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ARTICLE

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Integration of poultry litter and mineral nitrogen on growth and yield of winter canola

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Abstract

Canola (*Brassica napins* L.) has the potential to be used as a winter crop in the southeastern United States, but little is known about its nitrogen management when grown in this region. Increasing fertilizer costs have increased interest in using poultry litter (PL) as an alternative nutrient source for crops in this region. However, evaluation of the use of PL on canola growth and yield is lacking. Thus, a field study was conducted at Shorter, AL (loamy sand soil) and Prattville, AL (fine sandy loam soil) using a randomized complete block design with four replications. Fertility treatments consisted of an unfertilized control (P_0U_0), commercial fertilizer N (urea, 180 kg N ha^{-1}, P_0U_{180}), PL at 68 kg N ha^{-1} with 112 kg N ha^{-1} urea ($P_{68}U_{112}$), PL at 112 kg N ha^{-1} with 68 kg N ha^{-1} urea ($P_{112}U_{68}$), and PL at 180 kg N ha^{-1} ($P_{180}U_0$). Overall, the combination of PL and urea application significantly increased canola growth (plant height and aboveground biomass) and elevated grain yield compared with PL application alone or with the control. The $P_{68}U_{112}$ treatment resulted in an equivalent aboveground biomass, grain yield, and N uptake compared with the recommended urea treatment. This study suggests that a combination of PL and commercial fertilizer N could provide sustainable canola yield production in the southeastern United States.

1 | INTRODUCTION

Canola (*Brassica napins* L.) production has increased rapidly over the past two decades, rising to the second largest oil crop in the United States, with more than 2.16 million acres planted in 2017 (USDA-NASS, 2017). Most canola production in the United States is concentrated in the Northwest, where more than 80% of the total production occurs (USDA-NASS, 2017). Due to the demand and potential for increased profits, winter canola acreage has been expanding into southern states, such as Oklahoma, Alabama, South Carolina, Florida, and Georgia (Buntin et al., 2010; USDA-NASS, 2017).

Mild winters with adequate rainfall, the availability of local soybean oil processing facilities, and the potential for double cropping makes the southeastern United States a promising region for canola production. Interest in using canola as an alternative winter crop for wheat (*Triticum aestivum* L.) has increased in the southeastern region. Raymer, Auld, and Mahler (1990) indicated that winter canola could be used not only to reduce insect damage, break disease cycles, and decrease weed pressure that may occur with wheat but also could be a more profitable crop than wheat. In addition, rotating winter canola with winter wheat instead of continuously growing winter wheat can improve the marketability of the

Abbreviations: EVS, Alabama Agricultural Experiment Station's E.V. Smith Research Center-Field Crops Unit; PAU, Prattville Agricultural Research Unit; PL, poultry litter; SPAD, Soil Plant Analysis Development.

wheat because of improved consistency and quality of wheat after a canola rotation (Boyles, Peeper, & Medlin, 2004). Bishnoi, Kumar, Cebert, and Mentreddy (2007) set up a series of field experiments to evaluate the agronomic performance of winter canola in the southeastern United States and found that canola planted in early October with a seeding rate of 6.0 kg ha^{-1} and receiving 180 kg N ha^{-1} gave the highest seed yield in this region. Similarly, Zheljazkov, Vick, Ebelhar, Buehring, and Astatkie (2013) showed that increasing N rates (0–180 kg N ha^{-1}) resulted in greater seed yield and oil content and suggested that winter canola could be successfully planted in the hot and humid environment of the southeastern United States to produce seed and oil yields comparable to those in major canola production areas. However, canola research in the southeastern region has been limited, and most fertility studies to date have focused on seed and oil yield response to commercial fertilizer applications (Bishnoi et al., 2007; Porter, 1993; Raymer et al., 1990; Usherwood, 1993; Zheljazkov et al., 2013). In addition, overapplication of commercial fertilizer increases input costs and leads to environmental problems, such as water pollution and soil degradation (Baumhardt, Stewart, & Sainju, 2015; Bennett, Carpenter, & Caraco, 2001).

Large quantities of poultry litter (PL) are produced in the United States; ∼12.8 million t were produced in 2015 (1.5 kg litter/broiler) (Mitchell & Tu, 2005; USDA-NASS 2015). More than two-thirds of this production occurred in the southeastern region (Alabama, Arkansas, Georgia, Mississippi, and North Carolina). Poultry litter is a good source of organic nutrients, containing both macro- and micronutrients, and its application can increase soil organic matter (Watts, Torbert, Prior, & Huluka, 2010), thereby improving soil quality and productivity (Kingery, Wood, Delaney, Williams, & Mullins, 1994). Numerous studies have shown that PL is an effective alternative to commercial fertilizer and may produce yields equivalent to or greater than those of commercial fertilizer sources (Hirzel, Matus, Novoa, & Walter, 2007; Mitchell & Tu, 2005; Reddy, Nyakatawa, & Reeves, 2004; Tewolde, Adeli, Sistani, Rowe, & Johnson, 2010; Tewolde, Shankle, Adeli, Sistani, & Rowe, 2009; Watts & Torbert, 2011; Wiatrak, Wright, & Marois, 2004). For instance, Watts and Torbert (2011) reported that the yield of soybean [*Glycine max* (L.) Merr.] and corn (*Zea mays* L.) was increased with PL application in 8 out of 9 yr and 3 out of 9 yr, respectively, when compared to commercial fertilizer applied at the same total N rate. In a rate study, Tewolde et al. (2010) indicated that cotton (*Gossypium hirsutum* L.) fertilized with broiler litter had lower tissue N concentration and lower chlorophyll index but had leaf area index and yields comparable to cotton fertilized with ammonium nitrate. However, the use of PL alone may not always meet the plant nutrient requirements (primarily N) due to slow mineralization of the organic forms of nutrients (nutrient mineralization rate is temperature dependent), especially during winter months. For example, 10–60% of the total litter N is in the ammonium form of N, which is readily available for plant uptake (Chadwick, John, Pain, Chambers, & Williams, 2000; Collins et al., 1999). The organic fraction of litter N, which may constitute 40–90% of the total litter N, is in the form of proteins, nucleic acids, and other organic compounds derived from plant or animal tissues (Chadwick et al., 2000; Collins et al., 1999) and becomes available only after mineralization via soil microbial activity (Ma, Dwyer, & Gregorich, 1999). In reviewing 90 independent studies, Lin, Watts, van Santen, and Cao (2018) reported that PL did not always increase crop yield when compared to commercial fertilizer when applied at the same total N rate during the first year of application, whereas combining PL and commercial fertilizer resulted in an 18% increase in crop yield when compared with commercial fertilizer application alone. According to Adeli, Sistani, Rowe, and Tewolde (2007), application of 4.5 Mg ha^{-1} PL supplemented with 67 kg N ha^{-1} commercial fertilizer N increased cotton lint yield as compared to PL at 6.7 Mg ha^{-1} and commercial fertilizer (urea-ammonium nitrate at recommended N rate) alone during a 3-yr field study. Another field study conducted in the southeastern United States showed that a single PL application did not improve wheat or soybean production, whereas adding both PL and commercial fertilizer N increased winter wheat yield (PL and commercial fertilizer N were applied at the same total N rate), and the residual effects enhanced double cropped soybean productivity (Lin, Watts, Torbert, & Howe, 2019). Increased grain yield, dry matter production, and nutrient uptake was also observed with corn when the application of PL and commercial fertilizer N and P were combined (Fallah, Ghalavand, & Raiesi, 2013). Integration of PL and commercial fertilizer N may be an efficient nutrient management practice for crop productivity instead of applying PL or commercial fertilizer alone.

Several studies have been conducted to evaluate the response of canola from application of cattle manure (Hao, Chang, & Travis, 2004; Lupwayi, Benke, Hao, O'Donovan, & Clayton, 2014), hog manure (Katanda, Zvomuya, Flaten, & Cicek, 2016; Lafond, 2004), and swine manure (Qian & Schoenau, 2000). For instance, Stevenson, Johnston, Beckie,

Core Ideas

- Applying poultry litter and commercial fertilizer N may improve canola yield.
- Applying poultry litter and commercial fertilizer N may improve biomass production and N uptake.
- Applying poultry litter alone was less effective than applying only commercial fertilizer.

Brandt, and Townley-Smith (1998) reported that application of cattle manure had 22% lower grain yield and slightly lower grain N concentration and residue (straw and chaff) yield for canola in a 3-yr field study when applied at the same available N rate as commercial fertilizer N. In contrast, the use of broiler litter at the rate of 9.0 or 13.5 Mg ha^{-1} as a nutrient source resulted in increased grain yield of canola under a double-cropping system (Gascho et al., 2001) when poultry litter was used alone. However, little research has focused on PL or the combination of PL with commercial fertilizer on canola productivity. As the demand for edible oil and biodiesel from canola continues to expand, balances between fertilizer applications and sustaining the environment, increasing grain yield of canola with optimal field management, have become urgent issues for farmers and researchers. Thus, the objectives of this study were to evaluate the effects of PL and urea applications on canola growth and grain yield and to determine the best N fertilizer management for canola production in the southeastern United States.

TABLE 1 Initial soil for the Alabama Agricultural Experiment Station's E. V. Smith Research Center (EVS) and Prattville Agricultural Research Unit (PAU) and poultry litter properties on a dry-weight basis

Property[a]	EVS Loamy sand	PAU Sandy loam	Poultry litter
pH (1:1 soil/water)	6.7	5.5	–
Moisture content, g kg^{-1}	–	–	221
Total C, g kg^{-1}	3.8	8.9	292
Total N, g kg^{-1}	0.50	1.00	24.4
C/N ratio	7.6	8.9	12.0
P, g kg^{-1}	0.02	0.02	15.0
K, g kg^{-1}	0.06	0.10	25.2
Ca, g kg^{-1}	0.35	0.35	31.3
Mg, g kg^{-1}	0.08	0.06	6.4
Na, g kg^{-1}	0.03	0.03	10.4
Cu, mg kg^{-1}	1.36	0.99	212
Fe, mg kg^{-1}	7.9	11.7	1381
Mn, mg kg^{-1}	7.8	59.8	411
Zn, mg kg^{-1}	2.9	1.9	443

[a]Values for P, K, Ca, Mg, Na, Cu, Fe, Mn, and Zn represent Mehlich-1 extractable nutrient concentrations for soil and total nutrient concentrations for poultry litter.

2 | MATERIALS AND METHODS

2.1 | Site description

A field experiment was initiated during the winter of 2016 at Alabama Agricultural Experiment Station's E.V. Smith Research Center-Field Crops Unit (EVS) in Macon County, near Shorter, AL (32°26′ N lat, 85°52′ W long), and Prattville Agricultural Research Unit (PAU) in Autauga County, near Prattville, AL (32°25′ N lat, 86°26′ W long). These locations are separated by ∼77 km. The climate at both locations is humid subtropical, with a mean annual precipitation of ∼1350 mm and a mean annual temperature of 18 °C (Current Results, 2017). The soil at EVS is a Compass loamy sand (coarse-loamy, siliceous, subactive, thermic Plinthic Paleudult) and the soil at PAU is a Lucedale fine sandy loam (fine-loamy, siliceous, subactive, thermic Rhodic Paleudult). Both of these soil series are from soil types that are typically found in the Southern Coastal Plain physiographic region. The Compass series consists of very deep, moderately well drained, moderately slowly permeable soils located on broad uplands and sloping side slopes that lead to drainage ways. The Lucedale series consists of deep, well-drained, moderately permeable soils that form in loamy sediments. These soils range from nearly level to strongly sloping. The initial soil properties are shown in Table 1. Before the study was initiated in 2016, both sites had been managed under intensive row crop production.

Topsoil samples (0–15 cm) were collected from both sites for initial soil analysis. Analyses for initial soil properties were performed by the Auburn University Soil Testing Laboratory as described by Hue and Evans (1986). Briefly, total C and N were determined by dry combustion using a CN LECO 2000 analyzer (LECO Corp.). Soil pH was determined using 1:1 soil/water suspensions with a glass electrode pH meter. Phosphorus, K, Mg, and Ca were determined using a Mehlich 1 (double acid) extracting solution (Olsen & Sommers, 1982) and measured by inductively coupled Ar plasma emission spectrometry (Soltanpour, Jones, & Workman, 1982) using the ICAP 9000 (Thermo Jarrell Ash).

2.2 | Experimental design and treatments

This study was conducted as a randomized complete block design with five treatments and four replicate blocks laid out based on landscape position. Prior to laying out the plots at both locations, the experimental sites were prepared by disking (John Deere 210 Disk Harrow, Deere and Co.), field cultivating (KMC Field cultivator; Kelly Manufacturing Co.), and rotovating (Lely roterra; Lely Holdings). Each plot was 3.66 × 7.62 m with a 1.22-m buffer separating each plot within a block. There was a 6.10-m buffer separation between the blocks. Fertility treatments were imposed consisting of an unfertilized control (P_0U_0), urea (46% N) as commercial fertilizer N (180 kg ha^{-1}, P_0U_{180}), PL at a rate of 68 kg total N ha^{-1} with 112 kg ha^{-1} commercial fertilizer N ($P_{68}U_{112}$), PL at a rate of 112 kg total N ha^{-1} with 68 kg commercial fertilizer N ha^{-1} ($P_{112}U_{68}$), and PL at a rate of 180 kg total N ha^{-1} ($P_{180}U_0$).

2.3 | Cultural practices

Canola (Inspiration, Rubisco Seeds LLC) was seeded to a depth of 0.6 cm at a rate of 5.6 kg ha^{-1} using a no-till grain drill (Great Plains 1205NT Drill, Great Plains Manufacturing) with 19-cm row spacing in late October at both EVS and PAU. Poultry litter was applied at sowing, and the urea was applied in split applications according to Alabama Cooperative Extension recommendations as follows. For the P_0U_{180} treatment, 45 kg N ha^{-1} urea was applied at sowing, 45 kg N ha^{-1} urea was applied on 1 Mar. 2017, and 90 kg N ha^{-1} urea was applied on 1 Apr. 2017. For the $P_{68}U_{112}$ treatment, half of the urea (56 kg N ha^{-1}) was applied on 1 Mar. 2017 and the other half applied on 1 Apr. 2017. For the $P_{112}U_{68}$ treatment, all of the urea (68 kg N ha^{-1}) was applied on 1 Apr. 2017. Triple superphosphate (0-46-0) and KCl (0-0-60) were applied to the P_0N_0 and P_0N_{180} treatments at the time of sowing based on Auburn University's Soil Testing Laboratory's recommendations (Mitchell & Huluka, 2012). No triple superphosphate or KCl was needed for plots receiving PL. Flue gas desulfurization gypsum ($CaSO_4 \cdot 2H_2O$; 19% S) was applied to all plots as the sulfur source in split applications; half at the time of sowing and the other half on 1 Mar. 2017. Boron fertilizer was applied at 1.2 kg B ha^{-1} at flowering. The Alabama Cooperative Extension System recommends split applications for urea to improve N recovery by plants and to minimize leaching loss. Given that the N in poultry litter has to be mineralized, it is recommended to apply poultry litter at planting. The PL for this study was procured from a local broiler farm and consisted of manure and bedding material (wood shavings). Properties of the PL used in this study are shown in Table 1. The flue gas desulfurization gypsum was collected from a local coal-fired electric utility plant. Both the urea fertilizer and the PL were surface broadcast applied by hand. Weeds were controlled by spraying herbicides as needed according to Alabama Cooperative Extension System's recommendations at both locations.

2.4 | Measurements

Growth measurements were taken during the growing season. Ten plants were arbitrarily selected within each plot for determining plant height and leaf greenness (Soil Plant Analysis Development readings) before urea application (1 Mar. and 1 Apr. 2017). At the beginning of the seed ripening stage, another 10 plants were arbitrarily collected within each plot to determine plant height, leaf greenness, biomass, and N concentration. Plant height was determined by measuring from the ground to the highest growing point of the main stem. Leaf greenness was determined using a Minolta SPAD meter (Minolta Co., Ltd.). Leaf greenness readings were taken from the uppermost fully developed leaf's adaxial side. To determine total aboveground biomass, plants were cut with pruning clippers 5 cm above the soil surface (1-m border from the edge of the plot), and then total fresh weight was recorded in the field using a digital hanging scale. Plants were then coarsely ground using a chipper shredder (Cub Cadet). Subsamples of the ground plant material were collected in cloth bags and brought back to the laboratory for moisture determination. The subsamples were dried in a forced-air drying oven for ∼5 d at 55 °C until weight was constant. Once >50% of the silique turned brown (during the beginning of June), the canola leaves were defoliated using Gramoxone. One week later, grain yield was determined by harvesting the entire length of the center in each plot using an ALMACO SPC 40 plot combine at EVS and a Massey Ferguson 8XP plot combine at PAU (both had a 127-cm header width). The harvested grain reported for this study was adjusted to a moisture content of 10%. Total N concentration was determined on the plant tissue and seed samples. The samples were ground to pass through a 0.2-mm mesh sieve prior to N analysis. Total N was determined by the combustion method using an FP-528 Nitrogen/Protein Analyzer (LECO Corp.).

2.5 | Statistical analysis

Data for this study were analyzed using the MIXED procedure of SAS 9.4 (SAS Institute Inc., 2013), where fertilization treatments were analyzed as fixed effects and replication and locations were considered random effects as appropriate. Means separation was conducted using the LSMEANS statement in PROC MIXED, and the Tukey's HSD test at the .05 probability level was used to identify significant differences among treatments. Significant interactions ($P \leq .05$) were observed between the two study locations; thus, treatment means for each location are present separately for each time.

3 | RESULTS AND DISCUSSION

3.1 | Weather conditions

Weather conditions for the two locations of this study are presented in Figure 1. Mean growing season air temperatures were 17.9 and 19.7 °C for 2017 at EVS and PAU, respectively. Monthly temperatures for the growing seasons were normal and did not deviate more than 2–3 °C from the 30-yr average during the course of this study. Rainfall data collected from EVS showed totals of 1026 mm, with 608 mm occurring during the growing season (November to the beginning of June); data from PAU showed totals of 1232 mm, with 779 mm occurring during the growing season in 2016–2017. Rainfall occurring during the germination period was

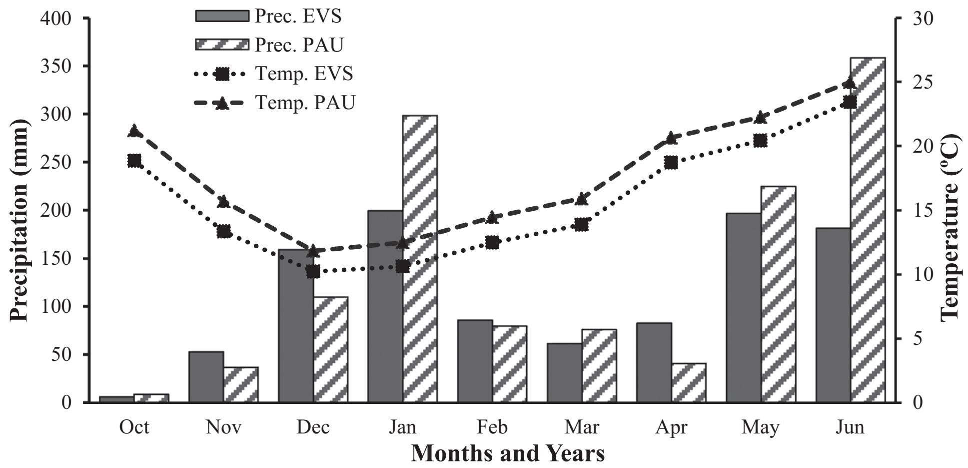

FIGURE 1 Monthly average air temperature and precipitation totals at the Alabama Agricultural Experiment Station's E. V. Smith Research Center (EVS) and Prattville Agricultural Research Unit (PAU) for October 2016 to June 2017

very low, with 5.8 and 8.6 mm of rain occurring at EVS and PAU, respectively. As a result, irrigation water was supplied the first week after seeding at a rate of 12 mm d^{-1} to promote germination. Although both locations had comparatively similar weather conditions, PAU had higher mean air temperature throughout the year and greater rainfall for the months of January through June in 2017.

3.2 | Canola growth and biomass accumulation

Canola plant height responded positively to N fertilization (Table 2) when compared to the control (no N fertilization, P_0U_0) at T1 (rosette stage, the end of February). The urea-only treatment produced significantly taller plants than the control (at EVS and PAU) and during all of the growth stages evaluated. However, differences between the urea-only and PL-only treatments were observed at T2 (flowering stage). The PL-only treatment produced significantly taller plants than the PL-with-urea treatments ($P_{68}U_{112}$ at EVS and $P_{68}U_{112}$ and $P_{112}U_{68}$ at PAU) and the unfertilized control at the rosette stage (T1, the end of February). Once the canola plants reached flowering (T2, the end of March) and seed-fill stage (T3, the end of April), the increase in plant height from the PL-only treatment observed during the rosette stage was no longer evident as compared to the other N fertilization treatments. Significantly shorter plants were observed with the PL-only application when compared to urea only or PL with urea at PAU during the seed-fill stage (T3). In contrast, combining PL with urea applications, except the $P_{68}U_{112}$, did not produce taller plants at the T1 and T2 vegetative growth stages but increased plant height 7.5 and 24.6% by the time it reached the seed-fill stage (T3) when compared to the unfertilized control at EVS and PAU, respectively. This may be due to the slow mineralization of litter N not being able to satisfy the high requirement of N needed during the reproductive stages, whereas the urea N was more readily available to improve plant growth during these growing periods. Results from this study are consistent with those observed by Lin et al. (2019), who evaluated the use of PL as a nutrient source for wheat production. They observed that, overall, combining PL with urea N produced plant heights comparable to that of urea alone. Similar to findings of this study, Lin et al. (2019) reported that 90 kg N ha^{-1} PL with 45 kg N ha^{-1} urea N did not result in taller wheat plants at the tillering stage when compared to applying only the recommended fertilizer N rate (135 kg N ha^{-1}). However, 90 kg N ha^{-1} PL with 45 kg N ha^{-1} urea N increased plant height at the late stem extension and late heading stages, whereas the single PL application had taller plants only at the tiller stage when compared to the recommended fertilizer N rate (Lin et al., 2019).

Chlorophyll concentration (SPAD readings) was minimally affected by PL or urea applications relative to the unfertilized control at the various growth stages (Table 2). The only significant effect on leaf greenness was observed at EVS during the rosette stage (T1) with the no N application control, which had a greater leaf greenness compared with the PL alone ($P_{180}U_0$) and the 112 kg N ha^{-1} PL with 68 kg N ha^{-1} urea ($P_{112}U_{68}$) treatments. Likewise, the addition of both PL and urea (both $P_{68}U_{112}$ and $P_{112}U_{68}$) seemed to have a relatively greater leaf greenness than the other treatments, albeit not significant, especially at the PAU location.

Chlorophyll concentration (SPAD readings) reflects the accumulation of N in plant leaves and may be related to N uptake. Our results were inconsistent with the study by Tewolde et al. (2010), which reported that PL resulted in much lower leaf chlorophyll index than fertilizer N when applied at the same total N rate during the cotton growth

TABLE 2 Plant height and SPAD readings measured at various growth stages as influenced by fertilizer sources at the Alabama Agricultural Experiment Station's E. V. Smith Research Center (EVS) and Prattville Agricultural Research Unit (PAU)

Site	Fertilizer treatment[a]	Plant height			SPAD readings	
		T1[b]	T2	T3	T1	T2
		cm				
EVS	P_0U_{180}	21.0 ± 0.96A[c]	79.0 ± 1.93A	135 ± 1.87A	54.6 ± 1.02AB	51.5 ± 1.60A
	$P_{180}U_0$	20.5 ± 1.03A	64.2 ± 2.00BC	128 ± 2.24AB	53.8 ± 1.03B	53.6 ± 0.92A
	$P_{112}U_{68}$	18.9 ± 0.87AB	67.0 ± 2.18B	128 ± 1.64AB	54.0 ± 1.13B	53.4 ± 1.02A
	$P_{68}U_{112}$	17.1 ± 0.91BC	70.0 ± 2.31B	135 ± 1.70A	57.8 ± 0.76AB	53.6 ± 1.04A
	P_0U_0	14.2 ± 0.79C	58.2 ± 2.56C	125 ± 2.07B	58.4 ± 0.92A	52.8 ± 1.25A
PAU	P_0U_{180}	19.4 ± 1.02ab	19.4 ± 0.75a	118.6 ± 1.86a	48.9 ± 0.94a	55.9 ± 0.83a
	$P_{180}U_0$	20.7 ± 1.06a	13.7 ± 0.59b	95.6 ± 3.07b	47.8 ± 0.83a	55.8 ± 1.04a
	$P_{112}U_{68}$	16.8 ± 1.13bc	11.1 ± 0.49bc	111.3 ± 1.82a	50.6 ± 1.00a	58.5 ± 0.86a
	$P_{68}U_{112}$	15.9 ± 1.00bc	18.1 ± 0.74a	118.2 ± 2.14a	55.4 ± 8.25a	57.6 ± 1.01a
	P_0U_0	13.1 ± 0.94c	10.8 ± 0.74c	94.9 ± 3.30b	52.0 ± 1.00a	58.2 ± 1.13a
		$P > F$ (.05)				
	EVS	<.001	<.001	.001	.021	.677
	PAU	<.001	<.001	<.001	.653	.148

[a]Fertilizer treatments consisted of an unfertilized control (P_0U_0), urea (46% N) as commercial fertilizer N (180 kg ha^{-1}, P_0U_{180}), poultry litter (PL) at a rate of 68 kg total N ha^{-1} with 112 kg ha^{-1} commercial fertilizer N ($P_{68}U_{112}$), PL at a rate of 112 kg total N ha^{-1} with 68 kg commercial fertilizer N ha^{-1} ($P_{112}U_{68}$), and PL at a rate of 180 kg total N ha^{-1} ($P_{180}U_0$).

[b]T1, 28 Feb.; T2, 30 Mar.; T3, 30 Apr. At T3, there were very few leaves left on the plants; thus, no SPAD readings are presented at this stage.

[c]Means and standard errors followed by the same letter or with no letter assignment within a column are not significantly different at $P < .05$. Uppercase letters show multiple comparisons of treatments at EVS; lowercase letters show multiple comparisons of treatments at PAU.

stages. They attributed their finding to N from the fertilizer being readily available at the time of application, whereas only a small percentage of PL-N was immediately available for plant uptake. Although N plays an important role in producing chlorophyll, growth parameters such as plant height, leaf numbers, and leaf area also influence the chlorophyll concentration by the dilution effect. For example, if two plants have the same chlorophyll content, the plant that is taller, has more leaves, or greater leaf area would have a lower chlorophyll concentration.

Nitrogen fertilization treatments at the EVS location had minimal influence on plant biomass (Table 3). Unlike EVS, at the PAU location, the N fertilization treatments had significant effects on plant biomass accumulation (Table 3). Plants receiving both 68 kg N ha^{-1} PL and 112 kg N ha^{-1} urea had significantly greater dry biomass, increasing 59.3% more than that with no N application at the PAU location. The urea N–only treatment significantly increased plant dry biomass when compared to the unfertilized control, with an increase of 55.6% at the PAU location (Table 3).

The increases in growth characteristics (e.g., plant height, leaf greenness) and plant biomass with the combined PL with urea application might be due to the role of mineral N (more available) from commercial fertilizer and macro- and micronutrients from PL in stimulating the vegetative growth. These results demonstrate that a combination of 68 kg N ha^{-1} PL and 112 kg N ha^{-1} urea could result in similar effects on canola growth as urea applied at 180 kg N ha^{-1}.

TABLE 3 Effect of poultry litter and urea application on biomass and grain yield of canola at the Alabama Agricultural Experiment Station's E. V. Smith Research Center (EVS) and Prattville Agricultural Research Unit (PAU)

Site	Fertilizer treatment[a]	Dry biomass	Grain yield
		kg	kg ha^{-1}
EVS	P_0U_{180}	0.63 ± 0.06A[b]	2234 ± 208A
	$P_{180}U_0$	0.53 ± 0.08A	1480 ± 269B
	$P_{112}U_{68}$	0.63 ± 0.09A	1830 ± 87.9AB
	$P_{68}U_{112}$	0.65 ± 0.12A	2287 ± 26.9A
	P_0U_0	0.49 ± 0.03A	1319 ± 111B
PAU	P_0U_{180}	0.42 ± 0.02a	2002 ± 285a
	$P_{180}U_0$	0.35 ± 0.05ab	1327 ± 97.7a
	$P_{112}U_{68}$	0.38 ± 0.04ab	1491 ± 31.8a
	$P_{68}U_{112}$	0.43 ± 0.05a	1637 ± 225a
	P_0U_0	0.27 ± 0.02b	366 ± 89.0b
		$P > F$ (.05)	
EVS		.490	.001
PAU		.025	.001

[a]Fertilizer treatments consisted of an unfertilized control (P_0U_0), urea (46% N) as commercial fertilizer N (180 kg ha^{-1}, P_0U_{180}), poultry litter (PL) at a rate of 68 kg total N ha^{-1} with 112 kg ha^{-1} commercial fertilizer N ($P_{68}U_{112}$), PL at a rate of 112 kg total N ha^{-1} with 68 kg commercial fertilizer N ha^{-1} ($P_{112}U_{68}$), and PL at a rate of 180 kg total N ha^{-1} ($P_{180}U_0$).

[b]Means and standard errors followed by the same letter or with no letter assignment within a column are not significantly different at $P < .05$. Uppercase letters show multiple comparisons of treatments at EVS; lowercase letters show multiple comparisons of treatments at PAU.

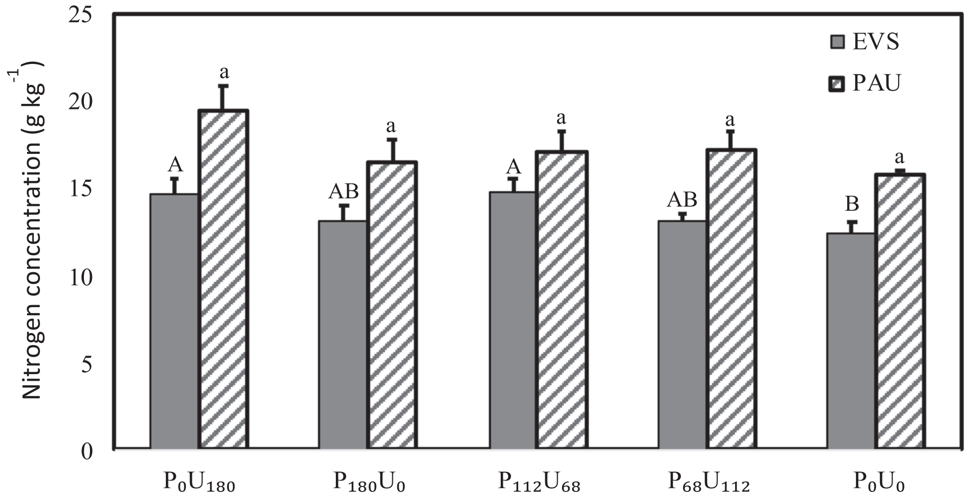

FIGURE 2 Nitrogen concentration of the plant biomass from the Alabama Agricultural Experiment Station's E. V. Smith Research Center (EVS) and Prattville Agricultural Research Unit (PAU). Data represent means and SE of replicates. Within each location, bar segments denoted by the same letter or with no letter assignment are not significantly different at $P < .05$. Fertilizer treatments consisted of an unfertilized control (P_0U_0), urea (46% N) as commercial fertilizer N (180 kg ha^{-1}, P_0U_{180}), poultry litter (PL) at a rate of 68 kg total N ha^{-1} with 112 kg ha^{-1} commercial fertilizer N ($P_{68}U_{112}$), PL at a rate of 112 kg total N ha^{-1} with 68 kg commercial fertilizer N ha^{-1} ($P_{112}U_{68}$), and PL at a rate of 180 kg total N ha^{-1} ($P_{180}U_0$).

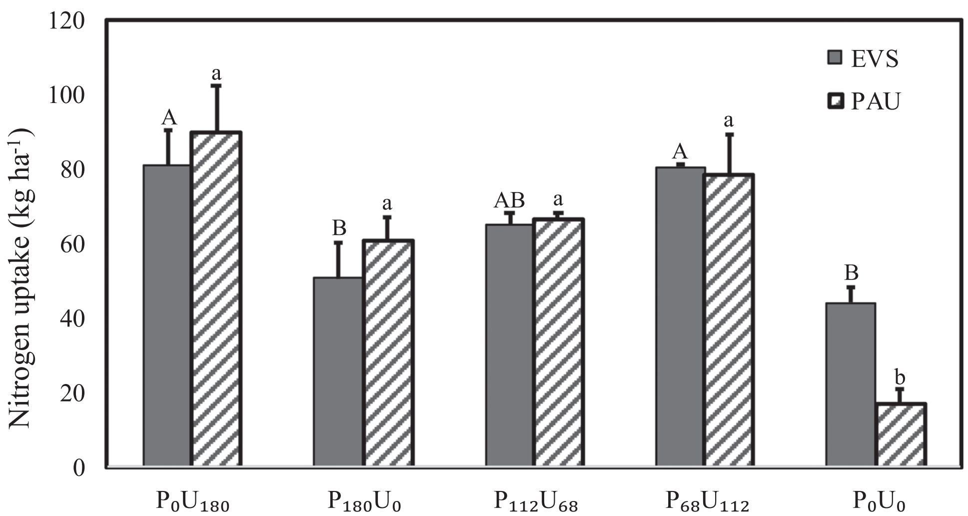

FIGURE 3 Nitrogen uptake of canola seeds from the Alabama Agricultural Experiment Station's E. V. Smith Research Center (EVS) and Prattville Agricultural Research Unit (PAU). Data represent means and SE of replicates. Within each location, bar segments denoted by the same letter or with no letter assignment are not significantly different at $P < .05$. Uppercase letters show multiple comparisons of treatments at EVS; lowercase letters show multiple comparisons of treatments at PAU. Fertilizer treatments consisted of an unfertilized control (P_0U_0), urea (46% N) as commercial fertilizer N (180 kg ha^{-1}, P_0U_{180}), poultry litter (PL) at a rate of 68 kg total N ha^{-1} with 112 kg ha^{-1} commercial fertilizer N ($P_{68}U_{112}$), PL at a rate of 112 kg total N ha^{-1} with 68 kg commercial fertilizer N ha^{-1} ($P_{112}U_{68}$), and PL at a rate of 180 kg total N ha^{-1} ($P_{180}U_0$).

3.3 | Grain yield

Application of N fertilizer significantly increased the grain yield of canola for all N sources at the PAU location (Table 3). A significant increase in grain yield was observed from plots receiving 68 kg N ha^{-1} PL with 112 kg N ha^{-1} urea and with the urea-only treatment applied at the recommended N rate when compared with the control at the EVS location (Table 3). In addition, the $P_{68}U_{112}$ treatment had the greatest grain yield, with an increase of 73.4% as compared to the unfertilized control (P_0U_0). The PL application treatment ($P_{180}U_0$) had significantly lower grain yield than the recommended fertilizer N application (P_0U_{180}) at the EVS location.

Stevenson et al. (1998) and Gao et al. (2010) reported that no significant differences were observed between manure and fertilizer N applications on grain yield of canola when both were applied at the same available N (available for plant uptake shortly after application) rate. The results for grain yield of canola in our study were consistent with these previous studies, although we applied the PL and fertilizer at the same total N rate. Moreover, Stevenson et al. (1998) reported that only when a high rate of manure (fresh and stockpiled cattle manure) was applied to canola did they observe similar grain yields to those of fertilizer application under no-till and conventional tillage systems. Combined applications of farmyard manure, compost, and fertilizer increased canola grain yield compared with a single fertilizer application (farmyard manure, compost, and commercial fertilizer) by an average of 59, 49, and 37%, respectively (Mohammadi & Rokhzadi, 2012). Using fertilizer N could provide available N immediately to the crop, whereas applying PL could provide other macro- and micronutrients for plant growth and a slow release of N over time. Moreover, PL application can improve soil physical and chemical properties, making suitable conditions for root development (Busari & Salako, 2015; Olatunji et al., 2012).

3.4 | Nitrogen concentration and uptake

Nitrogen concentration of the canola was measured for the aboveground plant samples and seeds (Figures 2 and 3). Nitrogen fertilization had no significant effect on plant N concentration at the PAU location ($P = .3065$) (Figure 2). A significant difference was observed for plant N concentration among N fertilization treatments at the EVS location ($P = .0186$) (Figure 2). Both treatments (the urea N treatment and the PL with 68 kg N ha^{-1} plus 112 kg N ha^{-1} urea treatment) significantly increased plant N concentration, with an increase of 18.8% for P_0U_{180} and 19.4% for $P_{68}U_{112}$, compared with the control N treatment at the EVS location.

The application of N fertilizer also significantly increased N uptake in canola seeds at both locations ($P = .0011$ for EVS and $P = .0008$ for PAU) (Figure 3). Addition of N fertilizer significantly increased N uptake of canola compared with the unfertilized control regardless of N sources at the PAU location (Figure 3). Application of 68 kg N ha^{-1} PL with 112 kg N ha^{-1} urea significantly increased the N uptake, with an increase of 82.0% when compared to the unfertilized control at the EVS location. The urea-only treatment was also significantly greater than that of the unfertilized control.

Greater plant N concentration and seed N uptake (significant only at the EVS location) was observed with application of both PL and urea together compared with the PL-only treatment ($P_{180}U_0$) and the unfertilized control (P_0U_0). This is mainly due to the application of PL along with fertilizer N providing higher available N at the time plants needed it most compared with a single application of PL. For example, Garrity and Flinn (1987) reported that adding both PL and fertilizer improved nutrient availability and soil conditions for plant growth by reducing the loss of nutrients, leading to greater yield. Moreover, the use of PL can enhance soil microbial enzyme activity and soil N availability for plants (Acosta-Martínez & Harmel, 2006; Mankolo, Reddy, Senwo, Nyakatawa, & Sajjala, 2012). In addition, the N concentration of a plant is relative to its biomass and grain yield. In this study, greater biomass and greater yield were observed in the P_0U_{180} and $P_{68}U_{112}$ treatments compared with the unfertilized control. Consistent with previous studies (Moe, Mg, Win, & Yamakawa, 2017; Naher, Fahim, & Wadud, 2016), these results indicate that a combination of PL and fertilizer N or fertilizer N alone can increase total N uptake. These results also indicate that applying PL alone to winter canola in the short term may not satisfy plant N requirements due to the slow mineralization of litter N, whereas a combination of PL and fertilizer N could supply sufficient N as well as other nutrients needed to optimize canola production.

4 | CONCLUSION

The fertility management strategy used for crop production can influence biomass production and yield. This study evaluated the influence of PL applied alone and in combination with fertilizer N compared with that of fertilizer N only. Compared with fertilizer N only, applying only PL did not consistently provide comparable plant growth or grain yield for winter canola in this study. Applying 68 kg N ha^{-1} PL with 112 kg N ha^{-1} urea resulted in improvement of plant growth and increased grain yield and N uptake from both the loamy sand (EVS) and sandy loam soils (PAU) compared with no N. Therefore, these results suggest that a combination of PL and fertilizer N could reduce the usage of chemical fertilizers without decreasing the yields of winter canola, thereby providing sustainable yield production for winter canola in the southeastern United States. However, the effect of canola on the following crop production is not clear. Future studies should be conducted to evaluate canola performance as a winter crop with PL application under double-cropping systems.

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