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Corn Grain Yield and Soil Properties after 10 Years of Broiler Litter Amendment

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ABSTRACT

Use of broiler litter (BL) nutrients for crop production benefits crops, soils, and aids in disposing manure. Understanding corn (*Zea mays* L.) grain production and soil properties resulting from long-term BL amendment helps establish a sustainable manure-based corn production with low environmental risk potential. This study conducted at Bowling Green, KY, during 2005 to 2015 examined effects of supplying N requirement of corn grain crop monoculture by broiler litter (full broiler litter, FBL), 1:1 mixture of BL and inorganic N (half broiler litter rate, HBL), and chemical fertilizer (CF) on corn grain yield and post-harvest soil properties under no-till (NT) and conventional tillage (CT). The FBL produced significantly higher grain yield (10.1 Mg ha^{-1}) than the HBL (9.6 Mg ha^{-1}), but similar to CF (9.8 Mg ha^{-1}). The FBL soils had greater cation exchange capacity (CEC), organic matter (OM), and total nitrogen (TN) (15.5 cmol kg^{-1}; 45 and 2.9 g kg^{-1}) than the HBL (12.3 cmol kg^{-1}; 42.3 and 2.4 g kg^{-1}) and CF (10.1 cmol kg^{-1}; 35.5 and 1.7 g kg^{-1}). The FBL and HBL soils had 478 and 270 mg P kg^{-1}; 15.7 and 9.6 mg Cu kg^{-1}; 40.9 and 21.1 mg Zn kg^{-1} levels, respectively. Soil pH increased in the FBL, but decreased in CF. Soil nutrient aggregation rate was greater in the NT. Having lower soil nutrient accumulation than FBL and equivalent grain production potential as CF,-HBL offers a better option for corn grain production with BL than by FBL.

Core Ideas

- This study examined effects of long-term broiler litter amendment on corn grain yield and post-harvest soil properties.
- Broiler litter at full and half rates has similar corn grain production potential as chemical fertilizer.
- Broiler litter induced high soil nutrient levels, but levels elevated by half litter rate was not environmentally significant.
- No-till and conventional tillage treatments have similar agronomic benefits and environmental risks.

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Kentucky is the seventh largest broiler producing state in the United States with more than 308 million broilers produced annually (NASS, 2014). Broiler production results in large volumes of litter (a combination of manure, feed, and feather) as a byproduct. Broiler litter contains high levels of plant nutrients (Tewolde et al., 2005; Adeli et al., 2007) and it is a valuable nutrient source for many crops. Corn is the second most widely grown crop in Kentucky. Corn provides a base for many livestock feed formulations which includes poultry rations. The Kentucky poultry industry alone utilizes around 33% of locally grown corn grains as a feed ingredient (Kentucky Poultry Federation, 2014). Integration of BL nutrients with corn production benefits broiler producers as a method of manure disposal and corn growers as a low cost fertilizer that is also beneficial to soil health. Forage and row crop species have shown positive yield response to BL application (Kingery et al., 1994; Wood et al., 1996; Endale et al., 2002; Tewolde et al., 2005). Increased nutrient supply, enhanced OM content and water retention, and improved soil chemical and physical properties have been attributed to crop yield increase by animal manure (Meek et al., 1982; Whalen and Chang, 2002). However, some short-term studies have shown minimal corn grain yield difference between plots amended by either BL or chemical fertilizer (Harmel et al., 2008).

The effect of organic amendments on soil chemical and physical properties varies by the rate, type, and application method (Mooleki et al., 2004). Studies by Kaur et al. (2005) and Adeniyan et al. (2011) compared effects of organic and inorganic fertilizer on soil chemical and physical properties and showed significant soil organic matter, total C, available P, and total N increase by organic amendments. Broiler litter has a smaller N/P ratio (2.1) than required by many crops (Evers, 2002). Broiler litter land application for prolong periods caused P and soil micronutrient accumulation in surface soils (Kingery et al., 1994; Han et al., 2000). Excessive P in surface soils has the potential to enter water bodies causing undesired water quality. It is also not clear whether the soil micronutrient levels in continually BL-amended soils can exceed phytotoxic levels.

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Abbreviations: BL, broiler litter; CEC, cation exchange capacity; CF, commercial inorganic fertilizer; CT, conventional till; DM, dry matter; FBL, full broiler litter rate; HBL, half broiler litter rate; M-3, Mehlich-3; NT, no till.

Both NT and CT are common land management practices adopted in crop production. Compared to the traditional tillage operations, low energy cost and time demands are known as some reasons for wide farmer adoption of NT (Lal et al., 1990). Compared to the CT, NT soils have higher surface OM content (Wander et al., 1998). No-till soils have also reported improved soil moisture retention (Blevins et al., 1971), soil structure stability induced reduction of sediment bound nutrient losses in runoff (Harrold and Edwards, 1974), and greater soil nutrient retention (Lal et al., 2007). However, problems such as soil compaction and poor seedling emergence have been noted in NT (Raper et al., 2000; Schwab et al., 2002). Continuous animal manure application to NT soils creates vertical stratification (Sharpley et al., 1993) and manure-derived soil nutrient accumulation in surface soils can pose soil, water, and air pollution risks (Cooper et al., 1984; Sharpley et al., 1994). Given that N management is vital in corn production from economic and environmental perspectives, broiler litter incorporation under CT has an advantage over NT to reduce N loss as NH_3 volatilization (Giddens and Rao, 1975).

Although corn production with BL has economic and agronomic benefits over chemical fertilizer application, continually applying BL can elevate manure derived soil nutrients causing agronomic and environmental problems. Understanding grain production and soil characteristics resulting from long-term BL amendment is important in establishing sustainable manure-based corn production. However, long-term research efforts and science-based information on corn production using manure nutrients are scarce for the Kentucky karst region. Therefore, the objectives of this study were to examine corn yield differences and resulting post-harvest soil properties by BL (FBL), 50:50 combination of BL and inorganic N (HBL), and chemical fertilizer (CF) amendment in NT and CT corn soils.

MATERIALS AND METHODS

This study was conducted from 2005 to 2015 on a Pembroke soil (fine-silty, mixed, active, mesic Mollic Paleudalf) with 2% slope in Bowling Green, KY. The experiment was established as split-plot design, with tillage and nutrient source as main plot (11.6 by 6.3 m) and subplot (2.9 by 6.3 m) treatments,

Table 1. Average nutrient composition of applied broiler litter (wet basis) to experimental plots, Bowling Green, KY.

Period	DM†	N	P	K	S	Ca	Mg	Fe	Cu	Zn
	kg kg^{-1}	g kg^{-1}								
2005–2008	0.7	26	13	18	6.6	21	5.2	1.3	0.9	0.4
2009–2012	0.7	25	11	16	8.7	19	5.6	0.3	0.2	0.0
2013–2015	0.6	22	7.9	16	6.0	13	3.5	1.7	0.5	0.4

† DM, dry matter.

Table 2. Mean broiler litter (BL), BL nutrients, and chemical fertilizer nutrients applied to plots during 2005 to 2008, 2009 to 2012, and 2013 to 2015 periods, Bowling Green, KY.

			Broiler litter nutrients						Inorganic nutrients			
Year/treatment†	Tillage‡	BL	N	P_2O_5	K_2O	Fe	Cu	Zn	N	P_2O_5	K_2O	Zn
		Mg ha^{-1}	kg ha^{-1}						kg ha^{-1}			
2005–2008												
FBL	NT	17.1	224	497	363	22.2	15.3	6.8	–	–	–	–
	CT	17.1	224	497	363	22.2	15.3	6.8	–	–	–	–
HBL	NT	8.5	112	248	181	11.1	7.7	3.4	112	–	–	–
	CT	8.5	112	248	181	11.1	7.7	3.4	112	–	–	1.7
CF	NT	–	–	–	–	–	–	–	224	74	63	–
	CT	–	–	–	–	–	–	–	224	65	62	1.1
2009–2012												
FBL	NT	17.5	224	424	340	5.2	3.5	–	–	–	–	–
	CT	17.5	224	424	340	5.2	3.5	–	–	–	–	–
HBL	NT	8.7	112	212	170	2.6	1.7	–	112	–	–	–
	CT	8.7	112	212	170	2.6	1.7	–	112	–	–	–
CF	NT	–	–	–	–	–	–	–	224	68	44	–
	CT	–	–	–	–	–	–	–	224	65	47	–
2013–2015												
FBL	NT	20.2	224	365	423	34.3	11.1	8.0	–	–	–	–
	CT	20.2	224	365	423	34.3	11.1	8.0	–	–	–	–
HBL	NT	10.1	112	182	211	17.1	5.5	4.0	112	–	–	–
	CT	10.1	112	182	211	17.1	5.5	4.0	112	–	–	–
CF	NT	–	–	–	–	–	–	–	224	53	46	–
	CT	–	–	–	–	–	–	–	224	53	45	–

† FBL, crop nitrogen requirement supply by broiler litter alone; HBL, crop nitrogen requirement supply by 1:1 mixture of broiler litter and inorganic nitrogen; CF, chemical fertilizer.

‡ NT, no-till; CT, Conventional tillage.

respectively. The treatments were replicated four times. The two tillage practices included no-till and conventional tillage. For the NT, all fertilizers were surface applied without incorporation where the fertilizers in the CT were incorporated into the soil within 1 to 2 d after application by a tractor mounted rotary tiller adjusted to 10-cm depth. The nutrient source treatments included FBL, which provided full N requirement by BL, HBL which supplied 50–50 BL and inorganic fertilizer mixture, and CF which used chemical fertilizer alone. In the CF, 19:19:19 NPK, urea (46% N), and muriate of potash (60% K_2O) were used to formulate the annual fertilizer dose. All fertilizers were manually applied pre-plant. The amounts of BL to be supplied to the FBL and HBL treatments were determined by assuming 50% N availability from BL (Cabrera and Gordillo, 1995). Average BL nutrient composition (wet basis), amounts of BL and chemical fertilizer applied, and nutrients supplied through fertilizers during 2005 to 2008, 2009 to 2012, and 2013 to 2015 periods are presented in Tables 1 and 2. All fertilizer sources and tillage treatments were imposed on the same plots in each year. Composite soil samples (0–15 cm) drawn prior to imposing treatments were used to characterize initial soil properties (Tables 3 and 4). During the course of the study period, pre-plant and post harvest soil samples (0–15 cm) were collected annually. Annual precipitation of the site over the experimental period is presented in Fig. 1. Corn hybrid with a 112 d maturity was planted in 2.9 by 6.3 m plots (75 cm row spacing) at the seeding rate of 78,000 kernels ha^{-1} in late April–early May. For grain yield estimations two center rows of plots (1.5 by 1.5 m) were manually harvested. Corn grain weights were determined after shelling cobs. Grain moisture content was measured using digital grain moisture meter (Agri-supply, Herts, UK). The average grain moisture contents over study period was 188 g kg^{-1}. After post-harvest soil sampling, crop residues were mowed down to the soil surface.

Soil samples were air-dried and ground to pass a 2-mm screen before analysis for total soil C, total soil N, OM, pH, cation exchange capacity (CEC), and Mehlich-3 (M-3) extractable P, Fe, Cu, and Zn. Soil pH was measured using a glass electrode with a 1:1 soil/water ratio. Mehlich-3 (Mehlich, 1984) extractable P, Zn, Fe, and Cu contents were determined by emission spectroscopy on an inductively coupled spectrophotometer (Vista Pro Varian Analytical Instruments, Walnut Creek, CA). A loss-on-ignition method (Nelson and Sommers, 1996) was used to determine soil organic matter content. Broiler litter samples were digested using microwave procedure (USEPA, 1986) and manure composition was determined by inductively coupled argon plasma spectrophotometer (ICP). Soil and manure C and N contents were measured by Vario Max CN analyzer (Elementar America Inc., Mt. Laurel, NJ).

Table 3. Mean soil pH, cation exchange capacity (CEC), total soil C, total soil N, and organic matter (OM) contents of fertilizer source treatments before experiment (2005), in 4th year (2008), 8th year (2012), and 11th year (2015) of amendment and linear trends over the 2005 to 2015 period.

Fertilizer treatment	2005 (Initial)	2008 4th year	2012 8th year	2015 11th year	Linear trend ($P < 0.05$)
pH					
FBL†	6.6‡ ± 0.4	6.8a§ ± 0.2	6.9a ± 0.3	6.5a ± 0.2	$y = 6.4 + 0.04x$ ($r^2 = 0.19$)
HBL¶	6.7 ± 0.4	6.7a ± 0.2	6.7ac ± 0.1	6.4a ± 0.2	ns#
CF††	6.4 ± 0.6	6.0b ± 0.4	6.3bc ± 0.4	5.8b ± 0.4	$y = 6.3 – 0.01x$ ($r^2 = 0.10$)
			cmol kg^{-1}		
CEC					
FBL	8.7 ± 0.7	10.2a ± 0.6	14a ± 2.0a	15a ± 1.6	$y = 4.9 + 0.7x$ ($r^2 = 0.80$)
HBL	8.7 ± 1.2	9.2bc ± 0.7	12ac ± 1.0	12b ± 1.2	$y = 6.5 + 0.4x$ ($r^2 = 0.64$)
CF	8.7 ± 1.6	8.7bc ± 0.8	11bc ± 2.6	10c ± 1.2	$y = 7.6 + 0.2x$ ($r^2 = 0.16$)
			g kg^{-1}		
Total C					
FBL	12 ± 2.1	14a ± 2.2	18a ± 2.1	24a ± 1.4	$y = 5.7 + 1.1x$ ($r^2 = 0.80$)
HBL	13 ± 3.1	13a ± 2.4	14ac ± 2.9	20b ± 1.6	$y = 8.3 + 0.7x$ ($r^2 = 0.47$)
CF	13 ± 3.0	13a ± 3.1	13bc ± 3.3	16c ± 2.2	$y = 11 + 0.3x$ ($r^2 = 0.11$)
Total N					
FBL	1.2 ± 0.2	1.4a ± 0.2	2.0a ± 0.2	2.9a ± 0.1	$y = 0.0 + 1.8x$ ($r^2 = 0.88$)
HBL	1.2 ± 0.3	1.3a ± 0.2	1.5b ± 0.3	2.4b ± 0.2	$y = 0.4 + 0.1x$ ($r^2 = 0.66$)
CF	1.3 ± 0.3	1.1a ± 0.2	1.2c ± 0.3	1.7c ± 0.2	$y = 0.8 + 0.1x$ ($r^2 = 0.34$)
OM					
FBL	21 ± 5.0	23a ± 1.8	35a ± 3.4	45a ± 2.7	$y = 5.8 + 2.5x$ ($r^2 = 0.85$)
HBL	22 ± 7.1	23a ± 6.7	32a ± 4.4	42a ± 5.2	$y = 8.7 + 2.1x$ ($r^2 = 0.63$)
CF	20 ± 5.4	20a ± 4.4	27b ± 2.3	35b ± 4.2	$y = 11 + 1.5x$ ($r^2 = 0.61$)

† FBL, crop N requirement supply by broiler litter alone.
‡ Mean ± SD.
§ Numbers with different letters within columns for each soil variables are significantly different at $P < 0.05$.
¶ HBL, crop N requirement supply by 1:1 mixture of broiler litter and inorganic N.
# ns, nonsignificant.
†† CF, chemical fertilizer.

Table 4. Mean total soil Mehlich-3 (M-3) P, Fe, Cu, and Zn contents of fertilizer source treatments before experiment (2005), in 4th year (2008), and 8th year (2012), and 11th year (2015) of amendment and linear trends over the 2005–2015 period.

Fertilizer treatment	2005 (Initial)	2008 4th year	2012 8th year	2015 11th year	Linear trend (P < 0.05)
	mg kg^{-1}				
M-3P					
FBL†	81.9 ± 23.7‡	224.1a§ ± 24.0	381.1a ± 58.5	478.4a ± 52.2	$y = 104.5 + 39.5x$ ($r^2 = 0.93$)
HBL¶	51.6 ± 18.8	137.1b ± 19.9	201.9b ± 31.7	270.9b ± 35.4	$y = 45.4 + 21.0x$ ($r^2 = 0.66$)
CF#	46.4 ± 27.4	94.1c ± 13.1	73.9c ± 11.2	103.7c ± 20.4	$y = 37.1 + 4.2x$ ($r^2 = 0.32$)
Fe					
FBL	131.7 ± 16.7	123.9a ± 12.4	181.1a ± 15.6	175.4a ± 16.3	$y = 95.7 + 5.7x$ ($r^2 = 0.55$)
HBL	126.0 ± 10.8	112.5a ± 10.0	165.7b ± 7.7	163.5ac ± 5.8	$y = 91.3 + 5.0x$ ($r^2 = 0.61$)
CF	137.1 ± 21.6	113.6a ± 8.0	148.9c ± 11.6	148.9bc ± 10.7	ns††
Cu					
FBL	3.7 ± 0.7	6.9a ± 0.4	12.5a ± 1.9	15.7a ± 2.2	$y = 2.5 + 1.2x$ ($r^2 = 0.91$)
HBL	3.1 ± 0.7	4.6b ± 0.2	7.5b ± 0.9	9.6b ± 0.9	$y = 0.4 + 0.6x$ ($r^2 = 0.91$)
CF	2.6 ± 0.8	2.2c ± 0.2	2.2c ± 0.2	2.5c ± 0.2	ns
Zn					
FBL	4.7 ± 1.0	13.4a ± 1.4	28.4a ± 4.9	40.9a ± 6.0	$y = 14.5 + 3.6x$ ($r^2 = 0.92$)
HBL	3.4 ± 0.9	8.3b ± 1.3	14.8b ± 2.1	21.1b ± 2.5	$y = 5.5 + 1.7x$ ($r^2 = 0.93$)
CF	2.9 ± 1.4	4.7c ± 0.9	3.4c ± 0.4	4.4c ± 1.0	ns

† FBL, crop N requirement supply by broiler litter alone.
‡ Mean ± SD.
§ Numbers with different letters within columns for each soil variable are significantly different at P < 0.05.
¶ HBL, crop N requirement supply by 1:1 mixture of broiler litter and inorganic N.
# CF, chemical fertilizer.
†† ns, nonsignificant.

The grain production and soil properties were analyzed by mixed model repeated measures analysis of variance procedure. The fertility or tillage treatments were considered as fixed effects and years were treated as random effects. Changes in soil properties by fertilizer source and tillage treatments over 11 growing seasons were assessed at three time points, 4th (2008), 8th (2012), and 11th year (2015). In the analysis, initial (2005) soil characteristic was used as covariates. When covariate effects were significant, initial soil characteristic values were included in the subsequent analysis models. The means of soil properties and grain production were compared as pairs using Bonferroni correction (SPSS. 23; IBM Corp., Armonk, NY). Trends of soil properties change by fertilizer source and tillage treatments over time was tested by linear regression analysis. When assumptions on regression residuals were not satisfied, data were transformed before analysis. Correlation between variables was measured by Pearson's correlation coefficient.

RESULTS AND DISCUSSION

Grain Production

Corn grain yields for tillage and fertilizer source treatments are presented in Table 5. For grain yield, there was a significant year × tillage interaction, but a nonsignificant year × fertilizer source or tillage × fertilizer source interaction. Mean grain yield comparison for fertilizer source treatments at three time points revealed significant effect (P < 0.05). Producers often adopt N requirement-based BL application rates for crop production when manure disposal is a high priority. Broiler litter land application at low rates with supplemental inorganic N has manure disposal and manure derived soil nutrient management concerns. The FBL, CF, and HBL produced 10.1, 9.8, and 9.6 Mg ha^{-1}yr^{-1} grain yield, respectively. Both manure-applied FBL and HBL plots produced grain yields similar to the CF, but the FBL yield was higher than the HBL. Our results agreed with findings of Jn-Baptiste et al. (2012) who reported <9 and <8 Mg ha^{-1} corn grain yields when similar amounts of BL nutrients (270 and 135 kg N ha^{-1}) were applied for 4 yr. Improved soil properties resulting from long-term BL application at high rate could be a reason for higher grain yield of FBL (Tables 3, 4, and 5). Both tillage treatments had similar soil nutrient concentrations (Table 6) and produced similar grain yields during majority of growing seasons (Table 5). Grain yield of fertilizer source or tillage treatments did not follow a linear trend over study period (data not shown).

By reducing volatilization and losses in run off, immediate BL incorporation after land application can conserve more manure nutrients (Adeli et al., 2008). In addition, soil cultivation incorporates surface-applied organic materials into the soil matrix, exposing protected organic matter to decomposers (Cambardella and Elliot, 1993), and thereby accelerate soil OM decomposition and plant nutrient release. However, in this experiment soil OM difference between tillage treatments was not found and apparently OM decomposition was not stimulated by tillage. Of the 10 growing seasons, CT plots had higher grain yield in four growing seasons with no particular trend (Table 5). This result was inconsistent with Sistani et al. (2010) who reported significantly higher grain yields of CT after 4 yr of BL application. The

Table 5. Mean corn grain yields of tillage and fertilizer source treatments.

Year	Tillage/fertilizer source treatment		
	Mg ha^{-1}		
Tillage treatment	NT†	CT	
2005	7.3 ± 1.1‡	8.1 ± 0.7	
2006	8.9 ± 0.8	8.9 ± 1.0	
2007	6.0b§ ± 0.5	7.9a ± 0.7	
2008	11 ± 1.0	12 ± 1.0	
2009	15 ± 2.2	15 ± 1.7	
2010	11 ± 1.3	12 ± 1.1	
2011	8.9b ± 1.8	12a ± 1.7	
2012	4.3 ± 1.2	4.8 ± 1.2	
2013	14 ± 1.5	14 ± 1.6	
2014	7.6b ± 2.0	9.4a ± 1.4	
2015	8.8b ± 1.7	11a ± 1.5	
Fertilizer source	FBL¶	HBL	CF
Average (2005–2015)	10a ± 0.4	9.6b ± 0.3	9.8ab ± 0.5

† NT, no-till; CT, conventional tillage.

‡ Mean ± SD.

§ Numbers with different letters across rows within tillage practice and fertilizer source treatments are significantly different at $P < 0.05$.

¶ FBL, crop nitrogen requirement supply by broiler litter alone; HBL, crop nitrogen requirement supply by 1:1 mixture of broiler litter and inorganic nitrogen; CF, chemical fertilizer.

annual grain yield differences between tillage practices or apparent trends of grain yield observed within tillage treatments over the study period did not tally with rainfall precipitation distribution pattern or respective soil fertility differences.

Effects on Soil Properties

There were no significant year × fertilizer source × tillage interactions for soil properties ($P < 0.05$). The year × fertilizer source interaction was significant ($P < 0.05$) for all soil properties. The year × tillage interaction was significant ($P < 0.05$) for the soil properties P, Fe, Cu, Zn, and CEC. Tillage had no significant effect for soil pH, total soil C, total soil N, and OM. Accordingly, soil properties with significant interaction effects

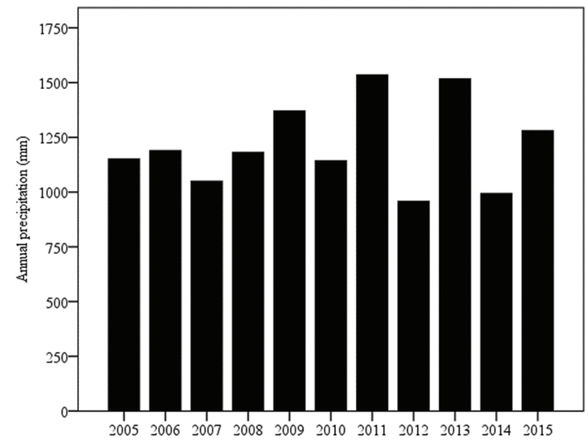

Fig. 1. Annual rainfall precipitation at the experimental site during the 2005 to 2015 period.

were tested separately at 4th, 8th, and 11th year. Soil properties change over time by fertilizer source and tillage practices was tested by regression analysis.

Soil pH, Total Soil Carbon and Nitrogen, Organic Matter, and Cation Exchange Capacity Levels

Table 3 present soil pH, total soil C and N, OM, and CEC of fertilizer source treatments before experiment (2005), at 4th (2008), 8th (2012), and 11th year (2015) of BL application. Initial soil pH range of all soils was 6.4 to 6.7. Due to its high Ca content of BL, continuous BL application was expected to slightly increase soil pH or cause no change (McGrath et al., 2010). Trend analysis showed linear pH increase in the FBL, but a decrease in the CF. After eight growing seasons, FBL soil pH increased by 0.3 units and CF soil pH dropped by 0.1 unit. Soil pH in the HBL did not change (Table 3). Inorganic N component (NH_4 nitrification) in HBL could have neutralized effect of Ca from manure to retain HBL pH unchanged. From 8th to 11th year, soil pH in the FBL and HBL decreased by 0.4 and 0.3 units, respectively. Soil pH drop in manure-amended plots during this period could be a result of comparatively low Ca input by

Table 6. Mean soil M-3P, Fe, Cu, and Zn contents of tillage treatments before experiment (2005), in fourth year (2008), eighth year (2012), and 11th year (2015) of amendment.

Tillage treatment	2005 (Initial)	2008 4th year	2012 8th year	2015 11th year
	mg kg^{-1}			
M-3 P				
NT†	50.7 ± 19.9‡	142.3 ± 50.8	238.2 ± 152.0	295.8 ± 173.8
CT§	69.3 ± 31.8	161.2 ± 65.7	199.8 ± 116.6	272.2 ± 153.4
Fe				
NT	124.3 ± 5.7	112.6 ± 6.2	166.7 ± 18.3	161.8 ± 12.8
CT	138.9 ± 21.1	120.7 ± 13.6	163.8 ± 17.8	163.3 ± 18.8
Cu				
NT	2.9 ± 0.8	4.5 ± 1.9	8.0 ± 5.0	9.9 ± 6.4
CT	3.3 ± 0.9	4.7 ± 2.0	6.8 ± 3.8	8.7 ± 5.2
Zn				
NT	3.2 ± 1.1	8.1 ± 3.6	16.9 ± 12.4	23.7 ± 17.7
CT	4.1 ± 1.4	9.4 ± 4.0	14.2 ± 9.3	20.5 ± 13.8

† NT, no-till.

‡ Mean ± SD.

§ CT, conventional till.

Table 7. Linear trends of cation exchange capacity (CEC), total C, total N, organic matter (OM), Mehlich-3 (M-3) P, Fe, Cu, and Zn change by tillage practices over the 2005 to 2015 period.

	Tillage	
Tillage treatment	NT†	CT
CEC	$y = 5.7 + 0.49x$ ($r^2 = 0.43$)	$y = 7.0 + 0.39x$ ($r^2 = 0.42$)
Total C	$y = 6.8 + 0.78x$ ($r^2 = 0.52$)	$y = 9.9 + 0.61x$ ($r^2 = 0.32$)
Total N	$y = 0.3 + 0.12x$ ($r^2 = 0.59$)	$y = 0.5 + 0.10x$ ($r^2 = 0.51$)
OM	$y = 5.7 + 2.16x$ ($r^2 = 0.75$)	$y = 11.1 + 1.18x$ ($r^2 = 0.58$)
M-3P	$y = 62.1 + 24.4x$ ($r^2 = 0.40$)	$y = 12.5 + 18.8x$ ($r^2 = 0.34$)
Fe	$y = 90.4 + 5.0x$ ($r^2 = 0.55$)	$y = 110.1 + 3.5x$ ($r^2 = 0.29$)
Cu	$y = 0.8 + 0.7x$ ($r^2 = 0.31$)	$y = 0.5 + 0.5x$ ($r^2 = 0.27$)
Zn	$y = 7.7 + 2.0x$ ($r^2 = 0.35$)	$y = 3.6 + 1.6x$ ($r^2 = 0.34$)

† NT, no till; CT, conventional till.

BL during latter phases (260 vs. 352 and 320 kg ha^{-1} yr^{-1}). Due to acidifying effects from NH_4^+ nitrification, chemical fertilizer applications over longer periods are known to reduce soil pH (Bowman and Halvorson, 1998). Because of high soil pH variability (Table 3), observed soil pH drop in the CF could not be explained as from acidification effect. In agreement with Hue (1992), manure-derived Ca of BL-amended plots heavily raised soil pH (0.4–0.7 units) than by the CF. Soil pH of FBL and HBL was not different at any time point (Table 3). This result agreed with Sistani et al. (2010) who reported no soil pH difference between corn soils applied with 11 and 22 Mg ha^{-1} BL.

Over the study period, total C content of FBL, HBL, and CF soils increased ($P < 0.05$) linearly (Table 3). The final soil C contents of FBL, HBL, and CF were 11.4 g kg^{-1} (91%), 7.6 (60%) g kg^{-1}, and 3.1 g kg^{-1} (24%), respectively greater than the initial levels. The greater total soil C increase observed in manure-amended FBL and HBL plots could be due to BL. Results from this study were consistent with those from short-term BL-amended cotton (*Gossypium hirsutum* L.) and corn studies of Adeli et al. (2007) and Jn-Baptiste et al. (2012) who reported soil total C content increase within the 15-cm soil depth after 3 to 4 yr of BL application. Two tillage treatments had similar total C contents and respective levels increased linearly over time (Table 6). Regression parameters indicated higher total soil C increase in the NT (Table 7). The greater total C accumulation in the NT (Table 7) could have caused by slower soil OM decomposition in NT soils (Cambardella and Elliot, 1993).

Nitrogen mineralized from applied fertilizer and decomposition of corn stalk residues contributed N pools of fertilizer source treatments. Total soil N contents of all fertilizer source treatments increased linearly ($P < 0.05$; Table 3). By the 11th year, total N contents of FBL and HBL increased to 2.9 (141%) and 2.4 g N kg^{-1} (100%), respectively (Table 3). Most N from manure is in organic form, thus total amounts in the FBL and HBL may not be readily available for plant growth. Total soil N contents of FBL, HBL, and CF were comparable to the levels reported by Jn-Baptiste et al. (2012). Total soil N in the CF increased from 1.3 to 1.7 g kg^{-1} (23.5%). All fertilizer source treatments contained similar total soil N contents in the 4th year, but levels were different at 8th and 11th year (Table 3). The highest final total soil N content was found in the FBL and the lowest was in the CF. In general manure + crop residue decomposition in CT soils are expected to be higher than the NT. With a crop cover to utilize released N, CT soils can have lower N losses than NT. However, results from this experiment showed no total N content difference between tillage treatments. Trend analysis results (Table 7) indicated soil N content in both tillage treatments increased linearly and greater rate of increase was in the NT.

Different sources contributed to soil OM contents in fertilizer source treatments. Post-harvest corn stalk residue mainly contributed CF soil OM. In addition to corn stalk residue, BL also contributed to FBL and HBL soil OM content. There was a significant soil OM aggregation ($P < 0.05$) in all fertilizer source treatments (Table 3). After 11 growing seasons, soil OM levels in FBL, HBL, and CF increased to 45.0 g kg^{-1}(116.3%), 42.3 g kg^{-1}(100.9%), and 35.5 g kg^{-1} (73.1%), respectively. Soil OM contents between BL applied and chemical fertilizer-amended soils were significantly different in the 8th and 11th year. Both FBL and HBL soils contained similar soil OM levels throughout. Higher soil OM decomposition can lower soil OM content in CT soils (Cambardella and Elliot, 1993). Angers et al. (1997) reported that an increased soil OM content was not always observed in NT soils, particularly when the C content of deeper soil depths is considered. Results from this study showed no soil OM difference between two tillage treatments (Table 6). The initial OM content of CT was higher than the NT (23.3 vs. 18.7 g kg^{-1}). Observed similar OM levels of two tillage treatments could have resulted from elevated initial OM levels of CT soils and depth of sampling (0–15 cm).

The CEC represents the total quantity of negative charge available to attract cations in soil solution. Cation exchange capacity is one of the most important soil chemical properties that strongly influence nutrient availability. Cation exchange capacity is strongly affected by nature and the amount of mineral and organic colloids present in the soil. Soils with larger amounts of clay and OM have a higher CEC than soils low in OM (Havlin et al., 1999). Initial CEC of all fertilizer source treatments was 8.7 cmol kg^{-1} CEC (Table 3). Over the time CEC in the FBL, HBL, and CF increased linearly ($P < 0.05$) and reached 15.5, 12.3, and 10.1 cmol kg^{-1}, respectively. There was a significant correlation ($P < 0.05$; $r^2 = 0.74$) between OM and CEC. As for soil OM, tillage practice did not influence CEC.

Mehlich-3 Phosphorus, Iron, Copper, and Zinc Contents

The mean M-3 P, Fe, Cu, and Zn contents of fertilizer source treatments and tillage practices at three time points (2008, 2012, and 2015) are shown in Tables 4 and 6. Over the experimental period, soil M-3 P levels of FBL, HBL, and CF increased linearly ($P < 0.05$). The FBL reported higher

M-3 P increase rate than the HBL and CF (Table 4). The FBL soils contained higher initial M-3P (81.9 mg kg^{-1}) than HBL (51.6 mg kg^{-1}), CF (46.4 mg kg^{-1}), and a nearby continually NT cropped soil with no manure amendment history (50–60 mg kg^{-1}). The fertilizer management history records for this site was not available to explain this difference. After 11 growing seasons, M-3 P levels of FBL, HBL, and CF soils reached 478.4 (484%), 270.9 (425%), and 103.7 (123%) mg kg^{-1} M-3 P, respectively. One of the major concerns with BL land application is soil P increase that can raise potential to release in runoff water (Cooper et al., 1984; Sharpley et al., 1994). In Kentucky, when M-3 soil P content exceeds the agronomic threshold of 200 mg kg^{-1}, steps are required to assess field factors associated with the P runoff risk and to minimize P accumulation in soil by applying only an amount of P that is removed in the harvested portion of the crop. The M-3 P levels more than 400 mg kg^{-1} is considered environmentally significant halting any form of future P land application (USDA-NRCS, 2001). The FBL soils reached 200 mg kg^{-1} agronomic and 400 mg kg^{-1} environmental thresholds by 8th and 11th years, respectively. In contrast, HBL soils with 30 mg kg^{-1} less initial M-3 P levels took 8 yr to reach agronomic threshold, but levels did not reach 400 mg kg^{-1} environmental threshold during the study period. The M-3P levels in NT and CT soils linearly increased over time (Table 7), but final levels were not significantly different.

Because of high micro-element concentrations in manure, there are concerns that continuous BL land application elevates soil micro nutrients (Kingery et al., 1994; Mitchell and Tu, 2006). Manure-induced high soil Cu and Zn contents may be harmful to plants and animals fed with plants (Mantovi et al., 2003). Over the study period, Fe, Cu, and Zn concentrations in the FBL and HBL increased linearly ($P < 0.05$). However, there was no such increase for the CF. The Fe, Cu, and Zn accumulation rates were higher in the FBL (Table 4). After11 BL application cycles, there was 175.4 mg Fe kg^{-1} (33%), 21.1 mg Cu kg^{-1}(324%), and 40.9 mg Zn kg^{-1} (770%) in the FBL and 163.5 mg Fe kg^{-1} (29%), 9.6 mg Cu kg^{-1} (209%), and 40.9 mg Zn kg^{-1} (520%) in the HBL. The amount of Zn accumulated in the FBL by fourth year (8.7 mg kg^{-1}) was lower than 10.9 mg Zn kg^{-1} increase reported by Sistani et al. (2010) after applying 22 Mg ha^{-1} BL to corn soil for 4 yr. Data from this study also confirmed that BL application at FBL and HBL rates would not elevate soil Cu (15.7 and 9.6 mg kg^{-1}) and Zn (40.9 and 21.1 mg kg^{-1}) concentrations to plant toxic levels (60 mg Cu kg^{-1} and 120 Zn mg kg^{-1}) as reported by Tucker et al. (2005). Although amount of Zn applied through manure was lower than the Cu (Table 2), BL-amended soils contained greater Zn content than Cu. Tillage did not influence soil Fe, Cu, and Zn contents, but levels increased linearly over time. The Fe, Cu, and Zn accumulation rates were higher in the NT (Table 7).

CONCLUSIONS

Understanding corn grain yield potential and resulting soil properties from long-term broiler litter amendment under no-till and conventional tillage provides important information for establishing economically, agronomically, and environmentally sustainable manure-based corn production. Broiler litter amendment at FBL and HBL rates for decade produce grain yields similar to inorganic fertilizer application, but also accumulate M-3P levels exceeding 400 and 200 mg kg^{-1}, respectively. In addition, both BL rates accumulate soil Cu and Zn considerably. As compared to the FBL, soil nutrient accumulation and rate of accumulation were lower in the HBL. Tillage had no influence on soil nutrient levels, soil chemical properties, and produced similar grain yields for majority of growing seasons. In general greater soil nutrient accumulation rate was observed in the NT than CT. Lower soil nutrient accumulation than FBL and equivalent grain production potential as CF makes HBL a better BL use option for corn production than the FBL. By adopting perineal crop rotations and winter annual forage cropping, producers can further enhance agronomic benefits of HBL and reduce associated environmental risk potential.

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