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Effect of seeding distance from subsurface banded poultry litter on corn yield and leaf greenness

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Abstract

Poultry litter is a nutrient-rich soil amendment and is generated in large quantities throughout the southeastern United States where row crop production, such as corn (*Zea mays* L.) occurs. However, extensive surface poultry litter applications have resulted in nutrient losses to atmosphere and water systems. Research objectives were to determine optimum corn planting distance from subsurface-applied poultry litter bands for maximizing plant N uptake and productivity under rainfed and irrigated conditions in a conservation tillage system. This experiment was conducted as a split-block at two locations in Alabama and one in Arkansas during 2016. Irrigation was the whole block and soil amendments the split-block, which included planting corn 13, 25, and 38 cm to the side of subsurface banded poultry litter, surface-applied poultry litter, inorganic N (all received total N; 168 kg ha^{-1}), and 0 kg N ha^{-1} (control). Chlorophyll readings indicated inorganic fertilizers and the 25 cm resulted in greatest leaf greenness, which was not different from the 13-cm litter band distance. Banding distance had no impact on rainfed forage yields; however, yields were not different from inorganic fertilizer applications. The 13-cm band distance resulted in the greatest grain yield, which was not different from the inorganic-N treatment. Grain neutral detergent fiber, crude fiber, and P and K fractions were all favorable for the 13-cm band distance treatment. Yield and quality results suggest subsurface banding poultry litter 13 cm from corn rows may be a viable replacement for inorganic fertilizers in fodder and grain systems, particularly in organic production systems.

1 | INTRODUCTION

Poultry litter, which is a mixture of poultry manure and a bedding material such as wood shavings, has proven efficacy at increasing soil fertility and meeting corn (*Zea mays* L.) N requirements (Endale et al., 2008). In addition to direct benefits from soil fertility, ancillary benefits include its liming effect on acidic soils, organic matter (OM) additions, and support of beneficial soil bacteria (Ashworth, Allen, Wight, Saxton, & Tyler, 2014; Tewolde, Adeli, Sistani, Rowe, & Johnson, 2010). Manufacturing inorganic-N fertilizers requires high pressure (100–200 atm), high temperature (400–500 °C), and large amounts of energy (8000 kcal kg^{-1} N), and consequently has pricing linked to petroleum markets (USDA, CCSP, 2008). Furthermore, breakdown of inorganic N in soils

Abbreviations: ADF, acid detergent fiber; CF, crude fiber; CP, crude protein; ESC, ethanol soluble carbohydrate; NDF, neutral detergent fiber; NIRS, near-infrared spectroscopy; OM, organic matter; SOM, soil organic matter; SP, soluble protein.

tends to increase acidity and is highly correlated to N_2O emissions which is more than 300 times more potent of a greenhouse gas (GHG) than CO_2 (IPCC, 1996). Therefore, more information is needed on the ability of poultry litter to displace inorganic N for organic and less input-intensive cropping systems.

Corn is arguably the world's most important food crop owing to its diverse uses for animal fodder, cellulosic and grain-based ethanol, and primary and secondary products being consumed by humans. In addition, the United States is the world's largest corn producer, with corn accounting for approximately 12% of U.S.'s agricultural export value (USDA, FAS, 2016). However, production of corn results in more soil erosion, and greater consumption of pesticides, water, and N fertilizers than any other crop in the United States on a per unit basis (NASS, 2003). These factors suggest that novel systems that reduce inputs in corn systems and promote system sustainability are needed (Ashworth et al., 2015; Pimentel & Patzek, 2005).

Soils of the U.S. Southeast are highly weathered due to high leaching and humid environments; and consequently, have low C contents (Shaw, Hajek, & Beck, 2010). Poultry production in this region is a leading enterprise. In 2018, 9.0 billion broilers were raised in the United States totaling US$31.7 billion in agricultural receipts, with approximately half of these broilers coming from four southeastern states (i.e., Alabama, Arkansas, Georgia, and North Carolina; NASS, 2019). Poultry litter has the potential to provide macronutrients and micronutrients to marginal soils.

Conventional application methods entail spreading poultry litter on the soil surface, which can result in up to 60% of total N being lost via NH_3 volatilization (Cabrera & Chiang, 1994). Additionally, ammonia losses to water and soil can cause P buildup, owing to reduced N/P ratios which can lead to excess soil P transport to aquatic systems, thereby accelerating eutrophication (Levine & Schindler, 1989). In addition, it is widely confirmed that planting directly into poultry litter bands results in stunted plant growth and poor stand establishment (Lin, Watts, & Way, 2017a; Lin, Watts, & Way, 2017b). In efforts to improve management options that prevent ammonia losses and aid in efficient poultry litter usage, a research team at the United States Department of Agriculture, Agricultural Research Service developed a prototype tractor-drawn implement for subsurface band application of dry poultry litter in conservation tillage systems (Pote et al., 2011). The trenching depth of the implement has typically been set to have the bottom bands 8 cm beneath the undisturbed soil surface. The height of each band is approximately 2 cm and the thickness of the layer of soil above the band after the implement has passed is typically 6 cm. The implement can decrease NH_3 volatilization by 88% (Pote & Meisinger, 2014), but little information exists on appropriate corn seeding distance from poultry litter bands to promote crop productivity and maximize leaf greenness.

Core Ideas

- Subsurface banding poultry litter reduces nutrient losses to air, soil, and water.
- Optimum corn planting distances from subsurface-applied litter was evaluated.
- Forage yields did not differ from subsurface poultry litter and inorganic N.
- Banding litter 13 cm from corn rows resulted in the greatest grain yield.
- Subsurface banding litter may replace inorganic N for corn production.

Ammonia lability from poultry litter assumedly increases under heightened soil water contents; however, for corn yield optimization, irrigation is often supplied. Therefore, irrigation effects on surface-and subsurface-applied poultry litter were also determined in this study. We hypothesize greater N losses under irrigated corn systems, which may translate into reduced plant productivity and greater chlorosis, particularly for broadcast-applied poultry litter. Diagnostic tools that quantify plant N status at various developmental stages are important in these systems to maximize N-use efficiency and ascertain plant nutritive deficiencies (Rorie et al., 2011). Therefore, research objectives were to determine optimum corn planting distance from subsurface-applied poultry litter bands that maximizes plant N uptake and plant productivity under both rainfed and irrigated conditions, thereby reducing potential losses in the environment. Treatments included corn row distances from subsurface-applied poultry litter bands to ascertain the potential for poultry litter to displace (a) inorganic N for corn production systems and (b) surface-applied poultry litter applications. Therefore, we hypothesized that subsurface-applied poultry litter will produce equivalent grain and biomass yields, resulting in leaf greenness comparable to that of the surface-applied inorganic-N treatment. Subsurface banding of poultry litter is expected to outperform surface-applied poultry litter owing to ammonia losses to the air, soil, and water.

2 | MATERIALS AND METHODS

2.1 | Site description and experimental design

This study was conducted at three sites to evaluate corn response to poultry litter band distance over a range of soil types and physiographic regions. One site was the

USDA-ARS, Dale Bumpers Small Farms Research Center in Booneville, AR. This location is situated in the Arkansas Valley and Ridges area. Soil at this site is classified as a Leadvale silt loam (fine-silty, siliceous, semiactive, thermic Typic Fragiudults), with water movement and plant rooting being limited by a fragipan at a depth of 14–97 cm. The Leadvale series soils are deep to very deep, moderately well-drained soils with a fragipan. The soils formed in silty materials in uplands or local silty alluvium from nearby uplands, and are underlain largely by shale and siltstone, or in places by sandstone, phyllite, and slate. These soils are on slightly concave toe slopes, benches, and terraces. This site has annual precipitation totaling 1210 mm (Western Regional Climate Center, 2019a) and an average annual temperature of 13–16 °C (NOAA, 2013). A wheat (*Triticum aestivum* L.) cover crop was planted prior to experimentation.

The other sites were at two locations of the Alabama Agricultural Experiment Station. The first site was in Shorter, AL, at the Field Crops Unit of the E.V. Smith Research Center on a Marvyn loamy sand (fine-loamy, kaolinitic, thermic Typic Kanhapludults), hereafter referred to as E.V. Smith Research Center. This location is in the Coastal Plain area. The Marvyn series soils are very deep, well-drained, moderately permeable soils on uplands, formed in loamy marine sediments. Precipitation at this site is 1230 mm (Western Regional Climate Center, 2019b) with average temperatures being 11–17 °C per annum (NOAA, 2013).

The second site in Alabama was at the Tennessee Valley Research and Extension Center near Belle Mina, AL, on a Decatur silt loam (fine, kaolinitic, thermic Rhodic Paleudults). This site is located in the Tennessee Valley. The Decatur series soils are very deep, well-drained, moderately permeable soils that formed in residuum derived from limestone. The soils are on level to strongly sloping uplands in valleys. The site has an average annual precipitation of 1260 mm (Western Regional Climate Center, 2019c). Long-term average (30-yr normal) annual temperature is 13–20 °C (NOAA, 2013).

At all locations, this experiment was conducted as a randomized complete block design with a split-block treatment design. Irrigation was the whole block and soil amendments the split-block. Treatments were allocated under a randomized complete block design with four blocks.

2.2 | Crop and treatment establishment

Prior to treatment application in spring of 2016, soil tests were conducted from 0- to 15-cm depths from each block to determine soil pH and concentrations of N, P, K, Mg, and Ca. Samples were ground to pass through a 1-mm sieve on a Wiley Soil Crusher (Thomas Scientific) and soil analyses were performed by the Auburn University Soil Testing Laboratory as described by Hue and Evans (1986). Soil pH was determined on 1:1 soil/water suspensions with a glass electrode meter. Concentrations of P, K, Mg, and Ca were determined using Mehlich-I (double-acid extracting solution; Olsen & Sommers, 1982) and measured using an ICAP 9000 spectrometer (Thermo Jarrell Ash). Total C was determined by dry combustion using an Elementar Vario Macro C-N analyzer (Elementar Americas). Given that soil pH values were below 7.0, total C was considered to be organic C. As a result, OM was calculated by multiplying the organic C values by 1.724 (Nelson & Sommers, 1982).

Before planting, herbicides were used to kill existing vegetation. Either paraquat (1,1′-dimethyl-4,4′-bipyridinium dichloride), glyphosate [N-(phosphonomethyl)-glycine], or glufosinate ammonium [ammonium(±)-2-amino-4-(hydroxymethylphosphinyl)butanoate] were applied approximately 30 d prior to planting. As needed, one or two post-emergence applications of glyphosate were applied to plots in May or June. A glyphosate-resistant corn hybrid DeKalb cultivar DKC 64-69 (DeKalb Genetics Corporation) was used at all experimental sites due to its range of adaptability and use in both rainfed and irrigated systems. The corn seeding rate was 69,200 seeds ha^{-1} for the Dale Bumpers Small Farms Research Center location and varied for non-irrigated and irrigated whole blocks at the E.V. Smith Research Center and the Tennessee Valley Research and Extension Center in Alabama, and included 69,200–79,100 and 69,200–85,300 seeds ha^{-1}, respectively.

Mechanized subsurface poultry litter applications (internal auger system) were banded 5-cm wide and to an 8-cm depth in four bands using a 76-cm band spacing, which preceded corn planting. The litter nutrient analysis was 3.99–3.07–3.34 (N–P_2O_5– K_2O, respectively). The equipment used was a tractor-drawn prototype and is further described by Pote et al. (2011). Briefly, four trench openers with a fluted coulter sliced the soil. Each coulter was followed by a double-disk opener which formed the trench. Following deposition of litter in the trench, the injected litter was covered with soil. This no-till band technique minimizes soil disturbance and has the added benefit of pulverizing the poultry litter, thus precluding the need for pregrinding litter.

Soil amendment treatments included planting corn nominally 13, 25, and 38 cm to the side of the subsurface poultry litter bands. Surface broadcast and subsurface-applied poultry litter plots received 168 kg total N ha^{-1} (6 Mg ha^{-1}; University of Arkansas Diagnostic Laboratory) at all experimental sites at the time of planting. Similarly, inorganic-N treatments received 168 kg N ha^{-1}. For this treatment, urea-ammonium sulfate (34–0–0) was applied in split applications during corn at planting (33.6 kg N ha^{-1}) and the remaining (134.5 kg N ha^{-1}) at the V4–V6 corn growth stage. In addition, 18 kg P (P_2O_5) and K (K_2O) were applied to the inorganic-N treatment at the time of planting. The control was represented by a 0 kg N ha^{-1}, thus resulting in six treatments total. The inorganic-N plots received the recommended amount of P and K needed for corn production based on Auburn University Soil Test Recommendations (Mitchell & Huluka, 2012). Soil amendment applications occurred in tandem with corn planting, which occurred 5 May, 28 Apr., and 30 Mar. 2016 at the Dale Bumpers Small Farms Research Center the E.V. Smith Research Center, and the Tennessee Valley Research and Extension Center, respectively.

Corn was planted with a Great Plains YP-425 planter (Great Plains) at the Dale Bumpers Small Farms Research Center site and with a Kinze 2100 planter (Kinze) and a John Deere MaxEmerge Plus planter (John Deere) at the E.V. Smith Research Center and Tennessee Valley Research and Extension Center, respectively. Four corn rows (per plot) were planted using a 76-cm row spacing, with a 1.52-m length of two rows being used to measure total biomass yields, and the remaining 9.14-m length of the middle two rows being used for grain yield determinations.

Each tractor was equipped with a GPS auto-steer system. At the Dale Bumpers Small Farms Research Center location, the tractor pulled the subsurface banding litter implement, which in-turn, pulled the planter, so the lateral position of each corn row relative to its corresponding litter band was set according to the position of the planter hitch point relative to the banding implement. This implement arrangement provided accurate positioning of the corn rows relative to the litter bands. At the two Alamba sites, the tractor pulled only one implement at a time, so it first pulled the litter banding implement with the auto-steer system guiding the tractor during this pass. During a subsequent pass for each plot, the tractor pulled the planter, and the auto-steer system guided the tractor during planting. At the E.V. Smith Research Center site, this use of two separate passes, with each pass guided by the auto-steer system, provided accurate positioning of the corn rows relative to the litter bands for the 13- and 25-cm band positions, while the nominal 38-cm band had an actual mean lateral distance of 36.7 cm.

Each soil amendment treatment occurred under both irrigated and non-irrigated conditions, which were located in neighboring but separate experimental blocks (irrigation was the whole plot and soil amendment the split block). Under irrigated conditions, when less than 2.54 cm of rainfall occurred during a given week from the VT growth stage until R6 (black-layer formation), supplemental irrigation was added as needed using a sprinkler irrigation system. The total irrigation amounts were 101.6 mm at the Dale Bumpers Small Farms Research Center, 55 mm at the E.V. Smith Research Center, and 188 mm at the Tennessee Valley Research and Extension Center (Figure 1).

Two harvest systems were employed, a corn forage and a corn grain; therefore, plots were separated so both harvests could be accomplished. Corn forage harvest was done at the R5 stage on 2 August at the Dale Bumpers Small Farms Research Center on 5 August at the E.V. Smith Research Center, and on 27 July at the Tennessee Valley Research and Extension Center in Alabama. At each site, 1.52-m sections of the middle two rows were hand harvested and run through a chipper shredder.

For grain yields, the remaining plot length for two center rows were harvested per plot in 2016 between 29 August and 8 September once the grain reached 160 g kg^{-1} moisture. Corn plots for grain yield were harvested at the Dale Bumpers Small Farms Research Center with a Gleaner model K combine (AGCO). An ALMACO SPC 40 combine (ALMACO) was used at the E.V. Smith Research Center and the Tennessee Valley Research and Extension Center. Corn forage was determined by hand harvesting two middle plot rows at physiological maturity. Measurements taken at all locations at the time of harvest were grain yield and grain moisture content. Corn yields were adjusted to a standard moisture content of 155 g kg^{-1}.

2.3 | Leaf greenness based on soil amendments

In addition to corn yield, plant N status was assessed to help determine optimum seeding distance from the litter band. Chlorophyll was measured on the most fully extended and fully expanded corn leaf using a SPAD meter (SPAD 502; Minolta Camera Co.) to assess relative N nutrition differences among treatments (Rorie et al., 2011). Leaf greenness was determined at approximately 30, 60, and 90 days after planting (DAP) on 15 random plants per plot per sampling period. In addition, plant height was measured on 15 plants per plot concurrent with SPAD measurements.

2.4 | Corn grain and forage quality evaluations

The effects of soil amendments (i.e., lateral distance from corn row to subsurface band, surface litter, and inorganic N) and irrigation, on feedstock characteristics, were quantified for both grain and forage harvest systems. Ground feedstock (grain and forage) was analyzed by Cumberland Valley Analytical Services (Waynesboro, PA) with near-infrared spectroscopy (NIRS) using a LabSpec Pro Spectrometer (Analytical Spectral Devices). Five scans were taken at a scan range of 1003–2500 nm. Analysis of feedstocks included acid detergent fiber (ADF), neutral detergent fiber (NDF), and lignin. Crude fiber (CF) was measured in accordance with Association of Official Analytical Chemists (978.10). Starch, including maltooligosaccharide was analyzed via Hall (2009). Forage and grain ethanol soluble carbohydrate (ethanol soluble carbohydrate (ESC), saccharides, and fructans) were determined according to Hall, Hoover, Jennings, and Miller

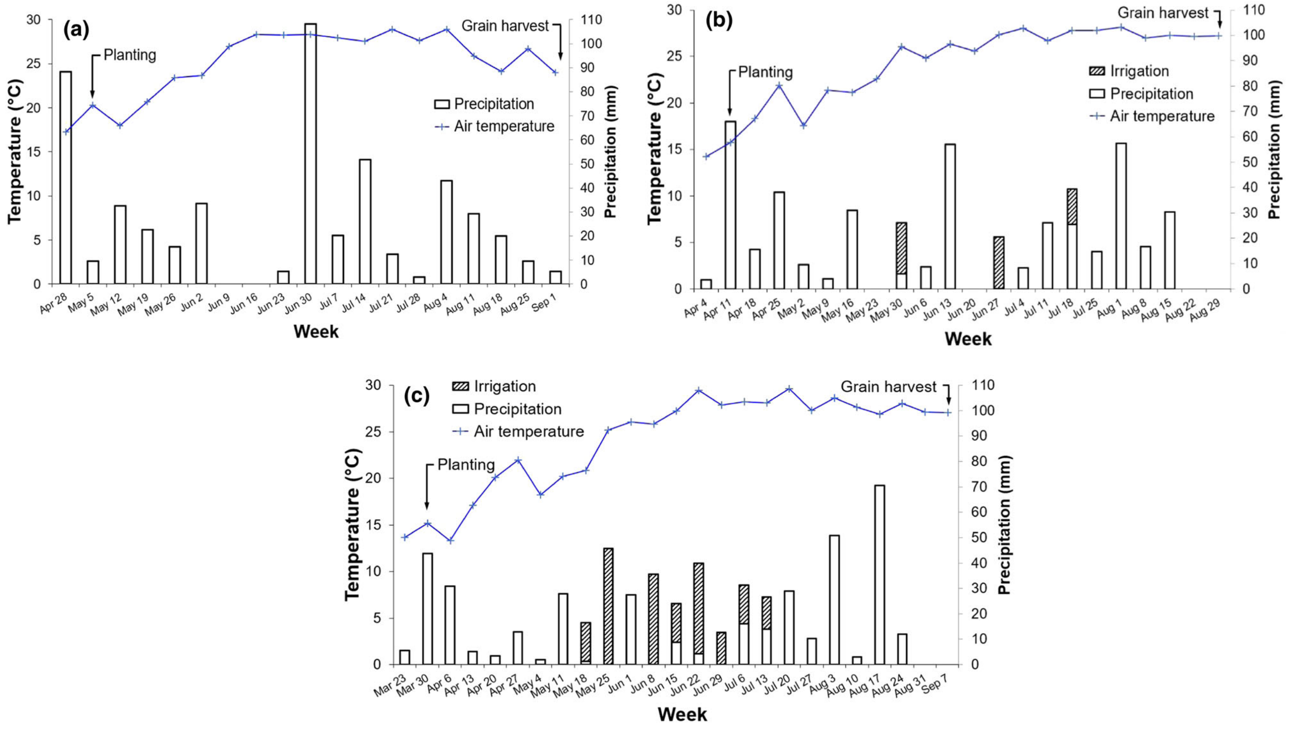

FIGURE 1 Weekly values of average air temperature, total precipitation, and total irrigation applied for (a) the Dale Bumpers Small Farms Research Center, (b) the E.V. Smith Research Center, and (c) the Tennessee Valley Research and Extension Center sites. While irrigation dates and amounts are not shown in (a), the total irrigation applied for this site was 101.6 mm

Webster (1999). Nitrogen was measured by combustion (LECO CN-2000) and crude protein (CP) was calculated by multiplying N by 6.25. Soluble protein (SP) was determined by the Borate–Phosphate procedure as detailed in N fractions in selected feedstuffs (Krishnamoorthy, Muscato, Sniffen, & Van Soest, 1982). Crude fat in corn grain was measured in accordance with Association of Official Analytical Chemists (2003.05; 2006). Unsaturated fatty acids were quantified in forage biomass as an ether extract by the same laboratory according to Sukhija and Palmquist (1988). Total ash was determined based on the ASTM standard E1755-01 (Sluiter et al., 2005). Grain and forage pH were determined by titrating with 0.1 M NaOH to a pH of 6.5 with a Mettler DL12 Titrator (Mettler). Finally, total minerals (P, K, Ca, S, and Mg) were analyzed by inductively coupled plasma-optical emission spectroscopy (ICP-OES) on an Agilent 5110 ICP-OES (Agilent Technologies).

2.5 | Analysis of data and model development

Analysis of variance (ANOVA) tests of corn yields (grain and forage), as well as quality traits were performed using the MIXED procedure of SAS (SAS V9.3; SAS Institute). In this model, irrigation (whole plot) and soil amendment (split block) were considered fixed effects whereas, block and location were considered random effects. When main effects or interactions were found, mean separations were performed using the SAS macro pdmix800 (Saxton, 1998) with Fisher's least significant difference (LSD) at a Type I error rate of 5% (SAS, 2007).

An additional model was run for leaf greenness and plant height data collected 30, 60, and 90 DAP. In this model, fixed and random effects were handled as mentioned above, although sampling date was considered a repeated measure. For the repeated measure, an autoregressive covariance was used and the denominator degrees of freedom for the Type III *F* test were adjusted with the Kenward–Roger method (Gomez, Schaalje, & Fellingham, 2005). The –2 Log Likelihood changed under the repeated-measure analysis (dropped by at least 5 per covariance parameter) and the autoregressive correlation value (0.24) indicated a strong correlation among observations; thus, the autoregressive covariance was used.

3 | RESULTS AND DISCUSSION

3.1 | Soil characterization

All tested soil extractable nutrients varied across locations and irrigation treatments ($P \leq .05$). Specifically, prior to soil amendment applications, the Dale Bumpers Small Farms

TABLE 1 Mehlich 1 soil extractable nutrients measured with inductively coupled plasma (ICP), and pH (based on 1:1 [soil/water ratio]). Baseline (prior to soil amendment application) results at three sites

Location	Soil physicochemical properties	Ca	K	Mg	P	Al	B	Cu	Fe	Mn	Na	Zn	OM[a]	pH
		mg kg^{-1}												
Typic Fragiudults														
Dale Bumpers Small Farms Research Center	IR[b]	1164.7b[c]	31.5d	57.1c	3.9c	121.8c	0.322b	0.715b	99.9a	119.7c	46.1a	1.3b	22400a	6.2b
	NIR	1320.4a	63.2bc	54.2c	6.7c	127.0c	0.279bc	0.669b	57.3b	115.1c	24.5b	1.0b	23400a	6.5a
Typic Kanhapludults														
E.V. Smith Research Center	IR	333.5c	81.1b	61.0bc	13.9b	114.5c	0.135d	0.271b	12.6c	53.8d	19.0bc	1.3b	8300c	5.6c
	NIR	326.2c	36.4cd	59.3c	19.7b	124.1c	0.187cd	1.754a	17.1c	19.0 e	17.0c	6.9a	11600c	6.2b
Rhodic Paleudults														
Tennessee Valley Research and Extension Center	IR	1329.1a	133.0a	73.2a	18.0b	245.7b	0.682a	0.681b	10.8c	164.5b	23.4bc	2.9ab	16600b	6.0b
	NIR	1252.4ab	112.7a	70.3ab	27.6a	308.6a	0.592a	0.702 b	11.8c	264.9a	24.8 b	3.1ab	20900a	5.8c

[a]OM = organic matter.

[b]IR = irrigated experiment, NIR = non-irrigated, or rainfed.

[c]Different letters indicate differences within a given analyte across locations at the $P \leq .05$ level.

Research Center had the lowest levels of P and K, but had the greatest SOM ($P \leq .05$). The E.V. Smith Research Center had the lowest levels of SOM, Ca, B, Mn, and Na (Table 1). Under both irrigated and non-irrigated treatments, the Tennessee Valley Research and Extension Center had the highest soil test levels of K, Mg, B, and Mn. Such variations within and among locations were likely due to prior management history and inherent soil characteristics.

3.2 | Growing-season leaf greenness based on poultry litter treatments

All fixed effects (irrigation, DAP, and soil amendments) affected leaf greenness, as did all two-way (irrigation × DAP, soil treatment × irrigation, and DAP × treatment) and three-way (irrigation × DAP × soil treatment) interactions ($P \leq .05$). As location did not significantly affect yield and quality variables, all data are presented across locations throughout this manuscript. Irrigated systems resulted in greater leaf greenness, as did the 60 DAP compared to other dates ($P \leq .05$). For the DAP × soil treatment interaction, greatest leaf greenness occurred for the 25-cm band distance and the inorganic-N treatment, which did not differ from the 38-cm band distance at 60 DAP (Figure 2). The lowest leaf greenness was observed for the control and the 38-cm band distance during 30 DAP (Figure 2). Root growth relative to the band placement may be the reason for the differences. Considering at 30 DAP, SPAD values decreased with increasing distance from the band, whereas at later stages, this trend was reversed (Figure 2).

Similarly, for plant heights, all fixed effects had treatment-induced changes, excluding that for soil treatments, and the two-way interaction of DAP × soil treatment ($P \leq .05$). Overall, plants were tallest during 90 DAP under irrigated treatments ($P \leq .05$). Surface applications of poultry litter had the greatest plant heights under irrigation, which was not different from any other soil treatment, excluding that of the control (0 kg N ha^{-1}; Figure 3). For rainfed corn, there were no differences in plant heights, but the 38-cm band distance and the control (no litter) had the lowest plant heights ($P \leq .05$); Figure 3).

3.3 | Yield impacts from alternative nutrient management

Forage yield was affected by soil amendment treatment and presence or lack of irrigation ($P \leq .05$), but not under soil amendment × irrigation ($P = .43$). Forage yields were greater (2.48 Mg ha^{-1}) under irrigation, compared to the rainfed system (2.22 Mg ha^{-1}). Overall, greatest yields were observed for the inorganic-N treatment under irrigated conditions (Figure 4). Among all subsurface banding treatments, the 13-cm distance tended to produce the greatest forage yields, although yields were not different among the three band distances or the surface litter application (Figure 4). Across all rainfed forage yields, there were no differences among the inorganic-N treat-

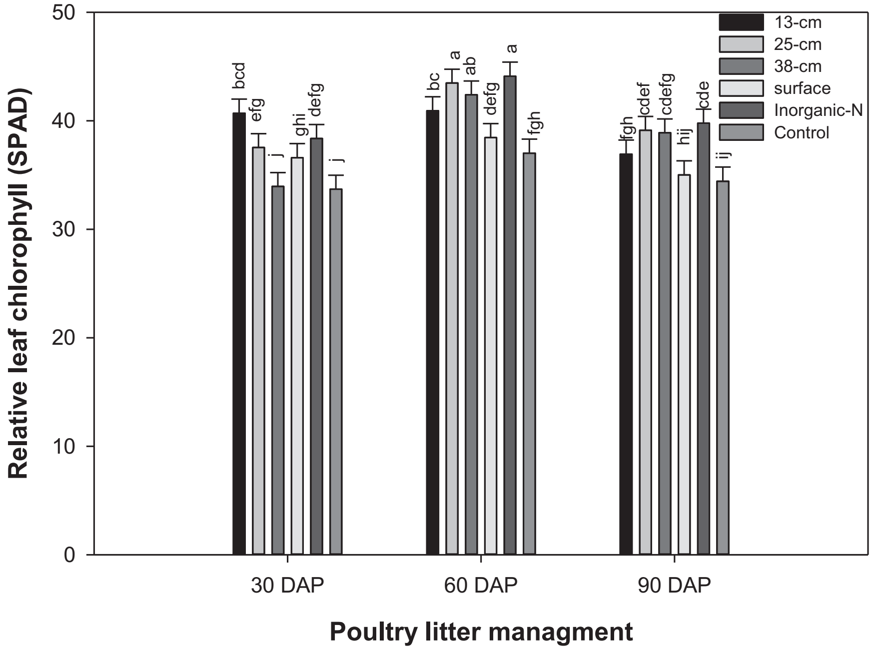

FIGURE 2 Corn leaf greenness per soil amendment treatments measured via a SPAD meter 30, 60, and 90 days after planting (DAP) at three sites (Dale Bumpers Small Farms Research Center, the E.V. Smith Research Center, and Tennessee Valley Research and Extension Center in Alabama) in 2016. Each error bar represents one standard error. Different letters indicate a significant difference by the LSD procedure for DAP × soil amendment treatment across locations and irrigation systems ($P \leq .0001$)

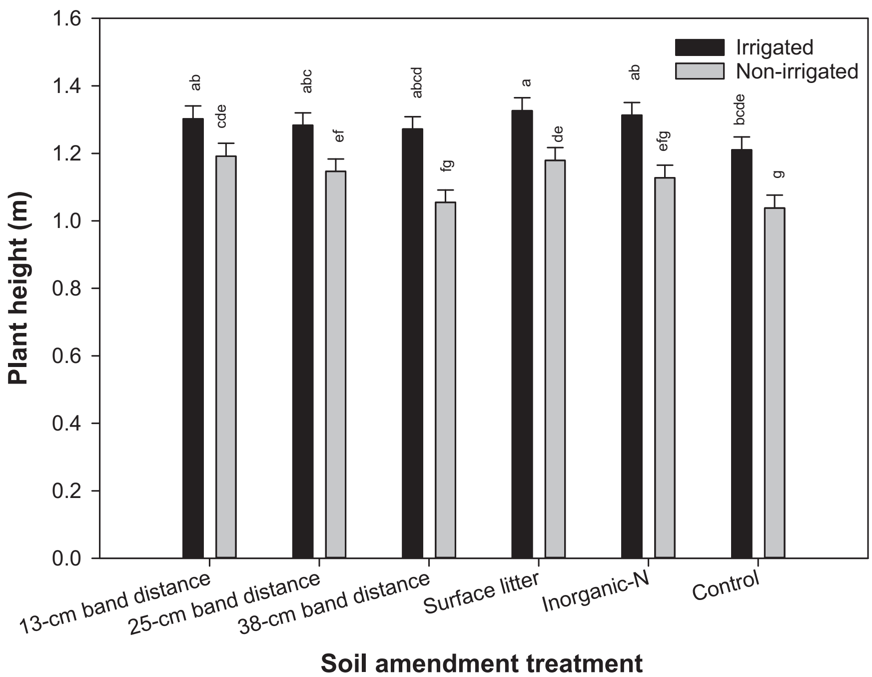

FIGURE 3 Plant heights per soil amendment treatments and irrigation systems (irrigated and non-irrigated) at three sites (Dale Bumpers Small Farms Research Center and the E.V. Smith Research Center and Tennessee Valley Research and Extension Center in Alabama) in 2016 during 30, 60, and 90 days after planting (DAP). Each error bar represents one standard error. Different letters indicate a significant difference by the LSD procedure for irrigation × soil amendment treatment across locations ($P = .0241$)

ment and the subsurface banding treatments. Several studies have found that subsurface litter incorporation has a strong tendency to improve forage yields relative to surface applications, likely because of reductions in ammonia volatilization (Pote et al., 2003; Pote et al., 2011; Burgess et al., 2000).

Similarly, grain yield was affected by soil amendment treatment and irrigation system ($P \leq .05$), but there was no interaction ($P = .06$). Overall, 56% greater yields were observed for irrigated treatments compared to non-irrigated. Across all soil amendment treatments, the 13-cm band distance resulted in the greatest numerical yield, but was not significantly greater than the 25-cm band distance or the inorganic surface application treatments (Figure 5). Specifically, 3.3, 39.4, and 82.7% greater yields were observed for the 13-cm band distance treatment compared to the inorganic N, surface poultry litter, and control (0 kg N ha^{-1}) treatments, respectively. Based on these data, subsurface applying poultry litter 13 cm from corn rows results in comparable grain yields to inorganic fertilizers. Future research is needed on the feasibility of the subsurface band application of litter to supply nutrients to row crops, such

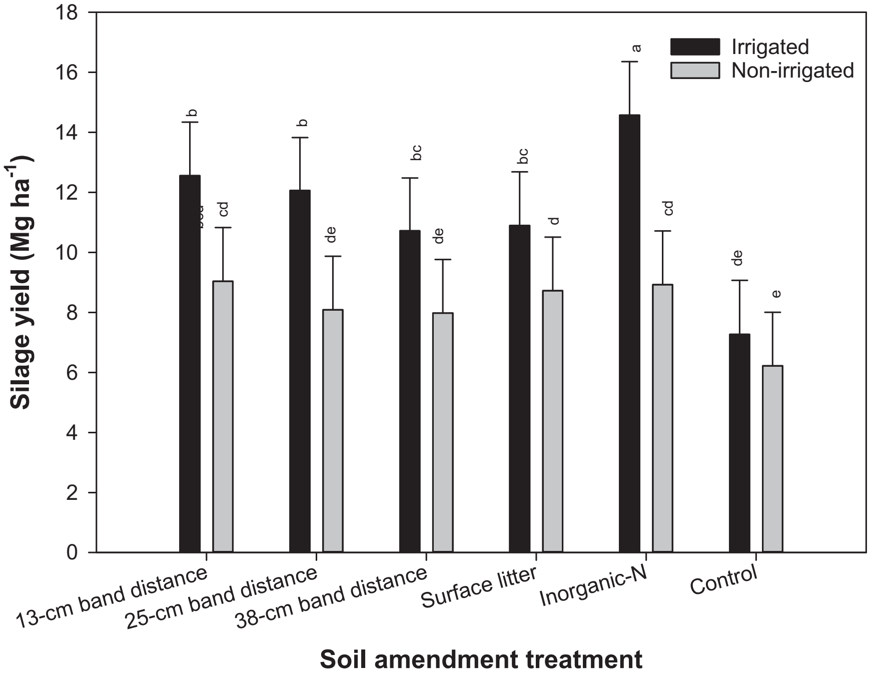

FIGURE 4 Corn forage yield per soil amendment treatment and irrigation systems (irrigated and non-irrigated) at three sites (Dale Bumpers Small Farms Research Center and the E.V. Smith Research Center and Tennessee Valley Research and Extension Center in Alabama) in 2016. Each error bar represents one standard error. Different letters indicate a significant difference by the LSD procedure for soil amendment treatments across locations ($P \leq .0001$)

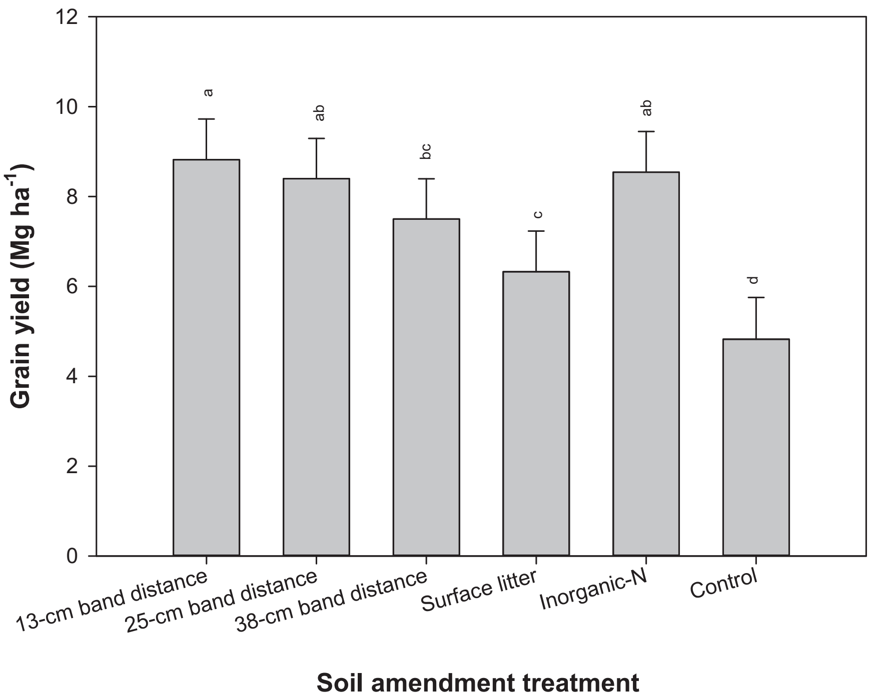

FIGURE 5 Corn grain yield per soil amendment treatment (averaged across irrigation treatment) across three sites (Dale Bumpers Small Farms Research Center, the E.V. Smith Research Center, and Tennessee Valley Research and Extension Center in Alabama) in 2016. Each error bar represents one standard error. Different letters indicate a significant difference by the LSD procedure for soil amendment treatments across locations ($P \leq .0001$)

as corn in a certified organic production system, and for crops with high P requirements, for example, soybean [*Glycine max* (L.) Merr.].

3.4 | Corn quality based on nutrient management

Overall, forage quality traits for CP, ADF, NDF, pH, fatty acids, and percent Ca, Mg, and S differed based on soil amendment treatment ($P \leq .05$; Table 2), whereas total P, K, lignin, ESC, starch, forage unsaturated fatty acids, and ESC did not ($P \leq .05$). Two-way interactions occurred for ESC and Mg, suggesting soil amendment and irrigation treatments interacted to affect these forage quality parameters. Overall, the inorganic-N treatment resulted in the greatest ($P \leq .05$) CP, Ca, Mg, S, and fatty acid levels, all of which are favorable forage traits suggesting the inorganic fertilizer resulted in better quality forage compared to subsurface banded

TABLE 2 Corn grain and forage quality per soil amendment treatment (averaged over irrigation treatments) across three sites (Dale Bumpers Small Farms Research Center, the E.V. Smith Research Center, and Tennessee Valley Research and Extension Center in Alabama) in 2016. Only significant quality parameters are presented

Soil amendment	Corn forage quality								
	CP[a]	ADF	NDF	Ash	Ca	Mg	S	Fatty acid	pH
	%								
13-cm band distance	6.45bc[b]	27.8ab	48.85ab	2.36ab	0.12b	0.12b	0.39ab	1.63bc	4.18b
25-cm band distance	6.6bc	26.57c	48.21bc	2.37a	0.12b	0.12b	0.37bc	1.63b	4.16b
38-cm band distance	6.82b	26.88bc	47.72bc	2.47a	0.13b	0.12ab	0.36bc	1.65b	4.18b
Surface litter	6.36bc	27.84ab	48.79ab	2.27ab	0.11b	0.12b	0.34bc	1.61bc	3.93b
Inorganic N	7.8a	26.68bc	47.13c	2.49a	0.14a	0.13a	0.43a	1.88a	4.72b
Control	6.03c	28.35a	49.75a	2.14b	0.11b	0.12b	0.33c	1.47c	3.8b
	Corn grain quality								
	CP	ADF	NDF	SP	CF	ESC	Ash	P	K
	%								
13-cm band distance	8.1b	4.02abc	9.87abc	1.51b	2.02abc	3.06bc	1.40abc	0.29ab	0.37abc
25-cm band distance	8.12b	3.88bc	9.56bc	1.51b	1.98cd	2.95cd	1.32c	0.28b	0.35cd
38-cm band distance	8.17b	4.0abc	9.76bc	1.54ab	1.99bcd	3.04bcd	1.37bc	0.28ab	0.36bcd
Surface litter	8.07b	4.11ab	10.07ab	1.56ab	2.09ab	3.1ab	1.44ab	0.29ab	0.37abc
Inorganic N	8.58a	3.78c	9.34c	1.60a	1.9d	2.91d	1.33c	0.28b	0.35d
Control	8.02b	4.23a	10.37a	1.56ab	2.1a	3.22a	1.48a	0.30a	0.38a

[a]CP = crude protein, ADF = acid detergent fiber, NDF = neutral detergent fiber.

[b]Per forage and grain quality section, different letters indicate a significant difference by the LSD procedure within a quality parameter and across locations ($P \leq .05$).

litter applications (Table 2). However, the 25-cm band distance had the lowest ADF, which indicates greater digestibility of the secondary cell wall for fodder. The control (0 kg N ha^{-1}) treatment had the lowest ash content and highest percent NDF, meaning less inorganic and non-digestible fractions for this treatment.

Grain quality traits (CP, ADF, SP, NDF, ESC, CF, K, P, and ash) were affected ($P \leq .05$; Table 2) by soil amendment treatments; however, lignin, pH, Mg, and Ca were not, so they are not reported in Table 2. In addition, no irrigation × soil amendment treatment interaction occurred for any grain quality parameter. The inorganic fertilizer treatment resulted in the highest CP, SP, and lowest ADF, indicating more favorable grain quality for animal growth and production (Table 2). Dissimilarly, this treatment resulted in some of the lowest CF, ESC, P, and K percentage, suggesting anti-quality traits for these parameters, and reduced suitability for feedstock and fodder use under the inorganic-N treatment. Neutral detergent fiber, crude fiber, and grain P and K fractions were all favorable for the 13-cm band distance treatment. Therefore, based on yield and quality characteristics, planting corn 13-cm from subsurface banded poultry litter is comparable and, in some cases, superior relative to inorganic fertilizer for grain and forage production. However, future research is needed on the economic feasibility of this conservation practice.

4 | SUMMARY

Subsurface banded poultry litter has proven to reduce the transport of nutrients from fields, relative to surface applications of poultry litter and inorganic fertilizers, particularly in pasture systems. However, little research has been done to identify subsurface yield and feedstock quality effects, particularly for row crop production. Chlorophyll results indicated inorganic fertilizer and subsurface band application of litter 25 cm to the side of the corn row resulted in the greatest leaf greenness, which was not different from the 13-cm band distance. Overall, greatest forage yields were observed for the inorganic-N treatment under irrigated conditions. Although, across all rainfed forage yields, there were no differences among the inorganic-N treatment and the subsurface banded poultry litter treatments. The 13-cm band distance resulted in greatest grain yield, which was not different from the inorganic-N treatment. Specifically, 3.3, 39.4, and 82.7% greater seed yields were observed for the 13-cm band distance treatment compared to the inorganic N, surface poultry litter, and 0 kg N ha^{-1} treatments, respectively. Grain neutral detergent fiber, crude fiber, and P and K fractions were all favorable for the 13-cm band distance treatment. Therefore, based on yield and quality characteristics, planting corn 13 cm from subsurface banded poultry litter is comparable and, in some cases, superior to inorganic fertilizers for grain and forage production. Adoption of subsurface banding poultry litter relative to surface applications of poultry litter and inorganic fertilizers would enhance soil and water conservation while improving nutrient cycling and sustaining crop production.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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