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Residual Benefits of Poultry Litter Applied by Subsurface Band vs. Surface Broadcast to Cotton

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Abstract: Poultry litter (PL) is known to have residual effects on crop productivity long after applications cease. Whether this advantage is greater if applied by subsurface vs. surface broadcast is unknown. The objective of this study was to determine whether the residual benefit of PL to corn and cotton production is greater if applied in subsurface bands vs. surface broadcast and identify PL components contributing to this effect. The residual effect of PL applied by the two methods or synthetic nitrogen (sN) at seven plant available N rates (0–292 kg ha^{−1} yr^{−1}) in 2014–2015 was tested on corn and cotton in 2016–2019. Corn was grown without applying PL or sN in 2016, and cotton was grown in 2017–2019 after applying 90 kg ha^{−1} yr^{−1} sN to all plots. Corn produced 40% greater grain and cotton produced 29% more lint yield due to residuals from PL than sN. Residuals from PL distinctly increased cotton leaf K over sN regardless of the method of application. Corn and cotton yield benefits from PL residual were greater if applied by subsurface banding vs. surface broadcast. This difference diminished with time. The overall results show PL components persist in the soil for up to 4 years and affect corn and cotton production, but this persistence is greater if the PL is applied by subsurface banding. This study identified K as the key PL nutrient that persisted in the soil and benefited cotton yield 4 years after the last application.

Keywords: cotton; corn; potassium nutrition; manure; chlorophyll index; ear leaf N; cotton leaf K



Citation: Tewolde, H.; Way, T.R.; Buehring, N.; Jenkins, J.N. Residual Benefits of Poultry Litter Applied by Subsurface Band vs. Surface Broadcast to Cotton. *Agronomy* **2024**, *14*, 582. <https://doi.org/10.3390/agronomy14030582>

Academic Editor: Andrea Baglieri

Received: 15 February 2024

Revised: 29 February 2024

Accepted: 6 March 2024

Published: 14 March 2024



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1. Introduction

Poultry litter (PL), a mixture of mostly poultry manure and one of several bedding materials, has proven to be a valuable fertilizer for row crops [1–3], forage and pasture grasses [4–6], and forest trees [7]. It is a near-complete fertilizer containing all mineral elements essential for healthy plant growth and crop production. Driven by its effectiveness and value as a fertilizer, its use for row crop production has steadily increased over the past two decades. In the US, it is generated in poultry production houses in the southeastern region where cotton (*Gossypium hirsutum* L.) and corn (*Zea mays* L.) are two of the three dominant row crops. Only six states in this region generated approximately 7.96×10^9 kg PL from broiler chickens alone, nearly 60% of the entire broiler litter generated in the US in 2022 [8].

Litter from broiler chicken operations, as it is obtained from poultry production facilities, is made up of approximately 60% organic matter, 25% water, and 15% plant nutrient elements including N, P, K, S, Mg, and many of the minor elements necessary for plant growth. Usually, it has a neutral to high pH, sometimes as high as 8.5 [9]. When PL is applied and incorporated into the soil, the organic matter breaks down, gradually releasing plant nutrients. The breakdown is rapid at the beginning [9,10] and slows with time. It may take years for the organic matter breakdown to be complete until the most recalcitrant fractions remain. Pitta et al. [10] recovered only 27% of the initial PL dry matter placed

on the soil surface in litter bags for 1 year. The remaining 73% is presumed to have either volatilized or leached into the soil.

The mineral elements in PL exist in various amounts, proportions, and forms. Some elements exist in organic forms and others in inorganic forms. The inorganic forms, K for example, are readily available for uptake as soon as the PL is applied. The ones in organic forms must be mineralized into forms plants can take up and use. Organic N, for example, must undergo conversion from organic forms such as proteins to inorganic forms (NH_4^+ and NO_3^-) for plant uptake. Similar to organic N, organic P and other elements must also undergo mineralization before they can be taken up and used by plants. The conversion process takes time and may not be complete in a single cropping season. Further, some fractions may be consumed by the soil microbiota and become available for plant uptake gradually after the soil microbes die and decompose releasing the nutrients [11].

Furthermore, the elements in PL do not exist in the same proportions taken up by plants. For example, PL contains about equal amounts of plant available N and P ($\approx 15 \text{ kg Mg}^{-1}$ PL), but plants require much less P than N and, therefore, will uptake less P than N during a growing season [12,13]. Potassium is taken up by cotton in substantial amounts also, but the amount removed with the harvested plant parts is just about 20% of the total uptake [14]. Poultry litter-derived elements not taken up by plant roots during the crop growing cycle remain in the soil for succeeding crops, although a fraction of them may also be lost to leaching, runoff, or volatilization. Some PL-derived plant nutrients may persist in the soil for years and benefit succeeding crops.

The residual benefit of PL to subsequent crops has been shown in some studies. In a no-till soil in Mississippi, including PL as a component of the cotton fertilization system increased cotton yield not only in the year of application but also in subsequent years after stopping litter application and resuming conventional fertilization with synthetic fertilizers [15]. In a Decatur silt loam soil in Alabama, residual N from PL applied to cotton 2 years prior was capable of meeting about half of the N need of corn [16]. In another Alabama study, residual PL in the second year after application resulted in as much as 50% of the cotton lint yield and 65% of the corn grain yield produced with standard N fertilization [17]. Others have shown similar residual effects of PL applied in previous years on current crops [18].

Poultry litter is traditionally applied by broadcasting on the soil surface with various kinds of spreaders and may or may not be incorporated into the soil. In no-till systems, the PL is left on the soil surface all season long, exposed to losses because the no-till practice proscribes mechanically disturbing the soil to incorporate the PL into the soil. Yet, the effects of PL applied to no-till systems persist for years after application [15].

Poultry litter is also applied by banding below the soil surface and has been shown to conserve mineral nutrients contained in the PL in the same season it is applied [19]. Similar to broadcast application, PL applied by sub-surface banding has also been shown to have residual effects on subsequent crops [20]. However, whether the residual benefits from PL applied by subsurface banding are greater than PL applied as surface broadcast years after stopping PL application is not known. The objectives of this study were to (1) determine whether PL applied in subsurface bands persists longer and affects crop growth and production greater than PL applied by surface broadcast and (2) identify PL components contributing to this effect up to 4 years after the last application.

2. Materials and Methods

This study was conducted from 2016 to 2019 at the Mississippi Agricultural and Forestry Experiment Station (MAFES) in Verona, MS, with a Leeper silty clay loam soil (fine, smectitic, nonacid, thermic Vertic Epiaquepts). It was a continuation of a 2-year study in 2014 and 2015 in which the value of poultry litter (PL) applied by surface broadcast and subsurface banding as fertilizer for corn (*Zea mays* L.) was tested [21]. The soil initially had 39 mg kg^{-1} Mehlich 3-extractable P, 136 mg kg^{-1} Mehlich 3-extractable K, 6.3 pH, and 1.7% organic matter, in a 0 to 15 cm depth.

2.1. Experimental Description

In 2014 and 2015, corn was grown following the application of poultry litter (PL) by two methods—surface broadcast vs. subsurface band—with six rates each ranging from 4.4 to 26.6 Mg ha^{−1} yr^{−1}. Corn was also grown in both 2014 and 2015 with synthetic N (sN) application with six rates ranging from 67 to 292 kg ha^{−1} yr^{−1}. An unfertilized control common to all three treatments was included. All PL or sN applications were made to target 0, 67, 135, 179, 213, 247, and 292 kg ha^{−1} plant available N. The actual applied PL rate with either method in 2014 and 2015 was not exactly the same as the target rate because the applications were based on calibrations. The actual applied sN rate, however, was equal to the target rate because the application was made by hand after weighing the amount for each plot. The study included a total of 19 treatments in a randomized complete block design replicated four times. Each plot consisted of four 15.2 m long rows spaced 0.97 m apart and received the same treatment both years. The treatments in 2016 to 2019 that had received poultry litter by surface broadcast, subsurface banding, and synthetic N treatments in 2014 and 2015 are, respectively, designated as LBCr (litter broadcast residual), LSSr (litter subsurface band residual), and sNr (synthetic N residual).

Chemical properties of the PL used in the 2014 and 2015 study are shown in Table 1. A more complete description of the 2014 and 2015 study is given in Tewolde et al. (2022) [21].

Table 1. Selected chemical properties of poultry litter used in the 2014 and 2015 study.

Property	Unit	2014	2015
Moisture	%	26.1	27.3
Total N	g kg ^{−1}	25.9	24.7
Total C	g kg ^{−1}	231	214
Ca	g kg ^{−1}	18.7	31.1
K	g kg ^{−1}	22.0	26.4
Mg	g kg ^{−1}	5.60	6.00
P	g kg ^{−1}	10.5	18.7
Cu	mg kg ^{−1}	227	69.0
Fe	mg kg ^{−1}	1182	656
Mn	mg kg ^{−1}	526	412
Zn	mg kg ^{−1}	347	357

2.2. Plot Management

Every year, the field was managed as a minimum till which involved reforming the beds after harvesting the previous crop in the fall or in early spring of the same season. Any tillage in 2014 to 2019 did not involve breaking the beds formed in the fall of 2013. In 2016, corn was grown in the same field without applying poultry litter or synthetic N fertilizers to any of the plots. The corn variety was Croplan 6640 (WinField United, Arden Hills, MN, USA) planted at 74,000 seeds ha^{−1} in all plots on 25 April 2016. While all sN treatments received 34 kg ha^{−1} P as triple superphosphate based on soil test recommendation, all poultry litter plots received no fertilization of any kind since this was designed to measure residual effects from the previous 2 years of fertilization treatments.

In 2017 to 2019, cotton was planted in the same plots every year. PhytoGen cotton varieties (PHY 444 WRF in 2017 and PHY 430 W3FE in 2018 and 2019) (Corteva Agriscience, Indianapolis, IN, USA) were planted at 112,000 seeds ha^{−1} in mid-May each year. All plots, regardless of the fertility treatment in 2014 to 2015, received the recommended synthetic N rate of 90 kg ha^{−1} at the match-head square stage (a stage commonly used for N application timing) each year for optimal cotton lint yield in the region. This was to allow for the quantification of the residual effects of all nutrients and poultry litter effects other than N. The synthetic N was applied in the form of urea-ammonium nitrate solution (UAN) (32% N) using a commercial liquid fertilizer applicator equipped with a coulter-knife system that opened slits about 0.20 m away from the row center into which the UAN solution was injected to a depth of ≈0.1 m. No other fertilization was applied to any of the treatments in any of the years.

In all years, regional pest control practices were followed for both corn and cotton, which are two of the three most dominant and economically important crops in the South-eastern US. The management employed kept the field free of weeds and other pests. The field was managed as a non-irrigated field each year, with total rainfall received in the critical months of May, June, July, and August of 265, 470, 389, and 568 mm in 2016, 2017, 2018, and 2019, respectively (Table 2).

Table 2. Monthly average air temperature and total rainfall for 2016 through 2019 at Verona, MS.

	Temperature				Rainfall			
	2016	2017	2018	2019	2016	2017	2018	2019
Month	°C	°C	°C	°C	mm	mm	mm	mm
May	21.6	21.4	25.0	24.0	28	115	78	114
June	27.7	25.3	27.7	26.1	85	146	143	90
July	28.9	28.6	28.4	28.0	45	47	64	214
August	30.3	29.1	29.5	29.7	107	162	104	150

2.3. Data Collection

Corn grain yield in 2016 was determined by harvesting the entire length of the middle two rows of each plot. This harvest was accomplished on 7 September 2016 with a two-row plot combine with the ability to record grain weight and moisture content (Kincaid Seed Research Equipment Company, Haven, KS, USA). The yield is reported after adjusting the moisture content to 15.5%.

Cotton lint yield in 2017 to 2019 was also determined by harvesting the full length of the middle two rows of each plot at the end of each year in the first two weeks in October. A two-row plot picker retrofitted with a self-weighting and dumping system was used. About 600 g of seedcotton subsamples from each plot was collected at the time of harvest for determining lint turnout and for converting harvested seedcotton to lint yield. A 10-saw benchtop gin was used to separate the lint from the seed of each subsample and the lint turnout determined as the ratio of lint weight to subsample weight. The lint yield per plot was calculated as the product of lint turnout and harvested seedcotton weight. Plant height was measured on 10 to 15 typical plants per plot within 1 wk after picking cotton each year. The measurements were made from the soil surface to the upper-most visible node.

Leaf nutrient concentration was determined from leaf samples collected at the R1 stage (silking) in 2016 for corn and at the flowering stage in each of the 3 years (2017–2019) for cotton. Six ear-leaf samples were collected for corn and 20 upper-most fully expanded whole leaves were collected for cotton. These samples were dried in a forced air drier at 80 °C to constant weight and ground to pass through a 1 mm sieve in preparation for nutrient analysis. The ground leaf samples were analyzed for total P, K, Mg, Ca, Cu, Mn, Fe, and Zn content using Inductively Coupled Plasma–Optical Emission Spectroscopy (ICP–OES; Varian Vista Pro; Varian Analytical Instruments, Walnut Creek, CA, USA) after ashing a 0.2 g sample in a muffle furnace at 500 °C for 4 h. The ashed samples were then digested in 1.0 mL 6 M HCl for 1 h followed by 40 mL solution of 0.0125 M H₂SO₄ and 0.05 M HCl for an additional 1 h. The ICP–OES was then used to analyze this digest. Both cotton and corn ground samples were analyzed for total N by an automated dry combustion method with an Elementar Vario MAX CN analyzer (Elementar Instrument, Mt. Laurel, NJ, USA).

Corn leaf chlorophyll index was measured on ear leaves at the R1 stage (silking) on 23 June 2016. The measurements were made on 10 ear leaves from the middle two rows with a Minolta handheld SPAD-502 m (Minolta Corp., Ramsey, NJ, USA). Leaf area index (LAI, the amount of one-sided leaf area per unit ground area) was measured on 30 June 2016 on the middle two corn rows using an AccuPAR 80 (Decagon Devices, Inc., Pullman, WA, USA). Cotton LAI was also measured by the same method on 3 August 2017, 30 July 2018, and 20 August 2019.

2.4. Statistical Analysis

All data were subjected to analysis of variance by crop using the PROC MIXED procedure of the Statistical Analysis System 9.4 (SAS Institute, Cary, NC, USA, 2013). Initially, as all plots were treated equally in all 4 years, the data were analyzed by crop as a one-way analysis of variance comparing the residuals from the four main fertility treatments in 2014 and 2015. Year was included in the model for cotton to test for interaction of year and fertility treatments, with fertility treatments as the fixed effect factor and replication and its interactions with fertility treatments as the random effect factors. Group comparisons were also made between PL and sN using single degree of freedom contrast tests. This initial analysis was followed by analysis of covariance (ANCOVA), which utilizes ANOVA and regression analysis to compare the two methods of PL application (LBCr vs. LSSr) by including PL rate in the model as the covariate. First, the ANCOVA model included the method of application, the PL rate as a covariate, and their interaction. When there was no interaction between the method of application and the covariate, the ANCOVA was repeated after eliminating the interaction term because the lack of interaction shows the two regression lines of the two methods were parallel to each other. The least squares means generated by this ANCOVA (which are predicted means of the two methods at an equal average PL rate) were then compared. Differences between two values were compared using Tukey's test at $p \leq 0.05$ unless stated otherwise. LS-means from ANCOVA have greater precision than from ANOVA because the means from ANCOVA are adjusted for the covariate. PROC REG was used to test the linear and nonlinear relationships between yield and applied PL and that of yield and leaf K concentration.

3. Results and Discussion

3.1. Corn Response 1 Year after Last PL Application

Corn was grown in 2016 without applying any fertilizers to any of the plots. So the corn planted in any of the plots should have performed the same if there were no carry over effects of the fertilizers applied in the previous 2 years. But corn grain yield and other measurements in 2016 differed among the treatments in the previous two years showing that the residuals from these treatments affected corn performance. One clear difference is between the synthetic N residual (sNr) and the poultry litter residual (PLr) treatments, regardless of the application method. When averaged across rates, the two PLr treatments produced 40% more grain and had 21% more leaf area index (LAI) and 7.6% greater chlorophyll index (Ci) than the sNr treatment (Table 3). These differences were clearly greatest with the largest rates of the PL or sNr treatments (Figure 1). The grain yield of the PLr treatments was as large as two-fold of the sNr treatment at the highest respective rates.

Table 3. Grain yield, leaf area index (LAI), chlorophyll index (Ci), and ear leaf N of corn grown in 2016 in a field that had received synthetic N (sNr) or poultry litter (PLr) applied by surface broadcast (LBCr) or subsurface banding (LSSr) or was unfertilized (UTCr) in 2014 and 2015. Each LBCr, LSSr, and sNr value is an average across four replications and six fertilization rates in 2014 and 2015. The UTCr value is an average of four replications.

Treatment	Grain Yield	LAI	Ci	Ear Leaf N
	Mg ha ^{−1}			g kg ^{−1}
LBCr	4.55 a	2.6 a	33.7 a	14.7 a
LSSr	4.65 a	2.5 ab	33.1 a	14.1 a
sNr	3.27 b	2.1 b	29.5 b	12.9 b
UTCr	3.41 ab	2.0 b	30.5 ab	13.2 ab
ANOVA	Pr > F			
Treatment (trt)	0.01	0.029	0.042	0.04
PLr vs. sNr [†]	0.002	0.008	0.009	0.01

Note. Means followed by the same letter within a column are not significantly different at $p < 0.05$. [†] PLr = Poultry litter (LBCr + LSSr).

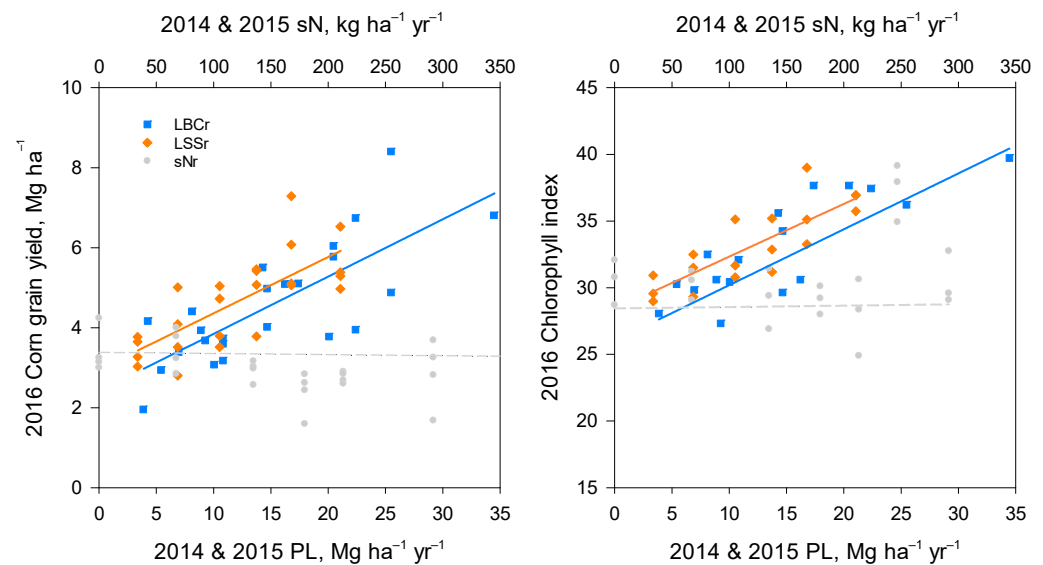


Figure 1. Grain yield and chlorophyll index (Ci) in 2016 for corn grown in plots that had received selected rates of synthetic N (sNr) or poultry litter (PLr) applied by surface broadcast (LBCr) or subsurface banding (LSSr) in 2014 and 2015. Table 4 shows the statistics for comparing LBCr vs. LSSr.

Table 4. Grain yield, leaf area index (LAI), chlorophyll index (Ci), and ear leaf N of corn grown in 2016 in a field that had received selected rates of poultry litter (PLr) applied by surface broadcast (LBCr) or subsurface banding (LSSr) in 2014 and 2015. Each value is the least squares mean derived from the analysis of covariance (ANCOVA) with actual applied PLr rate as a covariate.

Treatment	Grain Yield	LAI	Ci	Ear Leaf N
	Mg ha ⁻¹			g kg ⁻¹
LBCr	4.35 b	2.54	33.0	14.5
LSSr	4.85 a	2.49	33.7	14.3
ANCOVA			Pr > F	
Treatment (trt)	0.326	0.691	0.246	0.523
PLr rate	<0.001	0.017	<0.001	<0.001
PLr rate × trt	0.949	0.4833	0.432	0.367

Note. Values followed by the same letter within a column are not significantly different at $p < 0.05$. Values without letter assignment within a column are not significantly different at $p < 0.05$. Figure 1 shows the yield and Ci response to applied PLr rate as the covariate. No significant PLr × trt interaction signifies the two linear responses to PLr rate applied by LBCr or LSSr are parallel.

Grain yield and Ci remained the same or decreased with increasing sN rates applied in 2014 and 2015 (Figure 1). The grain yield of the sNr in 2016 was highest for the treatments that had received the least amount of sN or were not fertilized (UTCr) in 2014 and 2015. The sN treatments that were most productive in 2014 and 2015 produced equal or less grain yield in 2016 than the ones that were least productive in 2014 and 2015 [21]. Synthetic N applications considered optimal or above optimal in 2014 and 2015 depressed yield in 2016 when the corn was grown on residual nutrients, only likely because of greater soil nutrient depletion due to high grain yields than the suboptimal sN applications. The results suggest that, in real production situations, replenishment of the soil nutrients for crops that follow a highly productive corn crop fertilized with synthetic N fertilizers is necessary to maintain productivity of the soil.

The productivity of corn planted in 2016 in soil with PL residuals was proportional to the rate of the PL applied in 2014 and 2015, regardless of the application method (Figure 1). Residuals from the lowest PL rates did not result in grain yield or Ci that differed much from the UTCr or the sNr treatments. As the PL rates applied in 2014 and 2015 increased, however, the grain yield and the other measurements in 2016 also increased proportionally.

The grain yield in 2016 increased to as much as 5.9 Mg ha^{−1} with ≈16 Mg ha^{−1} yr^{−1} PL applied in 2014 and 2015. This shows PL-derived nutrients or other PL benefits from the previous 2 years of PL application carried over to 2016 and contributed to better growth and yield.

Grain yield did not increase beyond the 16 Mg ha^{−1} yr^{−1} PL rate, likely because other factors were limiting to yield. Nitrogen was the likely limiting nutrient for grain yield to exceed the 5.9 Mg ha^{−1} maximum in 2016. Ear leaf N measured around the silking (R1) stage in 2016 did not exceed 15.0 g kg^{−1} when averaged across all PL or sN rates (Table 3) and remained below 17 g kg^{−1} with any level of PL or sN applied in 2014 and 2015. This level of ear leaf N is less than half of the published sufficiency range of 28 to 40 g kg^{−1} for optimal corn grain yield [22,23].

Between the two PL application methods, the LSSr resulted in greater grain yield than the LBCr at a given application rate based on ANCOVA test (Table 4, Figure 1). The highly significant PLr rate effect on grain yield or the other measurements in Table 4 denotes a linear increase in these parameters with an increasing PLr rate applied in 2014 and 2015 by either method. The non-significant PLr rate*trt interaction denotes the two linear responses to PLr rate applied by LBCr or LSSr are parallel (same slopes). The y-intercepts of the two responses differed with greater y-intercept for the LSSr than the LBCr (not shown), which also means the LSSr resulted in greater grain yield at any level of PL since the two lines are parallel to one another. When the LS means (estimated means at the same PLr) were compared, the LSSr treatment produced 11.6% more grain yield than the LBCr (4.85 vs. 4.35 Mg ha^{−1}). Although the two treatments did not differ in the other measurements, these grain yield results indicate that applying PL by subsurface banding leads to greater conservation of PL than by surface broadcast 1 year after the last application.

As expected, the corn grain yield in all plots in 2016 was low because the corn received no PL or sN fertilizers as the purpose was to measure the residual effect of the treatments imposed in 2014 and 2015. The corn produced as much as 15 Mg ha^{−1} grain in 2014 and 11 Mg ha^{−1} in 2015 when the fertilizers were applied in the same season [21]. In 2016 when no PL or sN fertilizers were applied, grain yield remained below 8.5 Mg ha^{−1} (Figure 1). As discussed above, N is the likely key nutrient that limited the yield in all treatments, but the weather may have played a role. The year 2016 was the driest of the four seasons, with only 265 mm of total rainfall in the four critical months of May to August in 2016 compared with >389 mm total in 2017 to 2019 (Table 2).

3.2. Cotton Response to Poultry Litter 2 to 4 Years after Last Application

The cotton lint yield averaged across the 3 years (2017 to 2019) ranged from 1647 kg ha^{−1} for the sNr treatment to 2151 kg ha^{−1} for the LSSr treatment (Table 5). These rainfed yields are high for the region. The statewide average yield for 2017 to 2019 in Mississippi was only 1225 kg ha^{−1} [8].

Table 5. Lint yield, growth, and concentration of selected nutrients in leaves of cotton grown in plots that had received selected rates of synthetic N (sNr) or poultry litter applied by surface broadcast (LBCr) or subsurface banding (LSSr) or were unfertilized (UTCr) in 2014 and 2015. Each LBCr, LSSr, and sNr value is an average across four replications, six fertilization rates in 2014 and 2015, and 3 years (2017 to 2019). The UTCr value is an average of four replications and 3 years.

Treatment	Lint Yield	Plant Height	LAI	Leaf N	Leaf K	Leaf P	Leaf Mn
	kg ha ^{−1}	cm		g kg ^{−1}	g kg ^{−1}	g kg ^{−1}	mg kg ^{−1}
LBCr	2100 a	95.0 a	3.82 ab	37.0	11.6 a	4.94	45.1 b
LSSr	2151 a	96.5 a	3.99 a	36.1	11.6 a	5.11	43.9 b
sNr	1647 c	86.6 b	2.94 c	36.3	9.0 b	4.93	51.5 a
UTCr	1885 b	88.4 b	3.43 bc	37.3	9.7 b	5.44	43.6 b

Table 5. Cont.

Treatment	Lint Yield	Plant Height	LAI	Leaf N	Leaf K	Leaf P	Leaf Mn
	kg ha ⁻¹	cm		g kg ⁻¹	g kg ⁻¹	g kg ⁻¹	mg kg ⁻¹
ANOVA	Pr > F						
Year (Y)	<0.001	<0.001	0.016	<0.001	0.107	<0.001	<0.001
Treatment (T)	0.001	<0.001	<0.001	0.678	<0.001	0.11	0.013
Y × T	0.581	0.805	0.035	0.843	0.47	0.256	0.008
PLr vs. sNr [†]	<0.001	<0.001	<0.001	0.728	<0.001	0.372	0.002

Note. Means followed by the same letter within a column are not significantly different at $p < 0.05$. The entire field (all treatments) received recommended synthetic N fertilization every year in 2017 to 2019, thus the differences among the treatments are due to the residual effect of poultry litter or synthetic N applied in 2014 and 2015. Means without letter assignment within a column are not significantly different at $p < 0.05$. [†] PLr = poultry litter (LBCr + LSSr).

3.2.1. Residuals from Poultry Litter vs. Synthetic N

Although all plots/treatments were fertilized with the same recommended amount of sN in each of the 3 years, cotton grown in plots that had received poultry litter in 2014 and 2015 produced significantly greater lint yield when pooled across years (no year by treatment interaction) than cotton grown in plots that had received synthetic N (>2100 kg ha⁻¹ for PLr vs. 1647 for sNr) (Table 5). As in corn grain yield, the differences in lint yield between PLr and the sNr treatments were greater at the higher application rates than at the lower rates (Figure 2). The PLr treatments also had larger plants (plant height and LAI) than the sNr treatments.

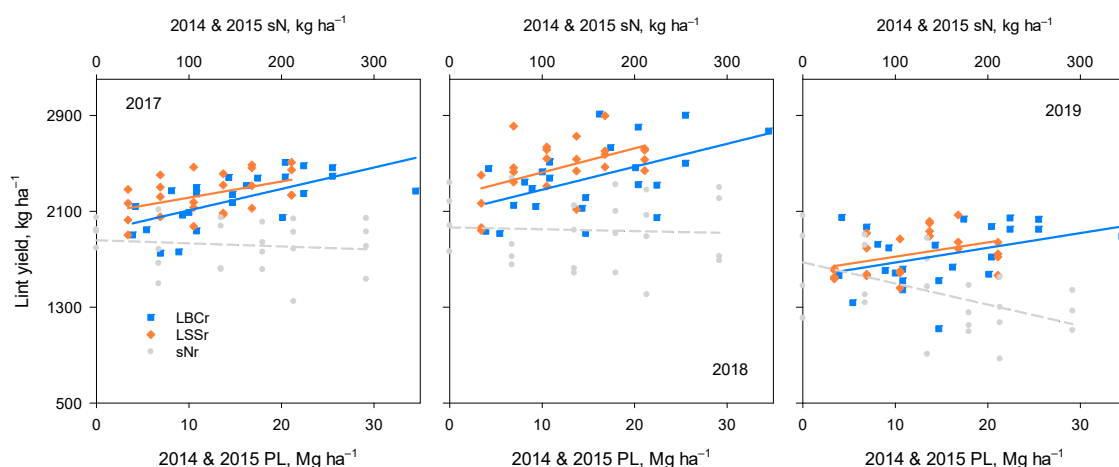


Figure 2. Lint yield of cotton in 2017 to 2019 grown in plots that had received selected rates of synthetic N (sNr) or poultry litter (PLr) applied by surface broadcast (LBCr) or subsurface banding (LSSr) in 2014 and 2015. Table 6 shows the statistics for comparing LBCr vs. LSSr.

Among the four treatments, the sNr produced the least yield (1647 kg ha⁻¹ pooled across 2017 to 2019) (Table 5). The UTCr which received no fertilization in 2014 and 2015 produced nearly 15% more lint than the sNr. This yield difference in 2017 to 2019 likely reflects differences in nutrient depletion in 2014 and 2015. The UTCr was likely less depleted of soil nutrients because of less corn grain yield in 2014 and 2015 than the sNr [21]. In 2017 to 2019, the entire field including these two treatments received 90 kg ha⁻¹ synthetic N as a blanket application based on local N recommendation for cotton. So, the difference in cotton lint yield and growth between the sNr and UTCr in 2017 to 2019 is likely related to the depletion of nutrients other than N in 2014 and 2015.

Table 6. Lint yield, growth, and concentration of selected nutrients in leaves of cotton grown in 2017 to 2019 in plots that had received selected rates of poultry litter (PLr) applied by surface broadcast (LBCr) or subsurface banding (LSSr) in 2014 and 2015. Each value is the least squares mean of all 3 years derived from the analysis of covariance (ANCOVA) with actual applied PLr as a covariate.

Treatment	Lint Yield	Plant Height	Leaf Area Index	Leaf N	Leaf K	Leaf P	Leaf Mn
	kg ha ⁻¹	cm		g kg ⁻¹	g kg ⁻¹	g kg ⁻¹	mg kg ⁻¹
LBCr	2077 b	95.6 b	3.87 b	36.3	11.4	4.94 b	45.1
LSSr	2179 a	98.4 a	4.12 a	36.6	11.8	5.12 a	43.3
ANCOVA	Pr > F						
Treatment (trt)	0.403	0.586	0.235	0.814	0.035	0.165	0.026
PL rate	<0.001	<0.001	0.002	0.364	<0.001	0.074	0.195
PL rate × trt	0.953	0.109	0.030	0.915	0.116	0.504	0.032

Note. Values followed by the same letter within a column are not significantly different at $p < 0.10$. Values without letter assignment within a column are not significantly different at $p < 0.10$. No significant PLr rate × trt interaction signifies the two linear responses to rate of PLr applied by LBCr or LSSr are parallel.

Cotton planted in plots that had received the two PLr treatments (LBCr and LSSr) did not significantly differ in yield (2100 vs. 2151 kg ha⁻¹) or plant growth when the means were pooled across rates and years based on ANOVA that did not take the PLr rates into consideration (Table 5). Analyzing the data by including PLr rates as a covariate, however, resulted in significant ($p < 0.10$) differences between LBCr and LSSr for lint yield, plant height, and LAI (Table 6). The LSSr treatment in all cases resulted in greater lint yield and plant growth, although the differences were small. The results, however, show that applying PL by subsurface banding leads to a greater conservation of PL components than applying by surface broadcast, considering the average PL applied in the 2 years (2014 and 2015) was 19% less for the LSSr than the LBCr (12.1 vs. 14.9 Mg ha⁻¹) (Table 7).

Table 7. Rates of poultry litter (PL) applied in 2014 and 2015 (each rate is the sum of the two years) and calculated amounts of selected nutrient elements supplied by these PL rates (each amount is the sum of the two years).

Applied PL Rate		Total N		P		K		Mg		Mn		Zn	
LBCr	LSSr	LBCr	LSSr	LBCr	LSSr	LBCr	LSSr	LBCr	LSSr	LBCr	LSSr	LBCr	LSSr
Mg ha ⁻¹		kg ha ⁻¹											
10.2	6.7	258	170	155	98	251	163	60	39	4.7	3.2	3.6	2.4
18.5	13.7	468	347	277	203	452	334	108	80	8.6	6.4	6.5	4.8
23.1	21.1	587	533	332	311	558	512	134	122	10.9	9.8	8.1	7.4
32.8	27.5	829	695	485	406	798	668	191	160	15.3	12.8	11.6	9.7
41.7	33.5	1054	850	613	488	1012	812	242	195	19.5	15.8	14.7	11.8
52.3	42.1	1324	1065	768	621	1270	1024	304	245	24.5	19.7	18.4	14.8

3.2.2. Cotton Lint Yield Response in 2017 to 2019 to PL or sN Rates Applied in 2014 and 2015

The cotton lint yield in each of the 3 years between 2017 and 2019 depended on the rate of PL applied in 2014 and 2015. Each year, the lint yield linearly increased with an increasing PL rate, whether it was applied as broadcast or by subsurface banding (Figure 2, Table 6). This increase in lint yield in 2017 to 2019 due to the PL rate or method of application may not be due to differences in N supplied by the PL, because all of the cotton in all treatments received the same recommended amount of synthetic N every year in 2017 to 2019. Thus, the increases due to PL rates may be attributed to components of PL other than N. These components persisted in the soil for 2 to 4 years to impact cotton yield in 2017 to 2019. The effect was dependent on the rate of PL application with weaker coefficients of determination in the last year (2019) than the previous 2 years. This may be reflective of the diminishing residual PL effects with time. These results are similar to the findings

by Tewolde et al. (2016) [15] who found that the residual benefit of surface-applied and unincorporated PL is greatest in the first year after stopping PL fertilization, and the benefit diminishes with subsequent seasons. Tewolde et al. (2018) [20] also reported that residuals from a relatively low rate of PL applied for 3 years increased cotton lint yield by a 2 years average of 29% after stopping PL applications.

These results overall suggest that the residual benefits of PL applied 2 to 4 years ago are proportional to the rate applied, whether applied by surface broadcast or subsurface banding. One year after the last application, the benefits to corn grain yield were greater if the PL was applied by subsurface banding vs. surface broadcasting. The greater benefit to yield when the PL was applied by subsurface banding continued in years subsequent to 2016, but this benefit seemed to diminish with time.

Unlike the PL residual response, the lint yield in 2017 to 2019 decreased (negative slope) or remained the same with increasing sN applied in 2014 and 2015 (Figure 2, Table 8). As described earlier, this decrease is likely due to increasing grain yield with increasing sN rates [21] and associated soil nutrient depletion in 2014 and 2015.

Table 8. Regression coefficients of regressing cotton lint yield in 2017 to 2019 on poultry litter rates applied by surface broadcast (LBCr) or subsurface banding (LSSr), or on synthetic N (sNr) rates, applied in 2014 and 2015. All treatments received recommended synthetic N fertilization ($90 \text{ kg ha}^{-1} \text{ yr}^{-1}$) in 2017 to 2019.

Year	Treatment	Intercept	Slope	Pr > F	R ²	n
		kg ha^{-1}	$\text{kg ha}^{-1} \text{ Mg}^{-1}$			
2017	LBCr	1929	17.9	0.001	0.41	24
	LSSr	2081	13.4	0.022	0.22	24
	sNr	1887	−0.8	0.190	0.07	28
2018	LBCr	2088	19.2	0.011	0.26	24
	LSSr	2223	20.1	0.010	0.26	24
	sNr	1981	−0.5	0.467	0.02	27
2019	LBCr	1548	12.3	0.066	0.15	24
	LSSr	1601	12.0	0.054	0.17	23
	sNr	1687	−2.0	0.004	0.29	27

3.2.3. Cotton Leaf Nutrient Levels in 2017 to 2019 Reflect PL or sN Rates Applied in 2014 and 2015

Cotton leaf K and Mn concentrations but not leaf N or P differed among the four treatments (LBCr, LSSr, sNr, and UTCr) when the data were pooled across rates and years (Table 5). Leaf N concentration averaged across all four treatments was 36.7 g kg^{-1} . All treatments received the same recommended sN rate (90 kg ha^{-1}) every year, so the treatments were not expected to differ in leaf N. The treatments also had similar leaf P with an average of 5.1 g kg^{-1} . Further, differences among the treatments for other mineral elements including Mg (2.77 mg kg^{-1} average), Ca (23.4 mg kg^{-1} average), and the microelements Zn, Fe, or Cu (average of, respectively, 28.6, 83.1, 10.9 mg kg^{-1}) did not exist.

The two treatments that received PL in 2014 and 2015 (LBCr and LSSr), however, clearly had greater leaf K concentration than the other two that did not receive PL (sNr and UTCr) (11.6 vs. 9.35 g kg^{-1}) and less leaf Mn than the sNr treatment (44.5 vs. 51.5 mg kg^{-1}) (Table 5).

Leaf K in 2017 to 2019, like lint yield, increased with increasing rates of PL and decreased or remained the same with increasing sN applied in 2014 and 2015 (Figure 3). The increasing leaf K level in all 3 years with increasing PL rate applied in 2014 and 2015 suggests that PL supplied K in proportion to the applied PL. The 2-year total amount of K supplied by the PL in 2014 and 2015 ranged from 251 to 1270 kg ha^{-1} for the LBCr treatment and from 163 to 1024 kg ha^{-1} for the LSSr treatment (Table 7). A fraction of these amounts was removed with the corn grain harvested in each of the 3 years (2014 to

2016). However, this amount is likely small relative to the amount applied, because the K concentration in corn grain typically is as low as 4.9 g kg^{-1} , and the amount removed at harvest is also low ($<50 \text{ kg ha}^{-1}$ depending on the grain yield) [24,25]. This implies that much of the K derived from PL applied in 2014 and 2015 remained in the soil and benefited cotton planted in 2017 to 2019. The removal of K with harvested seedcotton is also low ($<60 \text{ kg ha}^{-1}$) relative to the total applied [26]. Much of the K taken up by the cotton plant remains in non-harvestable plant parts including leaves and burs; thus, the K that carried over into 2017 likely depleted only gradually. These results suggest K derived from PL applied in a season or two may persist in the soil and benefit cotton production for an extended period, which was up to 4 years in our study.

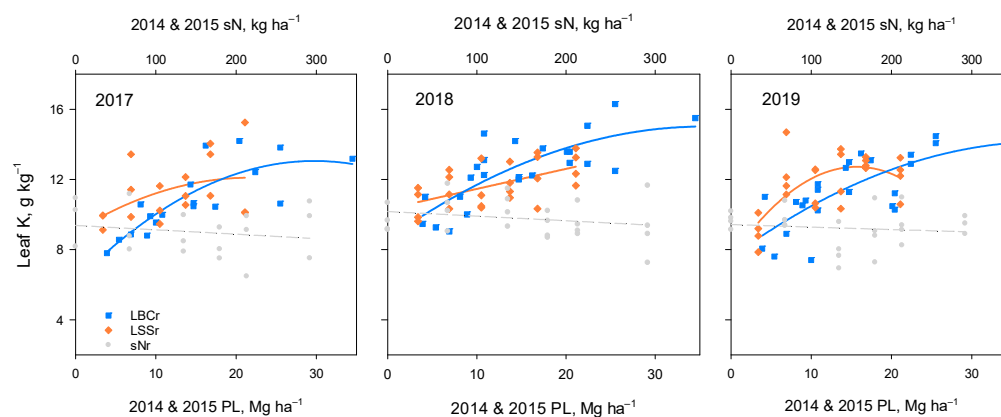


Figure 3. Cotton leaf K response in 2017 to 2019 to rates of synthetic N (sNr) or poultry litter applied by surface broadcast (LBCr) or subsurface banding (LSSr) in a field that was planted with corn in 2014 and 2015. The entire field received recommended synthetic N fertilization every year in 2017 to 2019.

Between the two PL application methods, there were no clear differences in leaf K when pooled across all the PL rates and years (11.4 vs. 11.8 g kg^{-1}) (Table 6). The difference between LBCr and LSSr in leaf K averaged across the PL rates within each year were also not significant, although the LSSr seemed to have greater leaf K at lower PL rates (Figure 3). This suggests the persistence of K from PL applied up to 4 years ago may be about the same whether applied by surface broadcast or subsurface band.

Leaf Mn was also affected by the treatments, although there was a year by treatment interaction (Table 5). Unlike leaf K, PL application, regardless of the method or rate of application, reduced leaf Mn relative to the sNr applied in 2014 and 2015. When averaged across the 3 years and rates, the sNr had leaf Mn of 51.5 mg kg^{-1} compared with $<45.1 \text{ mg kg}^{-1}$ for the PL treatments. The UTCr had similar leaf Mn as the PL treatments. The significant year by treatment interaction ($p = 0.008$) was because the greater leaf Mn of the sNr was significant in 2018 but not in 2017 and 2019. Within the same season of application, PL has been shown to reduce cotton leaf Mn concentration relative to synthetic N fertilizers [19]. This reduction is desirable in low-pH soils, as excessive Mn uptake in such soils can lead to Mn toxicity and yield reductions. Poultry litter tends to increase soil pH when applied to low pH soils [27,28] which occur widely in Southeastern US. Thus, the reduction in leaf Mn due to PL fertilization could be associated with its effect of reducing soil acidity. This effect seems to linger for as long as 4 years after the last PL application.

Unlike leaf K and Mn, leaf concentrations of N, P, Mg, and most microelements in 2017 to 2019 were not affected by the PL applied in 2014 and 2015. The PL applied in 2014 and 2015 supplied other elements including N, P, Mg, and microelements in proportion to the increasing PL rate. However, the increasing rates of application (Table 7) did not affect these elements, for multiple possible reasons. The first possibility is that much of the PL-supplied nutrients were used up by the corn or were lost to leaching, volatilization, or runoff in the first 3 years. This is the likely explanation for PL-supplied N. The lack

of leaf nutrient response in 2017 to 2019 to PL applied in 2014 and 2015 for some of the other nutrients including P, Mg, Fe, and Zn may be attributed to the existence of sufficient extractable levels of these nutrients in the soil for cotton uptake. Thus, any additional amount supplied by the PL applied in 2014 and 2015 should not be expected to increase their levels in leaves.

3.2.4. K Nutrition Explains the Lint Yield Increase Due to PL Application History

Potassium nutrition in 2017 to 2019 as measured by leaf K concentration seems to be the key factor that led to the yield differences among the PL and sN treatments including the rates. As discussed above, these treatments affected the lint yield when the data were pooled across the years (Table 5). This response seems to mirror the leaf K response to the treatments. The correlation of leaf K with the lint yield supports this observation (Figure 4). The lint yield increased with the increasing leaf K concentration in each of the 3 years, although this relationship was strongest in 2017 and weakest in 2019. The weak relationship in 2019 likely suggests that the effect of K nutrition fades over time, likely showing that K was gradually removed from the soil with harvested seedcotton.

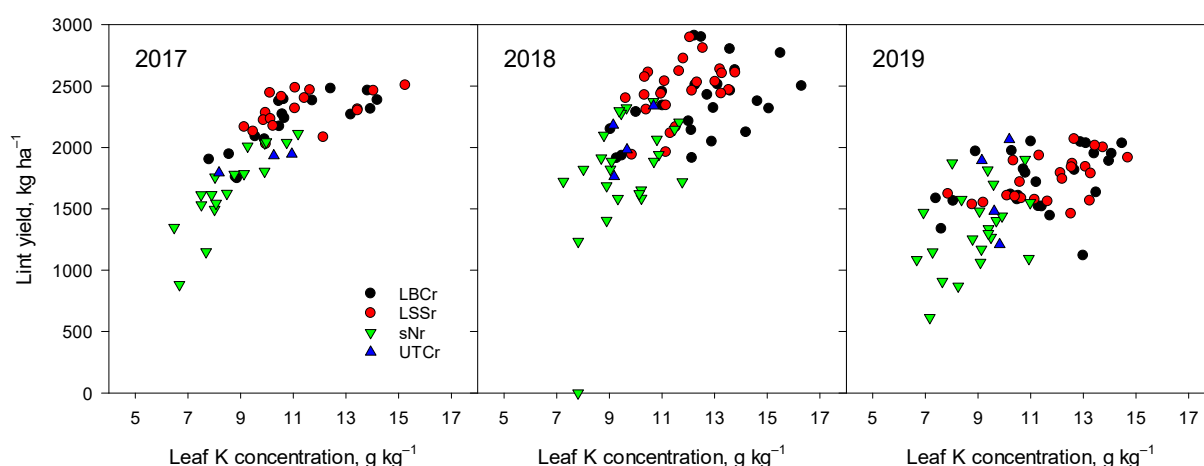


Figure 4. Relationship between lint yield and leaf K in 2017 to 2019 of cotton grown in a field that had received synthetic N (sNr) or poultry litter applied by surface broadcast (LBCr) or subsurface banding (LSSr) at different rates in 2014 and 2015. The entire field received recommended synthetic N fertilization every year in 2017 to 2019.

The reduction in leaf Mn levels due to PL fertilization relative to sN fertilization may also be considered desirable as Mn toxicity is a concern in low-pH soils. However, this soil was only slightly acidic, and the leaf Mn levels measured in the sN-fertilized treatments (Table 5) would not be considered toxic levels. Thus, improving the K nutrition of the cotton plant is the primary reason PL fertilization increased lint yield, although reduced leaf Mn may have contributed to a degree.

4. Conclusions

The results of this study showed that components of poultry litter persisted in the soil for as long as 4 years and benefited corn grain in the first year and cotton lint yield in the last 3 years. Residuals from PL increased the corn grain yield by an average of 40% and the cotton lint yield by an average of 29%, relative to residuals from synthetic N. Potassium was the key PL component that persisted in the soil and benefited lint yield, and N was one of the key components that benefited corn yield. Applying PL by subsurface banding vs. surface broadcast had greater a benefit on corn yield 1 year after stopping PL application. This advantage persisted in the cotton crop 2 to 4 years after the last PL application, but this advantage diminished in the later years. The results overall show PL components, regardless of the application method, persist in the soil for up to 4 years and

affect corn or cotton production. This study identified K as the key PL component that persisted in the soil and benefited cotton yield 4 years after the last application, showing that fertilizing cotton with poultry litter reduces or eliminates the need to apply K fertilizers long after stopping poultry litter applications.

Author Contributions: Conceptualization, H.T. and T.R.W.; methodology, H.T., T.R.W. and N.B.; validation, H.T.; formal analysis, H.T. and T.R.W.; investigation, H.T., T.R.W. and N.B.; resources, H.T., T.R.W. and N.B.; data curation, H.T. and T.R.W.; writing—original draft preparation, H.T.; writing—review and editing, H.T., T.R.W., N.B. and J.N.J.; visualization, H.T.; supervision, H.T., N.B. and J.N.J.; project administration, H.T. and N.B.; funding acquisition, N.B. and J.N.J. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The original contributions presented in the study are included in the article; further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

References

- Endale, D.M.; Schomberg, H.H.; Fisher, D.S.; Jenkins, M.B.; Sharpe, R.R.; Cabrera, M.L. No-till corn productivity in a southeastern United States ultisol amended with poultry litter. *Agron. J.* **2008**, *100*, 1401–1408. [CrossRef]
- Lofton, J.; Haggard, B.; Fromme, D.; Tubana, B. Utilization of poultry litter, tillage, and cover crops for cotton production on highly degraded soils in northeast Louisiana. *J. Cotton Sci.* **2014**, *18*, 376–384.
- Watts, D.B.; Smith, K.E.; Way, T.R.; Torbert, H.A.; Prior, S.A. Tillage and fertilizer application practices effects on greenhouse gas flux (CO₂, CH₄ and N₂O) and yield in a corn cropping system. In Proceedings of the 18th International Conference of the International Soil Tillage Research Organization, Izmir, Turkey, 15–19 June 2009.
- Edwards, D.R.; Daniel, T.C. Environmental impacts of on-farm poultry waste disposal—A review. *Bioresour. Technol.* **1992**, *41*, 9–33. [CrossRef]
- Pote, D.H.; Way, T.R.; Kleinman, P.J.A.; Moore, P.A.; Meisinger, J.J.; Sistani, K.R.; Saporito, L.; Allen, A.L.; Feyereisen, G.W. Subsurface application of poultry litter in pasture and no-till soils. *J. Environ. Qual.* **2011**, *40*, 402–411. [CrossRef]
- Warren, J.G.; Sistani, K.R.; Way, T.R.; Mays, D.A.; Pote, D.H. A new method of poultry litter application to perennial pasture: Subsurface banding. *Soil Sci. Soc. Am. J.* **2008**, *72*, 1831–1837. [CrossRef]
- Friend, A.L.; Roberts, S.D.; Schoenholtz, S.H.; Mobley, J.A.; Gerard, P.D. Poultry Litter Application to Loblolly Pine Forests. *J. Environ. Qual.* **2006**, *35*, 837–848. [CrossRef] [PubMed]
- USDA-NASS Mississippi Crop Production; USDA National Agricultural Statistics Service: Washington, DC, USA, 2022. Available online: https://www.nass.usda.gov/Publications/Calendar/reports_by_date.php (accessed on 5 March 2024).
- Li, Y.; Tewolde, H.; Miles, D.; Munyon, J.; Brooks, J.P.; Feng, G.; Zhang, F.; Yang, M. Decomposition of poultry litter organic matter co-applied with industrial and agricultural products/by-products. *J. Environ. Qual.* **2021**, *50*, 364–374. [CrossRef]
- Pitta, C.S.R.; Adami, P.F.; Pelissari, A.; Assmann, T.S.; Franchin, M.F.; Cassol, L.C.; Sartor, L.R. Year-round poultry litter decomposition and N, P, K and Ca release. *Rev. Bras. Cienc. Solo* **2012**, *36*, 1043–1053. [CrossRef]
- Hoorman, J.J.; Islam, R. *Understanding Soil Microbes and Nutrient Recycling*; Ohio State University: Columbus, OH, USA, 2010. Available online: <https://ohioline.osu.edu/factsheet/SAG-16> (accessed on 5 March 2024).
- Sadras, V.O. The N:P stoichiometry of cereal, grain legume and oilseed crops. *Field Crops Res.* **2006**, *95*, 13–29. [CrossRef]
- Tewolde, H.; Sistani, K.R.; Rowe, D.E. Broiler Litter as a Sole Nutrient Source for Cotton: Nitrogen, Phosphorus, Potassium, Calcium, and Magnesium Concentrations in Plant Parts. *J. Plant Nutr.* **2005**, *28*, 605–619. [CrossRef]
- Mullins, G.L.; Burmester, C.H. Dry Matter, Nitrogen, Phosphorus, and Potassium Accumulation by Four Cotton Varieties. *Agron. J.* **1990**, *82*, 729–736. [CrossRef]
- Tewolde, H.; Sistani, K.R.; McLaughlin, M.R. Residual effect of poultry litter applications on no-till cotton lint yield. *Agron. J.* **2016**, *108*, 1405–1414. [CrossRef]
- Nyakatawa, E.Z.; Reddy, K.C.; Brown, G.F. Residual effect of poultry litter applied to cotton in conservation tillage systems on succeeding rye and corn. *Field Crops Res.* **2001**, *71*, 159–171. [CrossRef]
- Mitchell, C.C.; Tu, S. Long-term evaluation of poultry litter as a source of nitrogen for cotton and corn. *Agron. J.* **2005**, *97*, 399–407. [CrossRef]
- Hirzel, J.; Walter, I.; Undurraga, P.; Cartagena, M. Residual effects of poultry litter on silage maize (*Zea mays* L.) growth and soil properties derived from volcanic ash. *Soil Sci. Plant Nutr.* **2007**, *53*, 480–488. [CrossRef]
- Tewolde, H.; Shankle, M.W.; Way, T.R.; Pote, D.H.; Sistani, K.R. Poultry litter band placement in no-till cotton affects soil nutrient accumulation and conservation. *Soil Science Soc. Am. J.* **2018**, *82*, 1459–1468. [CrossRef]
- Tewolde, H.; Shankle, M.W.; Way, T.R.; Pote, D.H.; Sistani, K.R.; He, Z. Poultry Litter Band Placement Affects Accessibility and Conservation of Nutrients and Cotton Yield. *Agron. J.* **2018**, *110*, 675–684. [CrossRef]

21. Tewolde, H.; Way, T.R.; Buehring, N.; Jenkins, J.N. Fertilizer value of poultry litter applied by subsurface band vs. surface broadcast in corn production. *J. Plant Nutr.* **2022**, *46*, 2044–2059. [[CrossRef](#)]
22. Campbell, C.R.; Plank, C.O. Reference Sufficiency Ranges: Corn. In *Reference Sufficiency Ranges for Plant Analysis in the Southern Region of the United States*; Campbell, C.R., Ed.; Southern Cooperative Series Bulletin #394; Southern Region Agricultural Experiment Station: Fayetteville, AR, USA, 2000. Available online: <https://aesl.ces.uga.edu/sera6/PUB/scsb394.pdf> (accessed on 5 March 2024).
23. dos Santos, C.L.; Roberts, T.L.; Purcell, L.C. Leaf nitrogen sufficiency level guidelines for midseason fertilization in corn. *Agron. J.* **2021**, *113*, 1974–1980. [[CrossRef](#)]
24. Heckman, J.R.; Sims, J.T.; Beegle, D.B.; Coale, F.J.; Herbert, S.J.; Bruulsema, T.W.; Bamka, W.J. Nutrient Removal by Corn Grain Harvest. *Agron. J.* **2003**, *95*, 587–591. [[CrossRef](#)]
25. Woli, K.P.; Sawyer, J.E.; Boyer, M.J.; Abendroth, L.J.; Elmore, R.W. Corn Era Hybrid Macronutrient and Dry Matter Accumulation in Plant Components. *Agron. J.* **2018**, *110*, 1648–1658. [[CrossRef](#)]
26. Rochester, I.J. Nutrient uptake and export from an Australian cotton field. *Nutr. Cycl. Agroecosyst.* **2007**, *77*, 213–223. [[CrossRef](#)]
27. Adeli, A.; Tewolde, H.; Rowe, D.E.; Sistani, K.R. Continuous and residual effects of broiler litter application to cotton on soil properties. *Soil Sci.* **2011**, *176*, 668–675. [[CrossRef](#)]
28. Moore, P.A., Jr.; Edwards, D.R. Long-term effects of poultry litter, alum-treated litter, and ammonium nitrate on aluminum availability in soils. *J. Environ. Qual.* **2005**, *34*, 2104–2111. [[CrossRef](#)]

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