN (≈593 g kg^{-1}) dietary needs of a mature lactating beef cow in the first 90 d after calving if forage was the only source of feed (National Research Council, 2016).

3.3 | Tissue nitrate concentration

The safety of tissue NO_3^- concentration was examined by sampling date. For all sampling events across the experiment, except for three instances in the first sampling event, tissue NO_3^- concentration averaged across N rate treatments were below 5,000 mg NO_3^- kg^{-1}. A NO_3^- concentration of 5,000 mg kg^{-1} is generally considered the toxic threshold for all kinds of livestock; although, the toxic NO_3^- threshold for feeding forages has been reported ranging from 2,500 to 5,000 mg NO_3^- kg^{-1} in extension publications (Anderson, 2016; Burns, 2019; Garner, 1958; Hancock, 2013; Poore et al., 2000; Strickland et al., 1996). Differences between N sources occurred in seven (out 14) sampling events; in five out those seven instances, the NO_3^- concentration was lower for broiler litter than chemical fertilizer treatment (Figure 4); however, those differences are considered of no biological importance given that tissue NO_3^- concentrations were below the toxic threshold for feeding livestock. Forages with NO_3^- concentration >5,000 mg kg^{-1} can still be fed as a proportion of the ration, and there are several feeding strategies to reduce toxicity risk proposed in the literature (Hancock, 2013; Poore et al., 2000). Tissue NO_3^- concentration values of Quick-N-Big crabgrass in our study did not reach concentrations as high as 20,000 mg kg^{-1} reported for Red River crabgrass grown in Virginia (Teutsch & Tilson, 2005) or 16,000 mg kg^{-1} for bermudagrass grown at spray fields in North Carolina (Spearman et al., 2021).

4 | CONCLUSIONS

Productivity of Quick-N-Big crabgrass was at least double in the Coastal Plain location (7,136 kg DM ha^{-1} averaged across

2 yr) vs. the Piedmont. Lower productivity at Piedmont 2020 was attributed to a shorter growing season due to poor establishment associated with heavy rainfall early in the season. In contrast, low productivity at Piedmont 2021 was attributed to limited rainfall during the experimental period.

Estimation of an agronomic optimum nitrogen fertilization rate (AONR), that is, the joint point of the linear-plateau model at which further addition of N fertilizer does not result in a measurable increase in HA, was only possible at Coastal Plain where there was no difference in HA as a function of N source. Herbage accumulation increased from 4,990 kg DM ha^{-1} at 0 kg N $ha^{-1}$and plateaued at 7,136 kg ha^{-1} at an AONR of 198 (SE = 49) kg N ha^{-1}. Removal of N in the harvested herbage was linearly associated with HA.

For both N sources and across locations, there was a marginal positive effect of increasing N rate on CP concentration, that is, three percentage points increase maximum for CP, and there was no effect of increasing N rate on calculated TDN concentration. It is worth noting that even at the fertilization rate of 0 kg N ha^{-1}, the concentrations of CP (≥126 g kg^{-1}) and TDN (≥596 g kg^{-1}) of crabgrass would meet the CP and TDN dietary needs of a mature lactating beef cow in the first 90 d after calving if forage was the only source of feed.

Tissue NO_3^- concentration values were below the toxic threshold for feeding livestock and concentrations tended be lower when poultry litter was the N source and during the late-season sampling events. Poultry litter is an effective alternative N source for production of crabgrass and crabgrass forage has potential to be used for achieving year-round forage systems in the U.S. transition zone, especially in the Coastal Plain as supported by the results of this study.

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AUTHOR CONTRIBUTIONS

Stephanie Sosinski: Data curation; Methodology; Project administration; Resources; Writing – review & editing. Miguel S. Castillo: Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Software; Supervision; Validation; Visualization; Writing – original draft; Writing – review & editing. Stephanie Kulesza: Conceptualization; Funding acquisition; Investigation; Methodology; Project administration; Resources; Software; Supervision; Writing – review & editing. Ramon Leon: Conceptualization; Investigation; Methodology; Supervision; Writing – review & editing.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

ORCID

Stephanie Sosinski https://orcid.org/0000-0002-8280-7742
Miguel S. Castillo https://orcid.org/0000-0003-1066-5906
Stephanie Kulesza https://orcid.org/0000-0001-6992-1105
Ramon Leon https://orcid.org/0000-0002-1924-3331

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