TECHNICAL ARTICLE

Nutrient Source and Tillage Impact on Corn Grain Yield and Soil Properties

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Abstract: Large amounts of animal manure, particularly poultry litter and dairy manure, are generated in southeastern United States, where corn (*Zea mays* L.) is also extensively grown. Characterizations of management practices and long-term manure and soil nutrient dynamics are critical. This study examined corn grain yield and soil nutrient status under three nutrient sources (two rates of each) as follows: inorganic fertilizer, poultry litter, and dairy manure compared with a nontreated control under two tillage practices (no-till and incorporated). Treatments were replicated four times in a split-plot design from 2004 to 2007. Soil samples were taken annually in the spring before treatment application to evaluate the status of the residual nutrients in soil. Significant differences in corn grain yield between the two tillage practices (main effect) were observed in all 4 years. The high rate of poultry litter application produced similar grain yield as inorganic fertilizer. However, results from dairy manure were not as consistent as poultry litter. After 4 years of poultry litter application, Mehlich-3 (M-3) phosphorus (P) increased from an initial 31.4 to 63.0 mg kg^{-1} for the 4.5 Mg ha^{-1} year^{-1} rate and to 178 mg kg^{-1} for the 13.5 Mg ha^{-1} year^{-1} rate. More specifically, 5.2 kg ha^{-1} year^{-1} of P applied as poultry litter increased soil M-3 P by 1 mg kg^{-1} after 4 years of application. Results indicated that poultry litter is a primary fertilizer at the rate of 13.5 Mg ha^{-1} applied in four consecutive years on a silt loam soil–produced corn grain yields similar to inorganic fertilizer under both no-till and incorporated systems and did not result in residual soil test P, Cu, and zinc levels considered to be harmful to surface water or cropping systems.

Key words: Broiler litter, poultry manure, dairy manure, corn, tillage, phosphorus.

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The USDA-NASS (2002) reported the production of more than 3 billion broiler chickens (*Gallus gallus domesticus*) in 2001, which generated 2.5 billion kilograms of litter (a combination of manure plus bedding materials). Significant amounts of the litter are commonly applied to pasture and hay fields as a source of plant nutrients, particularly in southeastern United States. However, little information is available on crop performance and soil quality as affected by long-term litter application on crops such as corn (*Zea mays* L.) (Sistani et al., 2004). Sims (1986) and Ma et al. (1999) reported that the application of poultry litter increased forage dry matter and corn grain yield. Other studies have indicated that poultry litter application improved soil quality compared with chemical fertilizers (Haynes and Naidu, 1998; Nyakatawa et al., 2001; Grandy et al., 2002; Adeli et al., 2007). In addition, Whalen and Chang (2002) reported that long-term manure and plant residue applications increased soil organic C. Other researchers have shown significant increases in corn yield with application of dairy manure (McIntosh and Varney, 1972; Jokela, 1992). Singh et al. (1996) reported that wheat yield increased because of manure application compared with chemical fertilizers and also observed significantly greater soil organic matter and extractable phosphorus (P) in the manure-amended plots. Similarly, McAndrews et al. (2006) reported an increase of 0.2 to 0.5 Mg ha^{-1} soybean grain yield in manure-treated plots compared with control or urea-fertilized plots. Eghball et al. (2004) showed a positive effect of residual manure nutrients on the subsequent corn yield. Harmel et al. (2008) reported that after 6 years of varying litter and inorganic fertilizer combinations in Texas, minimal differences in corn and wheat yields occurred. These researchers concluded that their results provide the scientific basis to support the use of litter as a cost-effective environmentally friendly fertilizer alternative in Texas and similar regions.

Long-term manure application based on N requirements for corn production may increase P and other nutrient levels in soil. This is because the N:P ratios of animal manure are significantly smaller than N:P uptake ratios for most crops. For example, Eghball et al. (1997) reported the N:P ratios of 2.6 for feedlot manure and 1.9 for composted manure, whereas Gilbertson et al. (1979) reported that the N:P grain uptake ratios of winter wheat, corn, and grain sorghum were 4.5, 5.9, and 4.5, respectively. Continued use of litter can accumulate P in surface soil horizons that can potentially enter runoff water. An increase of P in surface water that is P limited can cause undesired water quality problems. Movement of P from field to surface water can be estimated using source and transport factors (Sharpley et al., 2003). A source factor included is the soil test P level. For example, in Kentucky, when Mehlich-3 (M-3) P concentration of 200 mg kg^{-1} is exceeded, litter application is usually based on crop removal or a P index rating to evaluate the likelihood of P runoff (USDA-NRCS, 2001). It is important for growers to know how quickly soil test P levels will rise to the agronomic threshold value of approximately 200 mg kg^{-1} with continued litter application. Other nutrients such as Cu and zinc (Zn) may also accumulate in soil with continued manure application (Brock et al., 2005). North Carolina has critical toxic levels to plants of 60 mg kg^{-1} Mehlich-3 Cu and 120 mg kg^{-1} Mehlich-3 Zn (Tucker et al., 2005). However, it is not known if continuous litter application would result in elevated Cu and Zn soil levels that may be phytotoxic.

There are abundant research reports on the advantage of no-till cropping systems (Lal and Van Doren, 1990; Sidhu and Duiker, 2006). However, problems have also been reported in

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TABLE 1. Total Monthly Rainfall Precipitation During the Course of Study

	2004	2005	2006	2007	2008	Mean
	mm					
January	75	121	124	103	90	103
February	70	79	58	51	103	72
March	102	89	70	34	149	89
April	144	147	115	93	137	127
May	221	62	92	91	137	120
June	97	47	68	67	30	62
July	139	110	84	51	140	105
August	115	202	152	24	190	102
September	28	120	172	48	40	60
October	145	70	102	213	95	112
November	140	83	78	100	43	89
December	125	51	90	180	155	120

no-till systems, such as soil compaction, poor seedling emergence, and reduced yield (Raper et al., 2000; Schwab et al., 2002). Thus, the availability of plant nutrients in litter and losses (e.g., N volatilization) when applied to the soil surface without incorporation has been questioned (Grove, 1997). Application of poultry litter under no-till systems concentrates P at the soil surface that can be dissolved and transported in runoff water (Daverede et al., 2003; Kleinman and Sharpley, 2003). The objective of this study was to investigate corn grain yield and selected soil chemical properties under different nutrient sources (poultry litter, dairy manure, and chemical fertilizer) and tillage practices.

MATERIALS AND METHODS

This study was initiated in 2004 on a Crider silt loam soil (Fine-silty, mixed, active, mesic, Typic Paleudalfs) with 2% to 6% slope near Bowling Green, Kentucky. Treatments were arranged in a split-plot design, with tillage being the main plot and the nutrient source being the split plot. Tillage treatments consisted of no-till (No-till) and the incorporation of nutrient sources into soil (Tilled), which was accomplished using a tractor-mounted rotary tiller. Treatments consisted of a control that received no chemical fertilizer or manure, two rates of chemical fertilizers to provide 134 (low) and 403 (high) kg N ha^{-1} $year^{-1}$. The chemical fertilizer used was 19-19-19 to provide N, P, and K based on the soil test recommendations by the University of Kentucky, which was supplemented with ammonium nitrate (NH_4NO_3) to provide the remainder of required N. Two rates of poultry litter and dairy manure at 4.5 (low) and 13.5 (high) Mg ha^{-1} $year^{-1}$ were applied on dry weight basis and total N (TN) content. The low and high application rates of each nutrient source were selected based on conventional chemical fertilizer rates used by local corn producers. For tilled treatments, fertilizer or manure was applied as surface broadcast by hand and then incorporated, whereas for no-till, treatments were surface applied without incorporation. Corn (*Zea mays* L.), Asgrow hybrid (RX718; RR/YG) with a 110-day maturity rating was planted (76-cm row spacing) in plots (3.05 × 6.1 m) in early May and harvested as grain in September by picking the two center rows of each plot for a harvest area of 1.52 × 6.1 m. Treatments were applied on the same plots, and corn was planted each year from 2004 to 2007.

Monthly rainfall precipitation during the course of the study was recorded (Table 1). Initial soil samples were taken before litter or fertilizer application in spring of 2004 at 0- to 15-, 15- to 30-, and 30- to 60-cm soil depths. Initial soil pH, total N, C, and P, inorganic N, and Mehlich-3 (M-3) extractable nutrients were determined in 2004 (Table 2). Soil samples (0–15 cm) were also taken annually in the springs of 2005 to 2007 before application of manure and fertilizer. Soil samples were air-dried, ground to pass a 2-mm screen, and tested for pH using a glass electrode with a 1:1 soil:water ratio (Southern Cooperative Series Bulletin, 1983). Phosphorus, K, Ca, Mg, Zn, Fe, and Cu were analyzed after samples were extracted with M-3 extractant (Mehlich, 1984). For extraction, 2 g dry soil was placed in a 1:10 soil:M-3 extractant, then samples were shaken for 10 min, and filtered through a Whatman 42 filter paper for the determination of P and selected nutrients with inductively coupled plasma spectrophotometry (Vista Pro Varian Analytical Instruments, Walnut Creek, CA). A microwave procedure was used to digest poultry litter and dairy manure samples for determination of total nutrient content and the concentration of manure applied each year (Table 3). In this method, 0.5 g of manure was mixed with 9 mL HNO_3 and 3 mL HCl in a Teflon microwave digestion vessel, allowed to predigest under a vent hood for 45 min, and then placed in a MARS 5 Microwave (CEM Corp., Matthews, NC). The temperature of the mixture was increased to 175°C in 6.5 min and held at that temperature for an additional 12 min to complete the digestion process. Samples were then filtered through a Whatman 42 filter, followed by determination of Ca, Mg, K, Na, Mn, Al, S, and Zn concentrations using inductively coupled plasma. The total N and C concentrations of the manure were measured using a Vario Max CN analyzer (Elementar Americas, Inc., Mt. Laurel, NJ).

Analysis of variance was used to analyze the data using the GLM procedure of SAS (SAS Institute, 1999). Initial analysis of

TABLE 2. Initial Soil Chemical Properties, Spring 2004†

Soil Depth		TC	TN	NH_4−N	NO_3−N	TP	Ca	Mg	K	Na	Fe	Mn	Cu	Zn	Al
cm	pH	g kg^{-1}		mg kg^{-1}											
0–15	6.31	13.06	1.34	19.0	3.1	31.4	1896	188	324	25.1	58	126	1.37	2.07	940
15–30	6.39	5.93	0.72	13.8	1.1	4.7	1825	155	195	38.9	55	104	0.83	0.64	1123
30–60	6.23	2.8	0.43	10.4	0.5	1.5	1596	188	136	28.4	47	75	0.40	0.22	1193

†Microwave procedure was used to digest poultry litter and dairy manure samples for determination of total nutrient content.
TC: total carbon; TP: total phosphorus.

TABLE 3. Moisture and Chemical Properties of the Broiler Litter and Dairy Manure Applied to the Experimental Plots From 2004 to 2007†

Manure Type and Date	Moisture		TN	TP	TC	NH_4−N	Al	Ca	Fe	K	Mg	Mn	Na	S	Zn	Cu
	%	pH	g kg^{-1}													
Litter, May 2004	42	6.9	25.4	25.0	200.0	9.31	3.43	47.83	2.81	36.76	10.04	0.73	16.97	13.79	0.76	0.87
Dairy, May 2004	78	8.5	6.0	12.0	105.0	8.27	5.26	43.52	3.82	24.03	12.57	0.57	5.08	7.45	0.43	0.09
Litter, May 2005	32	7.1	27.7	24.0	225.5	7.20	3.01	43.83	2.82	41.03	11.27	0.62	15.01	12.21	0.63	0.84
Dairy, May 2005	79	8.3	6.2	12.0	95.1	5.22	7.20	59.23	5.47	14.23	13.66	0.54	5.39	8.12	0.41	0.09
Litter, May 2006	32	6.7	29.5	23.0	245.9	8.45	8.95	46.56	5.94	39.03	9.97	0.63	13.21	12.70	0.67	0.68
Dairy, May 2006	78	6.9	18.2	14.0	88.8	5.83	7.36	48.52	4.12	30.47	10.45	0.43	4.92	6.36	0.33	0.06
Litter, May 2007	32	6.2	29.8	25.0	265.1	8.19	2.47	39.73	2.45	44.68	11.32	0.77	16.27	20.01	0.80	0.59
Dairy, May 2007	58	7.7	10.1	11.0	196.1	4.07	1.74	35.88	1.77	31.81	7.86	0.33	6.02	10.11	0.25	0.06

†Concentration of nutrients expressed on a dry weight basis except for TN, TC, NH_4−N, and moisture content.

TP: total phosphorus; and TC: total carbon.

variance showed significant differences among years and between year and treatment interaction; therefore, data were analyzed and reported by year.

RESULTS AND DISCUSSION

Corn Grain Yield

Grain yield was affected by tillage practice from 2004 to 2007 (Table 4). In all 4 years, data showed that tilled treatments, regardless of the nutrient source and application rates, produced yields greater than no-till treatments. This may indicate a smaller loss of nutrients, particularly, N through volatilization or surface runoff. The smaller grain yield in 2005 and 2007 compared with 2004 and 2006 may have resulted from less rainfall precipitation during the growing season (May to September). Chemical fertilizer, poultry litter, and dairy manure as nutrient sources impacted corn grain yields in all 4 years compared with the nontreated control (Figs. 1 and 2). No significant difference in corn grain yield was detected between the low (134 kg N ha^{-1}) and high (403 kg N ha^{-1}) rates for chemical fertilizer from 2004 to 2007. This indicates that the 134 kg N ha^{-1} rate, which was smaller than the normal N rate used by corn growers in the region, can produce optimum corn grain yields under similar climate conditions. Corn grain yield was significantly greater for the high rate (13.5 Mg ha^{-1}) than the low rate (4.5 Mg ha^{-1}) of poultry litter application in 2004, 2005, and 2007. However, in 2006, corn grain yield was similar for the low and high rates of poultry litter application. Dairy manure had a similar effect on corn grain yield as poultry litter, in which significant differences were observed between the low and high rates, except in

TABLE 4. The Main Effect of Tillage on Corn Grain Yield From 2004 to 2007

Tillage	2004	2005	2006	2007
	Mg ha^{-1}			
Tilled	9.06 a*	6.73 a	6.65 a	5.34 a
No-till	8.54 b	6.03 b	5.81 b	4.92 b
LSD (0.05)	0.50	0.29	0.58	0.31

Data points are averaged across nutrient sources and rates.

*Means within each year followed by the same letters are not significantly different according to least significant difference (LSD) 0.05 level.

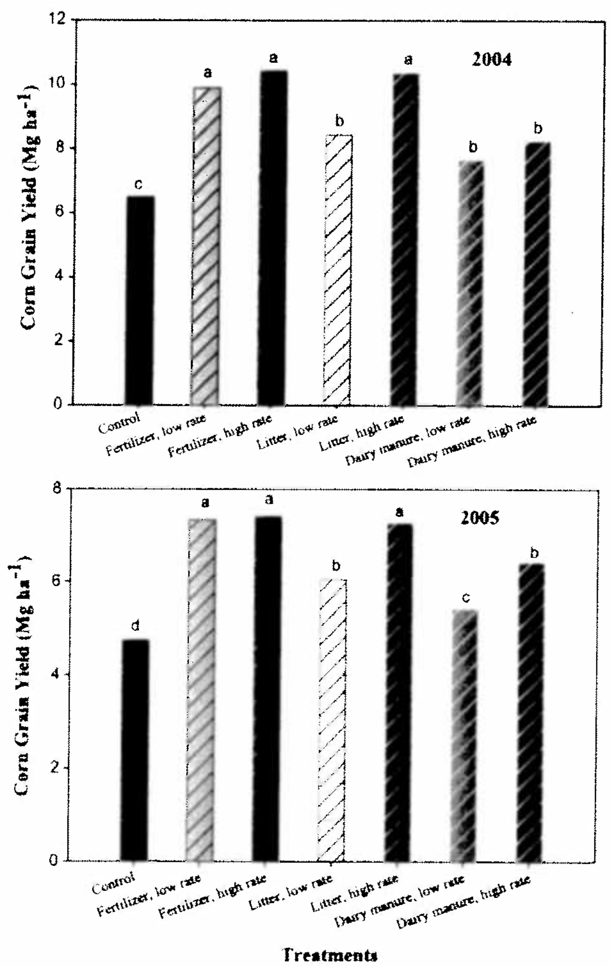

FIG. 1. Corn grain yield response to poultry litter, dairy manure, and chemical fertilizer as sources of nutrients for 2004 and 2005. Within each year, bars having the same letters are not significantly different according to LSD 0.05 level.

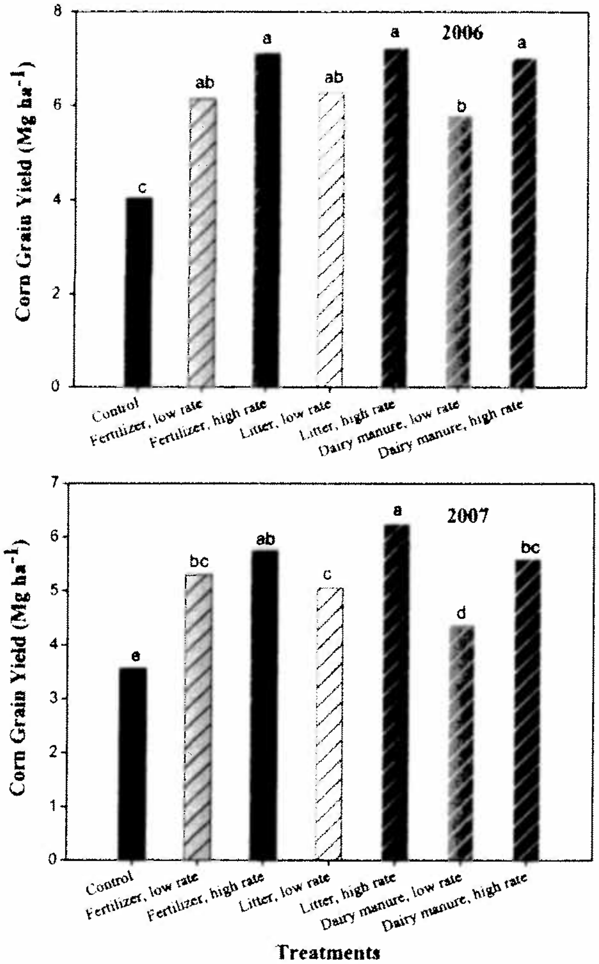

FIG. 2. Corn grain yield response to poultry litter, dairy manure, and chemical fertilizer as sources of nutrients for 2006 and 2007. Within each year, bars having the same letters are not significantly different according to LSD 0.05 level.

2004. There are some limitations with making direct comparisons among different nutrient sources because of the disparity in nutrients applied each year by chemical fertilizer, poultry litter, and dairy manure. Direct comparison of the three nutrient sources was not the objective of this study, these nutrient sources are being used by local producers differently, and we attempted to follow their practices. For example, a poultry producer or a dairy producer uses different management with regard to how much manure to be used for an optimum yield. However, the quantity of each nutrient source could be considered as an independent management practice, which can also be indicative of yield potential. Therefore, any comparison made here is based on comparing three different management practices not based on the total nutrient each source provided. In all 4 years (2004–2007), corn grain yield from the high rate of broiler litter application was similar or greater than chemical fertilizer treatment. The low rate of poultry litter produced a smaller yield than the chemical fertilizer treatment (except 2006), indicating that an application rate of 4.5 Mg ha^{-1} may not provide enough nutrients to obtain comparable corn grain yield. Except in 2006, dairy manure produced smaller corn grain yield than poultry litter and chemical fertilizer treatments. However, in 2006, the high dairy manure rate produced similar corn grain yield as poultry litter and chemical fertilizer treatments (Fig. 2).

Assuming half of the total N in each poultry litter application became available for plant uptake in the first year (Rasnake, 2002), an estimated average of 285 kg N ha^{-1} had become available from the 13.5 Mg ha^{-1} litter rate. This estimated available N from 13.5 Mg ha^{-1} poultry litter was 118 kg N ha^{-1} less than the 403 kg N ha^{-1} applied by the high rate of chemical fertilizer. However, in all 4 years, the high rate of poultry litter produced the same corn grain yield as the high rate of chemical fertilizer. The same trend was observed for the low rates of the two nutrient sources. The better N use efficiency of poultry litter compared with chemical fertilizer may be caused by the other side benefits of poultry litter, such as C, and micronutrients, such as Cu, Fe, and Zn, provided by litter. The smaller corn grain yield for dairy manure may be attributed to the smaller quantity of N provided (average of 212 kg N ha^{-1}) compared with 285 kg N ha^{-1} for poultry litter.

Soil Nutrient Status and Organic Carbon Content

Table 5 shows the statistical significance of main and interaction effects of nutrient sources, tillage, and sampling dates (year) on soil properties. Soil pH showed no substantial overall increase by the end of the study in 2008 compared with the initial soil pH of 6.3 in 2003 (Tables 6–9). However, a relatively higher soil pH for all treatments was detected in 2005 compared with other years (Table 6), whereas a significant decrease was observed in soil pH for fertilizer treatments in 2008. Soil pH was not increased by increasing poultry litter rate from 4.5 to 13.5 Mg ha^{-1}. In contrast, in all 4 years, significant increases were observed in soil pH by increasing dairy manure rates from 4.5 to 13.5 Mg ha^{-1}. Soil pH of the plots receiving chemical fertilizer decreased throughout the course of study by increasing the N application rate from 134 kg N ha^{-1} to 403 kg N ha^{-1} (Tables 6–9).

Soil total C increased during the course of study for high rates of poultry litter and dairy manure. However, the increase in soil C was greater for dairy manure than poultry litter compared with the nontreated control (Tables 6–9). This could be attributed to lower C losses from dairy manure because of the greater water content that facilitates percolation of manure into soil compared with dry poultry litter. All nutrient sources had a significant impact on soil properties, except NH_4−N content, indicating that a high level of nitrification may have converted NH_4−N to N_2O or NO_3−N. Soil TN content did not increase considerably during the 4-year study, particularly for the chemical fertilizer treatment compared with the initial soil TN content of 1.34 mg kg^{-1}. However, the high rates of poultry litter and dairy manure tended to increase soil TN compared with chemical fertilizer or control treatment. Soil M-3 P of plots receiving poultry litter and dairy manure increased from 2006 to 2008 after a small decrease in 2005. Relative to the initial M3-P of 31.4 mg kg^{-1} (Table 2), the soil M-3 P increased to 63 mg kg^{-1} for the low rate and 178 mg kg^{-1} for the high rate after 4 years of poultry litter application (Table 9). The same trend was observed for dairy manure application (about 43 and 78 mg kg^{-1} for the low and high rates, respectively).

A concern with animal manure application is the concurrent increases of P in soil that can potentially be released in runoff water and impair surface water quality (Harmel et al., 2008). In many states, including Kentucky, when soil M-3 P is greater than 200 mg kg^{-1}, certain actions are required to assess field factors associated with the risk of P in surface runoff water. Therefore, USDA-NRCS (2001) has recommended that only an amount of P that is removed in the harvested portion of the crop to be applied to minimize further P accumulation in soil. In this

TABLE 5. Statistical Significance at 0.05 Level Showing Main and Interaction Effects of Treatment, Tillage, and Sampling Date on Soil Properties at the 0- to 15-cm Soil Depth

	Source of Variation					
Soil Property	Soil Sampling Date (D)	Treatment (T)	Tillage (Till)	D × T	D × Till	T × Till
N	**	**	NS	**	NS	NS
P	*	*	NS	*	NS	NS
C	**	**	NS	**	NS	**
NH_4+	**	NS	NS	NS	NS	NS
NO_3−	**	**	**	**	NS	NS
BD	*	*	*	NS	NS	NS
pH	*	*	*	*	NS	*
Al	*	*	NS	*	*	NS
Ca	*	*	*	*	NS	*
Mg	*	*	*	*	NS	NS
K	*	*	*	*	*	NS
Na	*	*	NS	NS	NS	NS
Cu	*	*	NS	*	NS	NS
Fe	*	*	*	NS	NS	NS
Mn	*	*	NS	NS	NS	NS
Zn	*	*	NS	*	NS	NS

NS, *, **: not significant, $P < 0.05$ and $P < 0.01$, respectively.

study, the M-3 soil P in the top soil layer (0–15 cm) layer increased from 31.4 mg kg^{-1} (Table 2) at the beginning of the study to levels that ranged from 63 (low rate) to 178 (high rate) mg kg^{-1} for poultry litter and from about 43 (low rate) to 78 (high rate) mg kg^{-1} for dairy manure, respectively, in the spring of 2008 after 4 years (Table 9).

Based on calculation from Table 3 and the application rate, the total P applied from poultry litter during the 4 years was about 857 kg ha^{-1} for the high rate (13.5 Mg ha^{-1}). With the total 4-year grain yield of 31,120 kg ha^{-1} (Figs. 1, 2) and assuming a P concentration in the grain as 3.2 g kg^{-1} (Heckman et al., 2003), the total P removal for the 4 years was about 100 kg ha^{-1}. The difference between applied and removed P was 756 kg ha^{-1} for 13.5 Mg ha^{-} litter rates. Considering the quantity of P added to soil from the litter and the change in Mehlich-3 soil test P, it took 5.2 kg ha^{-1} of P added to soil to increase M-3 soil test P by 1 mg kg^{-1}. These values are similar to results from a laboratory incubation study where 2.9 to 7.8 kg ha^{-1} inorganic P increased M-3 soil test P by 1 mg kg^{-1}, depending on the initial M-3 values ranging from 15 to 62 mg kg^{-1} (Thom and Dollarhide, 2002). The lower the M-3 value of soil in the laboratory incubation, the greater amount of P was required to raise M-3 by 1 mg kg^{-1}. Thus, it is important to acknowledge that the practice of manure application concentrate nutrients near the soil surface may increase the risk of P being released in runoff water (Kleinman and Sharpley, 2003). Hence, more attention needs to be given to the practice of animal manure application, particularly on no-till systems and the potential risk for P runoff.

Mehlich-3–extracted soil K, Ca, Mg, Cu, Fe, Zn, and Al concentrations were greater with poultry litter and dairy manure application particularly in 2007 and 2008 compared with initial soil concentrations of these elements. However, no consistent trend was observed with any of these nutrients during the 4-year study. We speculate that soil concentrations of these nutrients may have been influenced by the soil moisture content, which may have also influenced soil pH and the solubility of these

TABLE 6. Soil pH, Total C, N, and Selected Mehlich-3 Soil Test Nutrient Concentrations for Soil Collected in Spring 2005

		C	N	P	Ca	Mg	K	Fe	Cu	Zn	Al
Treatment[†]	pH	g kg^{-1}		mg kg^{-1}							
Control	6.8 bc	11.3 b	1.3 b	19.3 c	1584cd	159c	283c	87b	1.49cd	1.56d	969a
Fertilizer, low	6.7 c*	11.7 b	1.3 b	20.8 c	1532d	159c	287bc	87b	1.43d	1.56d	978a
Fertilizer, high	6.4 d	11.7 b	1.3 b	22.4 bc	1427e	145d	272c	93a	1.41d	1.52d	994a
Poultry litter, low	6.9 b	11.8 b	1.4 b	29.6 b	1626bc	174b	305b	90ab	1.93b	2.3c	971a
Poultry litter, high	6.9 b	13.0 a	1.5 a	56.7 a	1677ab	176b	353a	94a	2.81a	3.89a	932b
Dairy manure, low	6.8 bc	11.7 b	1.4 b	21.2 c	1598c	163c	302b	89ab	1.49cd	1.87d	982a
Dairy manure, high	7.0 a	13.6 a	1.5 a	30.4 b	1711a	192a	343a	94a	1.68c	2.72b	933b
LSD	0.08	0.7	0.1	8.40	65.00	10.00	18.00	5.20	0.21	0.42	31.00

[†]Control: no nutrient applied; a low rate of fertilizer supplied 134 kg N ha^{-1}, 24.5 kg P ha^{-1}, and 46.5 kg K ha^{-1}; a high rate of fertilizer supplied 403 kg N ha^{-1}, 73.5 kg P ha^{-1}, and 139.5 kg K ha^{-1}; low poultry litter: 4.5 Mg ha^{-1}; high poultry litter: 13.5 Mg ha^{-1}; low dairy manure: 4.5 Mg ha^{-1}; high dairy manure: 13.5 Mg ha^{-1}.

*Means within each column followed by the same letters are not significantly different according to LSD 0.05 level.

TABLE 7. Soil pH, Total C, N, and Selected Mehlich-3 Soil Test Nutrient Concentrations for Soil Collected in Spring 2006

Treatment†	pH	C	N	P	Ca	Mg	K	Fe	Cu	Zn	Al
		---g kg⁻¹---		---mg kg⁻¹---							
Control	6.1b*	11.1cd	1.1d	19.9d	1708bc	165c	301d	78c	1.86cd	1.41d	959bc
Fertilizer, low	6.1b	11.5bc	1.2cd	29.1bcd	1670c	163c	353bc	82bc	1.87cd	1.42d	966b
Fertilizer, high	5.6c	10.5d	1.1d	24.3cd	1470d	143d	319cd	83bc	1.77d	1.17d	989a
Poultry litter, low	6.3ab	11.5bc	1.1d	35.0bc	1748bc	181b	361b	83bc	2.4b	2.10bc	947bcd
Poultry litter, high	6.27ab	12.3ab	1.3a	78.8a	1770ab	202a	472a	90a	3.68a	4.25a	935d
Dairy manure, low	6.2b	11.6bc	1.2bc	23.6cd	1711bc	173bc	321cd	80bc	1.90cd	1.61cd	945cd
Dairy manure, high	6.5a	12.8a	1.3a	37.4b	1857a	207a	386b	84b	2.12b	2.65b	937d
LSD (0.05)	0.20	0.9	0.1	11.60	66.00	12.00	36.00	6.00	0.32	0.61	21.00

†Control: no nutrient applied; a low rate of fertilizer supplied 134 kg N ha^{-1}, 24.5 kg P ha^{-1}, and 46.5 kg K ha^{-1}; a high rate of fertilizer supplied 403 kg N ha^{-1}, 73.5 kg P ha^{-1}, and 139.5 kg K ha^{-1}; low poultry litter: 4.5 Mg ha^{-1}; high poultry litter: 13.5 Mg ha^{-1}; low dairy manure: 4.5 Mg ha^{-1}; high dairy manure: 13.5 Mg ha^{-1}.

*Means within each column followed by the same letters are not significantly different according to LSD 0.05 level.

TABLE 8. Soil pH, Total C, N, and Selected Mehlich-3 Soil Test Nutrient Concentrations for Soil Collected in Spring 2007

Treatment†	pH	C	N	P	Ca	Mg	K	Fe	Cu	Zn	Al
		---g kg⁻¹---		---mg kg⁻¹---							
Control	6.3c*	12.3d	1.4c	23.3e	1754ed	182d	353d	108d	2.00d	1.84e	1130b
Fertilizer, low	6.1d	12.8d	1.4c	32.1ed	1661e	178d	421c	113cd	1.93d	1.79e	1143ab
Fertilizer, high	5.6e	13.2d	1.4c	33.6ed	1439f	153e	433c	117bc	1.89d	1.69e	1158a
Poultry litter, low	6.4b	13.4cd	1.6b	60.1c	1823cd	212c	453c	113cd	3.50b	3.81c	1096c
Poultry litter, high	6.5b	15.3ab	1.8a	175.3a	1959b	255b	574a	135a	6.44a	9.26a	1076cd
Dairy manure, low	6.5b	14.4bc	1.6b	38.6d	1886bc	206c	436c	115bcd	2.22cd	2.76d	1082c
Dairy manure, high	6.7a	16.2a	1.8a	83.2b	2225a	270a	511b	122b	2.53c	5.14b	1050d
LSD	0.10	1.1	0.1	15.0	93	13	38	8	0.41	0.83	27

†Control: no nutrient applied; a low rate of fertilizer supplied 134 kg N ha^{-1}, 24.5 kg P ha^{-1}, and 46.5 kg K ha^{-1}; a high rate of fertilizer supplied 403 kg N ha^{-1}, 73.5 kg P ha^{-1}, and 139.5 kg K ha^{-1}; low poultry litter: 4.5 Mg ha^{-1}; high poultry litter: 13.5 Mg ha^{-1}; low dairy manure: 4.5 Mg ha^{-1}; high dairy manure: 13.5 Mg ha^{-1}.

*Means within each column followed by the same letters are not significantly different according to LSD 0.05 level.

TABLE 9. Soil pH, Total C, N, and Selected Mehlich-3 Soil Test Nutrient Concentrations for Soil Collected in Spring 2008

Treatment†	pH	C	N	P	Ca	Mg	K	Fe	Cu	Zn	Al
		---g kg⁻¹---		---mg kg⁻¹---							
Control	6.2d*	11.8e	1.6b	31.6c	2007c	165cd	339d	87d	2.84c	2.23cd	904c
Fertilizer, low	5.9e	11.9e	1.4b	34.6c	1860d	151d	375cd	92c	2.86c	1.69cd	934b
Fertilizer, high	5.1f	12.9d	1.5b	36.0c	1548e	123e	367cd	100b	2.75c	1.54d	968a
Poultry litter, low	6.3c	12.9d	1.5b	63.0b	2085bc	190b	396c	92c	4.13b	4.07b	906c
Poultry litter, high	6.3c	14.9b	1.8a	178.0a	2200b	232a	587a	105a	6.76a	9.89a	856d
Dairy manure, low	6.4b	13.9c	1.5b	42.9c	2102bc	179bc	394c	92c	3.09c	2.72c	896c
Dairy manure, high	6.7a	16.8a	1.9a	78.0b	2371a	223a	519b	96bc	2.93c	4.37b	864d
LSD	0.10	0.9	0.2	19.1	124	15	38	5	0.71	1.07	25

†Control: no nutrient applied; a low rate of fertilizer supplied 134 kg N ha^{-1}, 24.5 kg P ha^{-1}, and 46.5 kg K ha^{-1}; a high rate of fertilizer supplied 403 kg N ha^{-1}, 73.5 kg P ha^{-1}, and 139.5 kg K ha^{-1}; low poultry litter: 4.5 Mg ha^{-1}; high poultry litter: 13.5 Mg ha^{-1}; low dairy manure: 4.5 Mg ha^{-1}; high dairy manure: 13.5 Mg ha^{-1}.

*Means within each column followed by the same letters are not significantly different according to LSD 0.05 level.

elements. There is some concern that continuous animal manure application will elevate concentrations of elements such as Cu and Zn in soil to levels harmful to plants or animals foraging on the plants (Warman and Cooper, 2000; Mantovi et al., 2003). Although the M-3--extracted soil Cu, Zn, and Al increased only slightly compared with initial soil concentrations of these elements after 4 years, longer term application of manure may cause the levels of these nutrients to approach critical phytotoxic levels.

CONCLUSIONS

Nutrient source and tillage practice impacted corn grain yield. No-till corn grain yield was lower than tilled corn. Corn yields did not differ with the rate of chemical fertilizer applied for corn production (low rate of 134 kg N ha^{-1} vs. high rate of 403 kg N ha^{-1}). Corn grain yields were similar with 13.5 Mg ha^{-1} of poultry litter as a primary fertilizer and chemical fertilizer (producer practice) under both no-till and tilled systems in four consecutive years. Both rates of dairy manure produced significantly less grain yield than poultry litter and chemical fertilizer treatments except for the high rate of dairy manure in 2006. Significant trends were found for the soil properties of this silt loam after 4 years of poultry litter and dairy manure applications. For example, M-3 soil P increased with both poultry litter and dairy manure compared with chemical fertilizer and control. The increase was much smaller for dairy manure. Calculation revealed that 5.2 kg ha^{-1} of P applied in poultry litter increased M-3 soil P by 1 mg kg^{-1} after 4 years of application. However, this study demonstrated that soil test P, Cu, and Zn levels were below values considered to be harmful to surface water quality or the crop. Soil total C increased during the course of study for high rates of poultry litter and dairy manure compared with the nontreated control soil, with a higher soil C increase under dairy manure, which can have positive implications to soil and environmental quality. Results indicate that poultry litter or dairy manure could be an effective alternative source of plant nutrient to produce optimum corn grain with proper management in this region.

ABBREVIATIONS

DM: dry matter;
M-3: Mehlich-3.

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