

Article



Does Soybean Yield and Seed Nutrient Content Change Due to Broiler Litter Application?

Rajveer Singh¹, Rishi Prasad^{1,*}, Dennis P. Delaney¹ and Dexter B. Watts²

- ¹ Department of Crop, Soil and Environmental Sciences, Auburn University, Auburn, AL 36849, USA; rzs0100@auburn.edu (R.S.); delandp@auburn.edu (D.P.D.)
- ² USDA-ARS, National Soil Dynamics Laboratory, Auburn, AL 36832, USA; dexter.watts@usda.gov
- * Correspondence: rzp0050@auburn.edu

Abstract: Broiler litter (BL) has the potential to be used as an alternative multi-nutrient source for soybean (Glycine max L.) production. While previous research on soybean yield response to BL has reported inconsistent results, the effects of BL application on soybean seed nutrient concentrations are largely unknown or less studied. The objective of this two-year field study was to investigate the effect of BL application on soybean yield and seed nutrient content in three different soil types and production environments. To pursue the objective, a field experiment was established in 2018 in a Compass loamy sand with four BL rates (0, 2.2, 5.6, and 11.2 Mg BL ha⁻¹). In 2019, the study was expanded to include two additional soil types (Decatur silty clay loam and Dothan fine sandy loam) totaling four site years. The experimental design at each site was a randomized complete block with four replications. Application of BL had no impact on soybean yield in the first year, regardless of application rate and soil type. In the second year of BL application, soybean yield was 43% higher overall compared to no BL plots on a Compass loamy sand. However, soybean yield with the application of 5.6 or 11.2 Mg BL ha⁻¹ was not statistically different from that at 2.2 Mg BL ha⁻¹. Soybean seed Ca and B concentrations changed significantly among the treatments; however, the change was not consistent across the sites. Consecutive year application of 11.2 Mg BL ha⁻¹ yr⁻¹ produced the highest seed K and Cu concentrations. The results of this research suggest that repeated BL application can boost soybean yield and potentially enrich seed with selected nutrients.

Keywords: poultry manure; application rate; soybean seed composition

1. Introduction

The broiler chicken (*Gallus gallus domesticus*) industry has expanded rapidly in the United States from 10 billion pounds of broilers produced in 1968 to about 60 billion pounds in 2018 [1]. The industry generates a by-product known as broiler litter (BL) which is a mixture of chicken excreta and bedding material. Typically, 1.1 to 1.5 kg litter is generated per broiler chicken [2]. Broiler litter is a valuable source of essential plant nutrients [3]. Much of the BL produced is land-applied as an alternative source of nitrogen (N), and to improve soil organic matter in row crop production systems such as cotton (*Gossypium hirsutum* L.) and corn (*Zea mays* L.). Typically, soils in the southeast USA are highly eroded, low in organic matter, and have low water holding capacities. Addition of BL to such soils increase the soil organic matter [4] improving soil physical, chemical, and biological properties, and subsequently overall soil health [5,6].

Soybean (*Glycine max* L.), being a leguminous crop meets most of its nitrogen (N) requirement through symbiotic N fixation eliminating the need for supplemental N. However, several studies have reported increased yield with N fertilization to soybean [7–10]. Schmidt et al. [11] found that average soybean yield was increased by 1.4 kg kg⁻¹ of applied available-N. Varvel and Peterson [12] found that soybean yielding 2.5 to 3.4 Mg ha⁻¹ may remove up to 200 kg N ha⁻¹ yr⁻¹ reporting soybean as a net N sink. In addition to N, soybean also requires a constant supply of phosphorus (P), potassium (K), and micronutrients for



Citation: Singh, R.; Prasad, R.; Delaney, D.P.; Watts, D.B. Does Soybean Yield and Seed Nutrient Content Change Due to Broiler Litter Application? *Agronomy* **2021**, *11*, 1523. https://doi.org/10.3390/ agronomy11081523

Academic Editors: Shiping Deng and Xiufen Li

Received: 2 June 2021 Accepted: 27 July 2021 Published: 30 July 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). optimal growth and development [13]. Gates and Muller [14] reported a stronger symbiotic association and greater N fixation in soybean with the addition of fertilizer containing N, P, and sulfur (S). Since BL contains these nutrients, its application to soybean fields could be beneficial long term by serving as a natural source of micronutrients for soybean plants.

Several studies have evaluated the effects of BL application on soybean yield [15–21], but reported contradicting results. For example, Adeli et al. [16] observed 9% greater soybean yield from BL application compared with conventional fertilizer due to the availability of secondary and micronutrients in the BL. Over the unfertilized control, Garcia and Blancaver [22] found that BL increased soybean yield by 62%. In contrast, Quinn and Steinke [19] reported that BL had no impact on soybean yield across traditional and intensive management systems at all site years studied. Slaton et al. [20] found that eleven out of twelve fertilization trails were unresponsiveness to BL application compared with conventional fertilizer at equivalent rates of P and K.

Traditionally, soybean is planted for seed protein and oil content in the United States. However, K deficiency in soybean lowers leaf photosynthesis and carbohydrates transport by phloem [23] which may adversely affect seed oil content [24]. Application of BL to soil can enhance the content of mineral elements such as P and K in the soil [6,25] influencing the nutrient uptake and subsequent nutritional status of the soybean plants [16,20]. Furthermore, research has shown that greater availability of mineral nutrients has the potential to increase the seed concentrations of minerals elements in soybean plants. Farmaha et al. [26] observed high positive correlation ($\mathbb{R}^2 > 0.90$) of soybean seed P and K concentrations with trifoliate leaf concentrations at R1 development stage. Enhanced mineral content of soybean seed could affect its nutritional quality and use as a food crop, and for specialty markets. For instance, seed calcium (Ca) content is critical for manufacturing a soy-based food, natto [27].

Previous research with or without BL has largely focused on protein and oil concentrations in soybean seeds [28–33]. Only limited studies have investigated the effect of BL application rates and their impact on soybean seed nutrient concentrations. Whether BL applications at higher rates enriches the soybean seed with mineral elements warrants further investigation. Therefore, the objective of this study was to evaluate the effects of application rates of BL on soybean yield and seed mineral concentrations.

2. Materials and Methods

2.1. Study Sites and Treatment

Field experiments were conducted in 2018 and 2019 under rainfed conditions at three sites in Alabama. These sites were Tennessee Valley Research & Extension Center (TVREC) near Belle Mina, AL (34°41' N, 86°53' S), E.V. Smith Research Center (EVS) near Shorter, AL (32°25′ N, 85°53′ S), and Wiregrass Research and Extension Center (WREC) near Headland, AL (31°22' N, 85°18' S), representing three different production environment and soil types of Alabama (north, central, and south, respectively). The TVREC and WREC research sites were added in 2019 for a total of four site years data. The soil was a Decatur silty clay loam (clayey, kaolinitic, thermic, Rhodic Paleudults) on a slope of 1 to 2% at TVREC, a Compass loamy sand (coarse-loamy, siliceous, sub active, thermic Plinthic Paleudults) on a slope of 1 to 3% at EVS, and a Dothan fine sandy loam (fine-loamy, kaolinitic, thermic Typic Kandiudults) on a slope of 0 to 2% slope at WREC. The baseline soil properties at the 0- to 15 cm depth are presented in Table 1. There was a large variation in the total precipitation received during the growing seasons (June–November) of 2018 and 2019 at EVS. Total precipitation between June and November was 45% less (402 mm) in 2019, compared to 736 mm in 2018 at EVS. Total growing season precipitation at WREC and TVREC was 537 mm and 553 mm, respectively, in 2019. The 5-yr mean (2013-2017) growing season precipitation at the experiment sites was 460 mm (EVS), 567 mm (WREC), and 524 mm (TVREC).

Location/Year	рH	Moisture	Total C	Total N	Р	К	Mg	Ca	В	Zn	Mn	Fe	Cu	
	%					g kg ⁻¹				$ m mgkg^{-1}$				
Soil														
EVS ⁺	6.2	_	14.4	3.5	0.01	0.04	0.04	0.60	0.1	0.7	10.4	14.1	0.2	
WREC	5.9	_	13.0	3.9	0.03	0.04	0.02	0.36	0.1	2.5	10.3	8.2	1.7	
TVREC	6.2	-	16.7	4.3	0.02	0.12	0.07	0.98	0.34	2	50	5.7	0.7	
Broiler litter														
2018	-	26.2	351.1	26.7	8.8	16.4	6.0	11.8	26	174.7	227	1498	59.3	
2019	-	26.7	300.0	31.8	20.2	28.1	4.1	17.6	25	250.0	400	600	300.0	

Table 1. Initial soil chemical characteristics at 0- to 15 cm depth (Mehlich 1 extraction) before experiment initiation and concentration of selected nutrients (on a fresh-weight basis) in broiler litter (BL) applied to soybean each year at the experimental sites.

⁺ E.V. Smith Research Center (EVS); Wiregrass Research and Extension Center (WREC); Tennessee Valley Research and Extension Center (TVREC).

The experimental design was a randomized complete block with four replications. Treatments included BL application at 0, 2.2, 5.6, and 11.2 Mg ha⁻¹ on a fresh weight basis, hereafter designated as control, BL2.2, BL5.6, and BL11.2, respectively. These rates were selected to represent the commonly used BL management practices. Individual plots were four-rows wide and 6.1 m long, maintained in a conservation tillage system.

2.2. Crop Management

The nutrient concentration of BL used in the study is presented in Table 1. The BL for the respective application rate was surface broadcasted by hand without incorporation before planting. All plots received a blanket application of phosphorus (P_2O_5) and potassium (K_2O) each year, surface-applied at a rate of 45 kg ha⁻¹ based on soil test P and K recommendations from the Auburn University Soil Testing Laboratory. These applications masked the effects of P and K supplied with BL [34]. In actual practice, BL is primarily applied as a soil builder for improving soil organic matter or to meet crop N demands. Information on the soybean cultural practices adopted at the research sites is summarized in Table 2.

Table 2. Cultural practices adopted in the study at the experimental sites.

Location	Year	Treatment Application	Cultivar	Planting	g Harvest		
EVS ⁺	2018	5 July	$AG74 \times 8$	12 July	29 November		
EVS	2019	4 June	$AG74 \times 8$	14 June	20 November		
WREC	2019	11 June	$AG74 \times 8$	18 June	20 November		
TVREC	2019	31 May	$AG52 \times 9$	14 June	3 October		

⁺ E.V. Smith Research Center (EVS); Wiregrass Research and Extension Center (WREC); Tennessee Valley Research and Extension Center (TVREC).

Herbicides were applied when necessary, to control weeds during each growing season.

2.3. Sample Collection and Nutrient Analysis

Baseline soil chemical characteristics were determined from the initial soil samples taken on 25 June 2018 at EVS, 11 June 2019 at WREC, and 28 March 2019 at TVREC, before BL application. Three to five soil cores (80 mm diameter) were collected at the 0–15 cm depth from the entire field, air-dried, and ground to pass through a 2 mm sieve. Total carbon (TC) and total N (TN) in the soil and litter samples were determined by dry combustion method using a LECO CN2000 analyzer (LECO Corp., St. Joseph, MI, USA). Soil samples were extracted with Mehlich-1 extractant using 1:4 (w/v) soil to solution ratio shaken for five minutes [35] and analyzed for P, K, Mg, Ca, S, B, Zn, Mn, Fe and Cu using an inductively coupled plasma-atomic emission spectrometry (ICP-AES; Spectro Ciros, Spectro Analytical Instruments Inc. Mahwah, NJ, USA). Soil pH was measured using a

4 of 10

glass electrode in a 1:1 soil/water ratio. To determine the change in these nutrient elements due to treatment effect, all plots were sampled (two soil cores at 0–15 cm depth) from the middle two rows at the end of the experiment on 22 November 2019 at EVS, 16 December 2019 at WREC, and 17 December 2019 at TVREC.

Soybean yield was determined by harvesting the middle two rows of each plot after physiological maturity and reported at a moisture of 130 g kg⁻¹. A harvested subsample (about 500 g) of soybean seed was collected from each plot, air-dried, and ground with a Wiley Mill to pass a 1 mm screen. Concentrations of total P, K, Mg, Ca, S, B, Zn, Mn, Fe and Cu in the seed and litter samples were determined by the ICP-AES (Spectro Ciros, Spectro Analytical Instruments Inc. Mahwah, NH, USA) following dry-ashing and acid-digestion of the samples [36]. Total N in the soybean seeds was determined by dry combustion method using a LECO CN2000 analyzer (LECO Corp., St. Joseph, MI, USA). Soybean nutrient uptake values were calculated from yield and seed nutrient concentrations [17].

2.4. Statistical Analysis

Data analyses were performed using the PROC GLIMMIX of SAS 9.4 as a randomized complete block design [37] by individual location and year due to differences in soil types, weather conditions, and BL used. The fertility treatments were treated as fixed effects and blocks were considered as random effects. Treatment means were separated using the least square means test at $\alpha = 0.05$ unless stated otherwise [38].

3. Results

3.1. Soybean Yield

Application of BL regardless of the rate, did not produce significantly greater soybean yield (p > 0.05) compared to no BL in the first year of application across sites (Table 3).

	Yield (kg ha $^{-1}$)										
Treatment	EVS ⁺ (2018)	EVS (2019)	WREC	TVREC							
Control	2843	814b	2087	1789							
BL2.2	3394	1188a ⁺⁺	2191	1819							
BL5.6	2779	1082a	1998	1950							
BL11.2	3498	1220a	2273	1957							
p value	0.1832	0.0181	0.6693	0.2677							

Table 3. Soybean yield as affected by fertilizer treatments at the experimental sites.

⁺ E.V. Smith Research Center (EVS); Wiregrass Research and Extension Center (WREC); Tennessee Valley Research and Extension Center (TVREC). ⁺⁺ Means followed by the different letter within a column are statistically different at $p \le 0.05$.

Repeating the BL application to the same plots in the succeeding year (i.e., at EVS in 2019) significantly increased soybean yield compared with control. The average soybean yield from the BL-treated plots was 42% greater than the control plots in 2019; however, the use of higher BL rates (5.6 or 11.2 Mg ha⁻¹) had no positive impact on soybean yield compared to 2.2 Mg BL ha⁻¹. Averaged across treatments, soybean yield at EVS was 205% greater in 2018 than in 2019 likely due to more rainfall during the 2018 growing season.

3.2. Seed Nutrient Concentration

The analysis of soybean seed nutrient concentration data indicated that in the first year of BL application, seed nutrient concentrations did not differ among the treatments at EVS; however, treatment difference was observed in seed Ca concentration at WREC and seed B concentration at TVREC (Table 4).

Treatment	Ν	Р	К	Mg	Ca	S	В	Zn	Mn	Fe	Cu
			g k	g^{-1}					${ m mg}{ m kg}^{-1}$		
EVS ⁺ (2018)											
Control	68.90	6.25	18.62	2.65	4.50	3.72	31.27	48.68	58.82	88.33	15.27
BL2.2	69.60	6.25	18.45	2.65	4.37	3.77	31.82	50.14	58.75	91.38	15.08
BL5.6	69.32	6.42	19.17	2.60	4.37	3.95	33.72	49.93	68.71	89.77	17.17
BL11.2	68.27	6.50	19.70	2.70	4.35	4.00	37.19	46.01	64.67	97.62	16.53
<i>p</i> value	0.5754	0.7249	0.2097	0.7473	0.9463	0.3650	0.0557	0.6163	0.5074	0.4204	0.2472
EVS ⁺ (2019)											
Control	60.55	6.15	19.92b	2.67	3.67	3.75	29.50	56.25	58.75	72.50	14.25b
BL2.2	60.87	6.02	19.77b ++	2.60	3.75	3.72	27.00	53.75	51.75	73.00	13.25b
BL5.6	61.02	6.27	20.80ab	2.67	3.57	3.67	26.50	51.50	51.75	69.50	14.75b
BL11.2	60.00	6.37	21.57a	2.67	3.60	3.72	28.75	51.50	53.25	74.75	16.50a
<i>p</i> value	0.9295	0.3880	0.0136	0.8661	0.1780	0.8571	0.4363	0.4186	0.1974	0.3738	0.0101
WREC											
Control	65.12	6.17	22.10	2.52	3.75a	3.65	29.25	56.25	54.75	72.50	14.25
BL2.2	64.95	6.32	21.42	2.50	3.50b	3.67	26.50	56.50	52.75	70.25	14.00
BL5.6	65.00	6.20	22.20	2.52	3.55b	3.72	28.25	56.75	51.00	71.75	14.75
BL11.2	63.95	6.15	22.12	2.52	3.57b	3.75	27.50	57.00	51.25	76.00	14.50
<i>p</i> value	0.6177	0.5271	0.3539	0.8017	0.0155	0.4918	0.8134	0.9771	0.4230	0.1113	0.7938
TVREC											
Control	61.70	5.92	20.32	2.32	4.00	3.25	42.25a	46.50	71.25	78.75	10.00
BL2.2	62.52	5.90	19.92	2.30	3.95	3.25	40.00ab	45.00	70.25	74.75	10.00
BL5.6	61.40	5.62	19.75	2.22	3.85	3.17	37.75b	44.25	59.75	80.50	10.00
BL11.2	63.02	6.05	20.87	2.30	3.82	3.30	37.75b	45.75	63.75	77.50	10.75
<i>p</i> value	0.2970	0.1910	0.0651	0.3373	0.2270	0.1097	0.0153	0.4303	0.3753	0.6883	0.2455

Table 4. Total seed nutrient concentrations of soybean fertilized with broiler litter (BL) measured across experimental sites.

[†] E.V. Smith Research Center (EVS); Wiregrass Research and Extension Center (WREC); Tennessee Valley Research and Extension Center (TVREC). ^{††} Means followed by the different letter within a column for the same year are statistically different at $p \le 0.05$.

Soybean seed Ca concentration from the plots which received BL irrespective of the rate was lower than the control plots at WREC. The control treatment also had the highest soybean seed B concentration at TVREC. In the second season (i.e., 2019) at EVS, treatment difference was observed in seed K and Cu concentrations. The plots fertilized at 2.2 and 5.6 Mg BL ha⁻¹ had similar seed K and Cu concentrations to those of the control plots but the BL11.2 treatment had the highest seed K and Cu concentrations. Soybean seed concentrations of N, P, Mg, S, Zn, Mn, and Fe were not affected by treatments at any site-year.

3.3. Seed Nutrient Removal

No significant variability in nutrient removal rates was observed between treatments in the first year of BL application (Table 5).

Although, treatments differed for some of the seed mineral element concentrations at WREC and TVREC, accumulation of macro- and micro-nutrients in soybean seed was not influenced by treatments. Seed nutrient uptake values were greater for BL than the control plots in the second year of application at EVS.

Treatment	Ν	Р	К	Mg	Ca	S	В	Zn	Mn	Fe	Cu
			kg l	na ⁻¹					g ha ⁻¹		
EVS ⁺ (2018)											
Control	201.2	17.5	52.4	7.5	13.3	10.7	86.5	147.4	152.4	244.3	42.3
BL2.2	236.7	20.4	62.2	8.9	14.4	12.7	106.0	166.2	192.4	311.0	50.4
BL5.6	187.1	17.5	52.7	7.2	12.1	11.1	98.9	129.4	171.3	247.7	48.1
BL11.2	232.5	22.4	68.1	9.2	13.6	13.9	126.9	156.9	204.2	360.8	56.4
<i>p</i> value	0.1648	0.2922	0.2817	0.1851	0.6263	0.3845	0.0801	0.5604	0.5180	0.2692	0.6198
EVS (2019)											
Control	49.7b	5.1b	16.5b	2.1	3.0b	3.1b	23.0	46.3b	47.5	59.0b	11.3c
BL2.2	72.4a ††	7.2a	23.5a	3.1	4.4a	4.4a	32.2	63.6a	60.8	86.8a	15.6b
BL5.6	66.0a	6.8a	22.5a	2.9	3.9a	4.0a	28.7	55.7ab	56.2	75.4ab	16.0b
BL11.2	73.0a	7.8a	26.3a	3.3	4.4a	4.5a	35.4	62.1a	64.6	91.6a	20.0a
<i>p</i> value	0.0107	0.0050	0.0201	0.0583	0.0077	0.0232	0.1154	0.0272	0.0883	0.0353	0.0030
WREC											
Control	135.6	12.9	46.2	5.3	7.8	7.6	61.1	117.1	113.8	151.5	29.5
BL2.2	142.0	13.8	47.0	5.5	7.7	8.0	57.8	123.4	115.6	153.9	30.7
BL5.6	129.3	12.3	44.2	5.0	7.1	7.4	55.5	112.6	101.5	142.8	29.1
BL11.2	145.0	14.0	50.4	5.7	8.1	8.5	61.2	128.7	116.2	172.8	32.7
<i>p</i> value	0.7045	0.6035	0.6682	0.6411	0.6612	0.5236	0.7004	0.6038	0.7337	0.3272	0.4690
TVREC											
Control	110.4	10.6	36.3	4.1	7.2	5.81	75.5	82.9	127.2	140.6	17.8b
BL2.2	113.7	10.7	36.2	4.2	7.2	5.91	72.6	81.7	127.8	136.0	18.2b
BL5.6	119.7	11.0	38.5	4.3	7.5	6.19	73.7	86.1	116.2	158.2	19.4ab
BL11.2	123.4	11.8	40.9	4.5	7.5	6.46	73.9	89.5	124.0	151.7	21.0a
<i>p</i> value	0.2454	0.3931	0.1685	0.4044	0.7482	0.2472	0.8888	0.1863	0.7053	0.4313	0.0387

Table 5. Seed nutrient uptake of soybean fertilized with broiler litter (BL) at the experimental sites.

[†] E.V. Smith Research Center (EVS); Wiregrass Research and Extension Center (WREC); Tennessee Valley Research and Extension Center (TVREC). ^{††} Means followed by the different letter within a column for the same year are statistically different at $p \le 0.05$.

4. Discussion

4.1. Soybean Yield

Application of BL did not influence soybean yield in the first season at any of the three sites. This could be because the treatments reflected similar soil M-1 extractable nutrient concentrations as observed at WREC and TVREC (Table 6).

According to Welch et al. [39], it is challenging to obtain soybean yield benefits from manure application in most soils with adequate levels of mineral elements to meet plant nutrient requirements. For instance, Slaton et al. [20] observed no yield response to BL fertilization in two out of four trials and attributed to sufficient soil P and K levels. Any positive changes to soil nutrient levels or physical properties from BL fertilization translating to yield gains likely did not occur due to short-term application of BL (i.e., one year) [40,41]. Subsequent BL application at EVS significantly increased soybean yield relative to control. Multiple studies have reported positive residual effects of BL on soybean yield [17,18]. However, temporal change in soil test nutrient contents at EVS indicated that 2.2 or 5.6 Mg ha⁻¹ yr⁻¹ BL was inadequate for increasing soil concentrations of M-1 extractable nutrients (except K with 5.6 Mg ha⁻¹ yr⁻¹ BL) at 0 to 15 cm depth over a twoyear period compared to control plots, but 11.2 Mg ha⁻¹ yr⁻¹ BL resulted in highest soil P, K, Zn, and Cu concentrations. This was also consistent with Adeli et al. [17] who reported increased levels of soil P, K, Zn, and Cu in plots which had received BL in the previous year at a rate greater than 5.6 Mg ha⁻¹ (i.e., 6.7 Mg ha⁻¹). Werner [42] and Drinkwater et al. [43] reported that nutrient loading of soils from periodic manure application is a slow process and may take years until significant differences in available nutrients can be

detected. Furthermore, since applied BL was left on the soil surface without incorporation, ammonia (NH₃) volatilization losses [44] and litter P losses via surface water runoff [45] could be significantly higher reducing soil nutrient availability [46]. Subsurface banding of BL could result in reduced runoff N, P, Zn, and Cu concentrations compared with surface application [46]. These findings were evidence that the organic fraction of BL could be related to a significant soybean yield benefit. The increased soybean yield with BL could be related to the enhanced levels of soil fungal population [47] or other soil microorganisms including actinomycetes and bacteria [48], and soil enzymatic activity [49], thus improving overall soil quality. However, changes in microbial numbers due to BL addition and whether they contributed to the better soybean yield were not determined in this study. In addition, there was no significant difference in soybean yield among BL2.2, BL5.6, and BL11.2 treatments at EVS in 2019 indicating that BL application at a rate >2.2 Mg ha⁻¹ exceeded the crop N demand in the second season.

Table 6. Soil pH, and Mehlich-1 extractable nutrients of soil samples (0–0.15 m depth) taken at the end of the study at the experimental sites.

Treatment	pН	Р	К	Mg	Ca	В	Zn	Mn	Fe	Cu
						${ m mg}~{ m kg}^{-1}$				
EVS [†]										
Control	6.05	7.25b	36.62b	42.12	494.63	0.11	0.44b	8.50	15.37	0.12b
BL2.2	6.37	11.87b ++	49.00b	46.50	483.75	0.16	0.56b	9.25	14.87	0.25b
BL5.6	6.40	17.12b	66.62b	42.62	435.50	0.15	0.89b	9.00	13.75	0.39b
BL11.2	6.42	50.37a	99.87a	62.12	425.60	0.17	2.37a	9.12	17.62	1.19a
<i>p</i> value	0.4009	0.0240	0.0060	0.3664	0.8587	0.4168	0.0290	0.9502	0.2188	0.0107
WREC										
Control	6.05	17.87	39.87	23.37	331.25	0.10	1.61	11.12	12.37	1.09
BL2.2	6.10	22.37	43.62	23.12	346.12	0.10	1.96	11.62	14.00	1.34
BL5.6	6.11	21.00	37.17	24.76	336.04	0.10	1.90	11.35	14.48	1.13
BL11.2	6.02	31.75	46.00	29.12	382.00	0.10	2.27	13.37	15.00	1.35
<i>p</i> value	0.9573	0.2232	0.6502	0.2384	0.4039	-	0.5692	0.4887	0.4858	0.7312
TVREC										
Control	6.22	25.12	122.87	66.37	947.13	0.25	1.30	86.00	12.87	0.52
BL2.2	6.35	25.00	138.12	68.37	1088.88	0.25	1.25	83.25	12.75	0.74
BL5.6	6.35	29.00	163.12	75.12	952.50	0.27	1.92	85.87	13.00	0.87
BL11.2	6.20	49.62	189.13	91.25	983.13	0.35	3.56	93.25	14.12	1.54
<i>p</i> value	0.5930	0.5311	0.3118	0.6639	0.8287	0.3549	0.4575	0.7275	0.8509	0.4257

[†] E.V. Smith Research Center (EVS); Wiregrass Research and Extension Center (WREC); Tennessee Valley Research and Extension Center (TVREC). ^{††} Means followed by the different letter within a column for the same year are statistically different at $p \le 0.05$.

4.2. Seed Nutrient Concentration

The results suggest that one year application of BL had no consistent influence on soybean seed nutrient concentrations. These results agree with Slaton et al. [20] who also reported varied trends in soybean seed concentrations among nutrient sources, including BL, at eight trials conducted from 2008–2010. Soybean seed nutrient composition can be affected by several factors including genetic and environmental variability [50], soil nutrient status, and fertilizer management practices [26,30,51]. Heckman et al. [52] reported variable grain nutrient concentrations with a single corn hybrid grown at six different site years. However, periodic application of BL at the higher rate may enrich soybean with limited mineral elements as evidenced by seed K and Cu levels in the present study.

4.3. Seed Nutrient Removal

Soybean seed nutrient removal followed similar trends as the seed yield at full maturity. These results indicated that soybean seed nutrient removal was primarily a function of seed yield rather than seed nutrient concentration. In line with our results, Adeli et al. [17] reported that soybean seed N, P, and K uptake followed a pattern like that for seed yield than for seed N, P, and K concentrations.

5. Conclusions

Broiler litter did not influence soybean yield in the first year of application. Although BL significantly increased soybean yield in the second year compared to no BL control, similar soybean yields were found among the 2.2, 5.6, and 11.2 Mg ha⁻¹ BL application rates. No residual effect of BL was observed on soil nutrient contents unless applied at the rate of 11.2 Mg ha⁻¹ yr⁻¹. Soil test P, K, Zn, and Cu levels at the 0- to 15 cm soil depth were significantly greater for 11.2 Mg BL ha⁻¹ yr⁻¹ than the 2.2 or 5.6 Mg BL ha⁻¹ yr⁻¹ following 2 yr of litter application. Our study indicated that a single application of BL has no consistent or major effect on soybean seed nutrient composition. However, long-term application of high rates of BL (>5.6 Mg ha⁻¹ yr⁻¹) may potentially enrich soybean seed with some of the mineral elements, but further research is needed to verify the finding and applicability to other locations.

Author Contributions: Conceptualization, R.P.; methodology, R.P.; formal analysis, R.S.; writing original draft preparation, R.S.; writing—review and editing, R.P., D.P.D. and D.B.W.; supervision, R.P.; funding acquisition, R.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Alabama Soybean Producers, grant number "commodity funding".

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data supporting reported results are available on request from the corresponding author.

Acknowledgments: This project was supported by Alabama Soybean Producers, Alabama Agricultural Experiment Station and Hatch Program of the National Institute of Food and Agriculture, United States Department of Agriculture.

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

References

- 1. USDA-NASS. Agricultural Statistics 2018; USDA-NASS: Washington, DC, USA, 2019.
- Brye, K.R.; Golden, B.; Slaton, N.A. Poultry litter decomposition as affected by litter form and rate before flooding for rice production. *Soil Sci. Soc. Am. J.* 2006, 70, 1155–1167. [CrossRef]
- Sharpley, A.N.; Smith, S.J.; Bain, W.R. Nitrogen and phosphorus fate from long-term poultry litter applications to Oklahoma soils. Soil Sci. Soc. Am. J. 1993, 57, 1131–1137. [CrossRef]
- 4. Watts, D.B.; Torbert, H.A.; Prior, S.A.; Huluka, G. Long-term tillage and poultry litter impacts soil carbon and nitrogen mineralization and fertility. *Soil Sci. Soc. Am. J.* 2010, 74, 1239–1247. [CrossRef]
- Edmeades, D.C. The long-term effects of manures and fertilizers on soil productivity and quality: A review. *Nutr. Cycl. Agroecosyst.* 2003, 66, 165–180. [CrossRef]
- 6. Adeli, A.; Tewolde, H.; Sistani, K.R.; Rowe, D.E. Comparison of broiler litter and commercial fertilizer at equivalent N rates on soil properties. *Commun. Soil Sci. Plant Anal.* **2010**, *41*, 2432–2447. [CrossRef]
- 7. Lamb, J.A.; Rehm, G.W.; Severson, R.K.; Cymbaluk, T.E. Impact of inoculation and use of fertilizer N on soybean production where growing seasons are short. *J. Prod. Agric.* **1990**, *3*, 241–245. [CrossRef]
- 8. Sorensen, R.C.; Penas, E.J. Nitrogen fertilization of soybeans. Agron. J. 1978, 70, 213–216. [CrossRef]
- 9. Brevedan, R.E.; Egli, D.B.; Leggett, J.E. Influence of N nutrition on flower and pod abortion and yield of soybeans. *Agron. J.* **1978**, 70, 81–84. [CrossRef]
- 10. Bhangoo, M.S.; Albritton, D.J. Nodulating and non-nodulating Lee soybean isolines response to applied nitrogen. *Agron. J.* **1976**, *68*, 642–645. [CrossRef]

- 11. Schmidt, J.P.; Lamb, J.A.; Schmitt, M.A.; Randall, G.W.; Orf, J.H.; Gollany, H.T. Soybean varietal response to liquid swine manure application. *Agron. J.* 2001, *93*, 358–363. [CrossRef]
- 12. Varvel, G.E.; Peterson, T.A. Nitrogen fertilizer recovery by soybean in monoculture and rotation systems. *Agron. J.* **1992**, *84*, 215–218. [CrossRef]
- Varco, J.J. Nutrition and fertility requirements. In Soybean Production in the Midsouth; Heatherly, L.G., Hodges, H.F., Eds.; CRC Press: Washington, DC, USA, 1999; pp. 53–70.
- 14. Gates, C.T.; Muller, W.J. Nodule and plant development in the soybean: Growth response to nitrogen, phosphorus, and sulfur. *Aust. J. Bot.* **1979**, *27*, 203–215. [CrossRef]
- 15. Lin, Y.; Watts, D.B.; Torbert, H.A.; Howe, J.A. Double-crop wheat and soybean yield response to poultry litter application. *Crop. Forage Turfgrass Manag.* **2019**, *5*, 180082. [CrossRef]
- 16. Adeli, A.; Sistani, K.R.; Rowe, D.E.; Tewolde, H. Effects of broiler litter on soybean production and soil nitrogen and phosphorus concentrations. *Agron. J.* 2005, *97*, 314–321. [CrossRef]
- 17. Adeli, A.; Read, J.J.; McCarty, J.; Jenkins, J.N.; Feng, G. Soybean yield and nutrient utilization following long-term pelletized broiler litter application to cotton. *Agron. J.* **2015**, *107*, 1128–1134. [CrossRef]
- 18. Adeli, A.; Brooks, J.P.; Read, J.J.; Feng, G.; Miles, D.; Shankle, M.W.; Jenkins, J.N. Corn and soybean grain yield responses to soil amendments and cover crop in upland soils. *J. Plant Nutr.* **2019**, *42*, 2484–2497. [CrossRef]
- 19. Quinn, D.; Steinke, K. Comparing high- and low-input management on soybean yield and profitability in Michigan. *Crop Forage Turfgrass Manag.* **2019**, *5*, 190029. [CrossRef]
- Slaton, N.A.; Roberts, T.L.; Golden, B.R.; Ross, W.J.; Norman, R.J. Soybean response to phosphorus and potassium supplied as inorganic fertilizer or poultry litter. *Agron. J.* 2013, 105, 812–820. [CrossRef]
- 21. Watts, D.B.; Torbert, H.A. Long-term tillage and poultry litter impacts on soybean and corn grain yield. *Agron. J.* **2011**, *103*, 1479–1486. [CrossRef]
- 22. Garcia, J.M.; Blancaver, A.T. Effect of animal manure on the growth and yield of soybean and physical properties of the soil. *CMU J. Agric. Food Nutr. (Philippines)* **1983**, *4*, 196–212.
- 23. Wallingford, W. Functions of potassium in plants. In *Potassium in Agriculture*; Potash and Phosphate Institute: Atlanta, GA, USA, 1980; pp. 10–27.
- 24. Gaydou, E.M.; Arrivets, J. Effects of phosphorus, potassium, dolomite, and nitrogen fertilization on the quality of soybean. Yields, protein, and lipids. *J. Agric. Food Chem.* **1983**, *31*, 765–769. [CrossRef]
- 25. Tewolde, H.; Adeli, A.; Sistani, K.R.; Rowe, D.E. Mineral nutrition of cotton fertilized with poultry litter or ammonium nitrate. *Agron. J.* **2011**, *103*, 1704–1711. [CrossRef]
- 26. Farmaha, B.S.; Fernández, F.G.; Nafziger, E.D. No-till and strip-till soybean production with surface and subsurface phosphorus and potassium fertilization. *Agron. J.* **2011**, *103*, 1862–1869. [CrossRef]
- 27. Zhang, B.; Chen, P.; Shi, A.; Hou, A.; Ishibashi, T.; Wang, D. Putitive quantitative trait loci associated with calcium content in soybean seed. *J. Hered.* 2008, 100, 263–269. [CrossRef]
- Wood, C.W.; Torbert, H.A.; Weaver, D.B. Nitrogen fertilizer effects on soybean growth, yield, and seed composition. *J. Prod. Agric.* 1993, *6*, 354–360. [CrossRef]
- 29. Kaur, G.; Serson, W.R.; Orlowski, J.M.; McCoy, J.M.; Golden, B.R.; Bellaloui, N. Nitrogen sources and rates affect soybean seed composition in Mississippi. *Agronomy* **2017**, *7*, 77. [CrossRef]
- 30. Yin, X.; Vyn, T.J. Potassium placement effects on yield and seed composition of no-till soybean seeded in alternative row widths. *Agron. J.* **2003**, *95*, 126–132. [CrossRef]
- 31. Taylor, R.S.; Weaver, D.B.; Wood, C.W.; van Santen, E. Nitrogen application increases yield and early dry matter accumulation in late-planted soybean. *Crop. Sci.* 2005, 45, 854–858. [CrossRef]
- 32. Yin, X.H.; Bellaloui, N.; McClure, A.M.; Tyler, D.D.; Mengistu, A. Phosphorus fertilization differentially influences fatty acids, protein, and oil in soybean. *Am. J. Plant Sci.* 2016, 7, 1975–1992. [CrossRef]
- 33. Blair, R.M.; Savin, M.C.; Chen, P. Composted and formulated poultry litters promote soil nutrient availability but not plant uptake or edamame quality. *Agron. Sustain. Dev.* **2014**, *34*, 849–856. [CrossRef]
- 34. Ruiz Diaz, D.A.; Sawyer, J.E.; Mallarino, A.P. On-farm evaluation of poultry manure as a nitrogen source for corn. *Soil Sci. Soc. Am. J.* **2011**, *75*, 729–737. [CrossRef]
- 35. Mehlich, A. Determinations of P, Ca, Mg, K, Na, and NH4 by North Carolina Soil Testing Laboratories; North Carolina State University: Raleigh, NC, USA, 1953.
- 36. Donohue, S.J.; Aho, D.W. Determination of P, K, Ca, Mg, Mn, Fe, Al, B, Cu, and Zn in plant tissue by inductively coupled plasma (ICP) emission spectroscopy. In *Plant Analysis Reference Procedures for the Southern Region of the United States*; Plank, C.O., Ed.; Southern Cooperative Series Bulletin 368; University of Georgia: Athens, GA, USA, 1992; pp. 34–37.
- 37. SAS Institute. The SAS System for Windows: Version 8.02; SAS Institute Inc.: Cary, NC, USA, 2003.
- 38. Littell, R.C.; Milliken, G.A.; Stroup, W.W.; Wolfinger, R.D. SAS for Mixed Models, 2nd ed.; SAS Institute Inc.: Cary, NC, USA, 2006.
- 39. Welch, L.F.; Boone, L.V.; Chambliss, C.G.; Christiansen, A.T.; Mulvaney, D.L.; Oldham, M.G.; Pendelton, J.W. Soybean yields with direct and residual nitrogen fertilization. *Agron. J.* **1973**, *65*, 547–550. [CrossRef]
- 40. Mitchell, C.C.; Tu, S. Nutrient accumulation and movement from poultry litter. Soil Sci. Soc. Am. J. 2006, 70, 2146–2153. [CrossRef]

- Celik, I.; Ortas, I.; Kilic, S. Effects of compost, mycorrhiza, manure, and fertilizer on some physical properties of a Chromoxerert soil. *Soil Till. Res.* 2004, 78, 59–67. [CrossRef]
- 42. Werner, M.W. Soil quality characteristics during conversion to organic orchard management. App. Soil Eco. 1997, 5, 151–167. [CrossRef]
- 43. Drinkwater, L.E.; Letourneau, D.K.; Workneh, F.; van Bruggen, A.H.C.; Shennan, C. Fundamental difference between conventional and organic tomato agroecosystems in California. *Ecol. Appl.* **1995**, *5*, 1098–1112. [CrossRef]
- 44. Sharpe, R.R.; Schomberg, H.H.; Harper, L.A.; Endale, D.M.; Jenkins, M.B.; Franzluebbers, A.J. Ammonia volatilization from surface-applied poultry litter under conservation tillage management practices. *J. Environ. Qual.* 2004, 33, 1183–1188. [CrossRef]
- 45. Adeli, A.; Tewolde, H.; Shankle, M.W.; Way, T.R.; Brooks, J.P.; McLaughlin, M.R. Runoff quality from no-till cotton fertilized with broiler litter in subsurface bands. *J. Environ. Qual.* **2013**, *42*, 284–291. [CrossRef]
- 46. Tewolde, H.; Shankle, M.W.; Sistani, K.R.; Adeli, A.; Rowe, D.E. No-till and conventional-till cotton response to broiler litter fertilization in an upland soil: Lint yield. *Agron. J.* **2008**, *100*, 502–509. [CrossRef]
- 47. Pratt, R.G.; Tewolde, H. Soil fungal population levels in cotton fields fertilized with poultry litter and their relationships to soil nutrient concentrations and plant growth parameters. *Appl. Soil Ecol.* **2009**, *41*, 41–49. [CrossRef]
- 48. Acea, M.J.; Carballas, T. Microbial response to organic amendments in a forest soil. Bioresour. Technol. 1996, 57, 193–199. [CrossRef]
- 49. Acosta-Martinez, V.; Harmel, R.D. Soil microbial communities and enzyme activities under various poultry litter application rates. *J. Environ. Qual.* 2006, *35*, 1309–1318. [CrossRef] [PubMed]
- 50. Kleese, R.A.; Rasmusson, D.C.; Smith, L.H. Genetic and environmental variation in mineral element accumulation in barley, wheat, and soybeans. *Crop. Sci.* **1968**, *8*, 591–593. [CrossRef]
- 51. Ross, J.R.; Slaton, N.A.; Brye, K.R.; DeLong, R.E. Boron fertilization influences on soybean yield and leaf and seed boron concentrations. *Agron. J.* 2006, *98*, 198–205. [CrossRef]
- 52. 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]