Manure As A Source of Leached Nitrate in Tilled and Untilled Soil

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Introduction

Application of manure to soils in crop production fields is strongly encouraged so that the nutrients in the manure will be utilized and the fecal organisms exposed to conditions adverse to their survival. Conservation tillage systems seek to maintain crop residues on the soil surface to reduce erosion. However, most manure management recommendations suggest immediate incorporation following surface applications in order to limit volatilization of ammonia (Lauer et al., 1976). Incorporation is also believed to reduce the potential for bacterial contamination of surface waters from field runoff (M. S. Coyne, personal communication).

Manure is a resource that may have the potential to cause degradation in subsurface water quality. No-tillage management is associated with the creation of stable "biopores" that can serve as conduits for dissolved materials (Edwards et al., 1992) and microorganisms (Smith et al., 1985) and which bypass much of the bulk soil's filtration potential. However, soils that are well drained often require no-tillage soil management to minimize further erosion and optimize summer crop performance. Such soils still have somewhat limited yield potential, especially during periods of drought. This reduced yield potential can contribute to greater residual soil nitrate levels at corn harvest. Macroporosity may result in there being less soil residence time for this residual nitrate prior to its being leached into shallow groundwater aquifers.

Groundwater nitrate contamination is generally thought to be associated with heavy manure/sludge use in Europe (Aslyng, 1986). Except where animal density is very high, the prevailing view in the United States has been that fertilizer nitrogen (N) represents a major source of the contamination (Papendick et al., 1987). Sims (1987) reported that poultry manure application was associated with less nitrate leaching than where equivalent amounts of fertilizer N were applied. Others have observed greater levels of nitrate in waters underlying manured sandy soils in the U. S. Coastal Plain (Hubbard et al., 1987; Weil et al., 1990).

No-till soils tend to be wetter early in the season and this may result in increased N loss via denitrification when manure is applied (Pratt et al., 1976), as well as greater N use due to raised crop yield potential. It remains unclear whether a greater yield potential will reduce the leaching of nitrate from manure-amended no-till soils, but differences in seasonal denitrification potential may have contributed to the observation that the seasonal timing of manure application has been found to be important in nitrate leaching in European studies (vanDijk, 1985; Bertilsson, 1988).

Studies combining tillage treatments with manure use have been few. The potential for conflict(s) between soil and manure management have not been defined. Once these conflicts are better described, soil erosion and manure management plans can be better integrated. The objectives of this research were: (1) to monitor the leaching of nitrate and determine its relationship, if any, to manure application timing, surface tillage, and fertilizer N use; and (2) to examine the tradeoffs between manure and fertilizer as sources of N in two conservation tillage soil management systems.

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Methodology

The results to follow are for the 1993 cropping season, which begins with manure application in the fall of 1992 and continues through the 1993194 leaching season, which ends just prior to manure application in the spring of 1994. An existing (started in 1991) field research site established on a well-drained Maury silt loam (Typic Paleudalf) and located on the Spindletop Research Farm near Lexington, Kentucky, was used. The experimental design in place is a split-plot with three replications laid out in randomized blocks. Main plots consist of 12 tillage-manure timing treatments. Nitrogen rates of 0, 75, and 150 lb N/A make up the subplots. Subplot size is 12 feet (four rows) wide by 30 feet long. The cropping system is continuous corn *(Zea mays* L.), with a winter rye *(Secale cereale* L.) cover sown subsequent to corn harvest each year.

Six main plot treatments were used in this study. These tillage-manure timing treatments were (1) no-tillage, no manure; (2) no-tillage, fall manure every year; (3) no-tillage, spring manure every year; (4) no-tillage, fall and spring manure every year; (5) chisel plow and disking, no manure; and 6) chisel plow and disking, spring manure every year.

Tension-free "pan" lysimeters (Tyler and Thomas, 1977) were installed under undisturbed soil in two replicates of subplots chosen within the main plot (tillage-manure timing) treatments. Two experiments were put in place. In the first, to examine interactions between tillage, spring manure, and fertilizer N, the pans were installed in the 0 and 150 lb N/A subplots in main plot treatments 1, 3, 5, and 6 (see above).

In the second, to observe effects due to the timing of manure application, pans were installed in the 0 lb N/A subplot of main plot treatments 1, 2, 3, and 4 (see above). Because of overlap between experiments of some subplots, only 20 pans were required. The pans were made from stainless steel and measured 3 feet wide (across the row) by 2 feet deep (along the row). Pans were installed such that the surface of the pan was 3 feet below the soil surface.

Water samples were collected and volumes measured following each rain event of sufficient intensity and/or duration to result in percolation. Samples were kept refrigerated at 4 *"C* until chemical analysis for nitrate (usually completed within 24 hours). Water data reported here are from April 15, 1993 until April 14, 1994. Due to the hydrologic cycle's impact on seasonal water flow, as well as the timing of field treatments, soil sampling, and crop growth, the water data were subdivided into four seasonal "periods." The four periods were: (I) April 15 to June 30, 1993 (early crop development); ((2) July 1 to Nov. 14, 1993 (late crop development/harvest); ((3) Nov. 15 to Dec. 31, 1993 (soil moisture recharge); and (4) January 1 to April 14, 1994 (soil moisture excess-drainage). Sampling events were combined within each period and the data pooled to give total water flux (in inches), volume weighted average nitrate concentration (in ppm N) and nitrate flux (in lb N/A) for each period.

Dairy *(Bos taurus)* manure applications (Dec. 9, 1992, May 10, 1993, and Nov. 24, 1993) were made by a tractor-pulled box-end spreader. To determine the rate of application, 20 to 24 flat trays, measuring 14 by 18 inches, were randomly assigned throughout the plots prior to spreading. After collection, the samples were dried on the trays, without heat, and then weighed, cleaned, and weighed again to determine the dry matter application rate. A subsample of manure was taken from each tray for chemical analysis and ground to pass a 0.5- mm screen opening.

Chisel plow tillage was done to a depth of 8 inches after the spring manure application (May 17, 1993) with twisted, 4 inches wide shovels on 1-foot centers. Secondary tillage consisted of disking twice (May 19, 1993). Pioneer 3279 corn was planted on May 21, 1993 at 23,100 seed/A at a row spacing of 3 feet using a John Deere 7000 Max-Emerge no-till corn planter equipped with row cleaners in front of double disc openers. Glyphosphate, atrazine, and alachlor were used for burndown and residual weed control. The nitrogen fertilizer treatments were broadcast top-dressed on June 25, 1993 using ammonium nitrate as the nitrogen source.

Corn yields were measured by hand harvesting 10 feet of each of the center two rows of each subplot on Oct. 15, 1993. Grain moisture was determined by weighing a random sample of five ears taken from each subplot, drying these ears at 60 °C for 1 week, weighing them again, shelling off the grain, and reweighing the grain. Yield data were corrected to a uniform 15.5% moisture. A subsample of grain was taken for chemical analysis. The grain subsamples were ground to pass a 0.5-mm screen opening.

Common winter rye was drilled over the entire plot area at a rate of 150 lb seed/A in 7-inch rows on Nov. 23, 1993 using a Lilliston 9680 no-till drill.

Soil sampling was performed before manure application in the spring (10 May 10, 1993 and April 20, 1994) and fall (Nov. 22, 1993) using a tractor-mounted hydraulic soil probe. Four cores (1.125-inch diameter), two between and two within the old corn rows, were taken and composited for each subplot. Samples were taken to a depth of 36 inches and divided into 0-6, 6-l2, 12-24 and 24-36-inch depth increments prior to compositing. Soil samples were air dried and crushed to pass a 2-mm screen opening. Soil bulk density was determined across the plot area, at each depth increment, using cores that did not exhibit any compression during sampling.

Manure and grain N concentrations were determined by microKjeldah1 digestion (Nelson and Sommers, 1973) with automated N detection by the colorimetric indophenol-blue reaction (Keeney and Nelson, 1982). Soil nitrate was found by extraction with molar KCL (25 mL so1ution:l0 g soil for 30 minutes), filtering the extract through Whatman 42 paper, and automated determination of nitrate by the colorimetric Greiss-Hosvay method (Keeney and Nelson, 1982) after reduction of nitrate to nitrite by Cd. Soil nitrate was expressed in lb N/A after correction of soil nitrate concentrations for the bulk density. Results were then summed across all the depth increments. Nitrate in water samples was determined using the same filtering and colorimetric procedures as for soil nitrate, above.

Statistical analyses of the measured variables were performed with the use of the Statistical Analysis System (SAS Institute, 1989). The General Linear Models (GLM) procedure was used for analysis of variance due to a few missing data. Means separation was performed using the Least Significant Difference (LSD) procedure. The experimental design of the first experiment (I) was a 2x2x2 factorial with split plots (2 tillage treatments by 2 manure rates by 2 fertilizer N rates). The experimental design of the second experiment (II) was a 2x2 factorial (yes or no fall manure vs. yes or no spring manure). There were two replications for water data and three replications for the crop and soil data.

Results and Discussion

Manure application rates were not consistent from one application date to the next (Table I). The December 1992 (fall) application was somewhat under the target rate of 5 tons dry

Table 1. Manure applications made during the study period.

Application Date	Application Rate of:		
	Dry Matter	Total N	Available N*
	lb/acre	-------- lb N/acre	----
Dec. 9, 1992 (fall)	8,800	195	98
May 10, 1993 (spring)	18,600	401	200
Nov. 24, 1993 (fall)	12,800	324	162

* Available N assumed to be one-half the total N in the year of application.

matter per acre, while the two later applications were over the target rate. The nitrogen contained in the manure was always greater than the highest fertilizer N rate used (150 lb N/A). The "available" N from the manure, calculated as half of that applied, was also greater than the highest fertilizer N rate, except for the December, 1992 application (Table 1).

Corn grain yields were generally quite good, but were unaffected by tillage in experiment I (Table 2). Grain N removal was similarly unaffected. There was an interaction between manure and fertilizer N use on corn grain yield and N removal in experiment I (Table 2). The spring manure application severely diminished the positive grain yield and N removal responses to fertilizer N. In the presence of manure, fertilizer N removal in corn grain (calculated by difference) was only 17 lb N/A, but was about 54 lb N/A in its absence. Grain removal of manure N was similarly affected by the use of fertilizer N.

In experiment II, there was a strong interaction between times of manure application (Table 2). While the fall manure application raised both grain yield and N removal in relation to the unamended control, spring manure application resulted in greater yield and N removal. Further, there was no benefit to fall manure when manure was also applied in the spring. This response pattern is due in part to a greater potential for N losses between manure application and corn planting.

Profile soil nitrate levels were generally higher where fertilizer N was used, especially under chisel plow soil management in experiment I (Table 3). Prior spring manure applications did not raise soil nitrate levels at this time. This was not the case for the more recent fall manure applications evaluated in experiment II, where mineralization resulted in greater soil nitrate in the spring of 1993 (Table 3).

After corn harvest, soil profile nitrate was still generally greater where fertilizer N was used, again especially after chisel plowing (Table 3). Spring manure applications raised soil profile nitrate levels only when no fertilizer N was used. Without manure use, fertilizer N application resulted in greater residual soil nitrate levels than did spring manure amendment without fertilizer. This occurred despite the fact that much more manure N was applied. Spring manure application also increased soil profile nitrate in experiment 11, but fall manure application did not (Table 3). Profile nitrate was generally greater after corn harvest than prior to corn planting. The fall manure treatments without fertilizer N in experiment II were the only treatments to evidence less profile nitrate at corn harvest than existed prior to corn planting. The gains in profile nitrate observed in other treatments between April and November 1993 were generally modest (1-14 lb NIA). The fraction of fertilizer and manure N accounted for in these changes in soil profile nitrate was generally small (less than 10%).

Apparent losses of nitrate from the soil profile between November 1993 and April 19994 were between 1 and 29 lb N/A in experiment I (Table 3). In experiment 11, plots receiving fall manure in November, 1993 (Table 1) evidenced gains of 12-14 lb N/A in profile nitrate over this period. In experiment I, fertilizer N treatments were less apparent in these data than in those of April 1993, but spring manure applications were more evident (Table 3).

Collected percolate was quite minimal during the cropping season, averaging 1.0 and 0.7 inch for the April 15 to June 30, 1993 and July 1 to Nov. 14, 1993 periods (1 and 2), respectively. More leachate was collected after crop harvest and over the winter, with the pans averaging 3.1 and 6.9 inches for the Nov. 15 to Dec. 31, 1993 and the Jan. 1 to

Table 2. Corn grain yields and nitrogen removal in 1993.

Tillage System	Manure Application Timing	Fertilizer N Rate	Grain Yield	Grain N Removal
		lb N/acre	bu/acre	lb N/acre
Experiment I: Main Effect of Tillage				
No-tillage			140.3a*	85.1a*
Chisel/disk			134.2a*	89.8a
Experiment I: Interaction of Manure and N Rate				
	none	0	89.3b*	43.3c*
		150	156.3a	97.1b
	spring only	0	149.7a	96.0b
		150	153.7a	113.3a
Experiment 11: Interaction Between Times of Manure Application				
–	none	0	89.6c*	42.8d*
All	fall only	0	116.6b	70.6c
No-till	spring only	0	145.4a	93.6a
–	fall + soring	0	137.5a	83.3b

*Means within a sub-column followed by the same letter are not significantly different at the 90% level of confidence by the LSD method.

Table 3. Soil profile (0 to 3 ft) nitrate prior to, and after, the 1993 growing season.

Tillage System	Manure Application Timing	Fertilizer N Rate	Soil Profile Nitrate: May 93	Nov. 93	April 94
		lb N/acre		lb N/acre	
Experiment I: Interaction of Tillage and N Rate					
No-tillage		0	5.1c*	10.4c*	8.3a*
		150	14.3b	24.1b	11.7a
Chisel/disk		0	5.3c*	11.3c	8.8a
		150	24.4a	37.5a	10.6a
Experiment I: Interaction of Manure and N Rate					
	None	0	4Sb*	6.0c*	5.0c*
		150	18.4a	30.6a	8.1bc
	Spring only	0	6.0b	15.6b	12.2ab
		150	20.3a	31.0a	14.1a
Experiment II: Interaction Between Times of Manure Application					
–	none	0	4.4b*	5.7b*	4.6c*
All	fall only	0	16.1a	9.1b	22.7a
No-till	spring only	0	9.1b	15.0a	12.9b
–	fall + spring	0	18.6a	16.9a	29.3a

*Means within a sub-column followed by the same letter are not significantly different at the 90% level of confidence by the LSD method.

April 14, 1994 periods (3 and 4), respectively. Percolate water quality, as affected by nitrate concentration, was not significantly impacted by choice of conservation tillage system in experiment I (Table 4). However, both spring manure application and fertilizer N use generally resulted in significantly greater concentrations of nitrate in leachate (Table 4). Except for the first period, fertilizer N generally raised water nitrate concentrations more than manure application. This observation supports a similar trend reported for profile soil nitrate levels (Table 3, above). Leachate nitrate concentrations tended to be lowest in the second period (Table 4), when the crop was most actively utilizing N. Leachate nitrate concentrations tended to be greatest in periods 3 and 4, when plant metabolism was lowest.

In experiment II, fall manure application significantly increased water nitrate concentrations in period 1, but not in other periods (Table 4). The fall plus spring manure application resulted in greater water nitrate concentrations than other treatments in period 2. No manure timing effects were observed in water nitrate concentrations in period 3, but spring manure applications resulted in generally greater water nitrate in period 4 (Table 4).

Quantities of leached nitrate were influenced by differences in water flux (data not shown) as well as differences in nitrate concentration. In experiment I, no-tillage generally resulted in less, and fertilizer N use more, nitrate flux (Table 5). Spring manure use had little effect on nitrate flux, primarily because water flux was reduced where spring manure was amended. In experiment II, there were also few differences in quantities of leached nitrate due to differences in the time of manure application. Nitrate leaching losses were generally small in periods 1 and 2, coincident with both greater water and nitrogen use by the growing crop.

In experiment I, nitrate leaching losses measured in water collected during periods 3 and 4 were generally greater than losses apparent due to changes in profile soil nitrate over the same period (Table 3). This suggests that some mineralization was generally occurring over the winter months. The rye cover crop would have been expected to have reversed the relationship between leached nitrate flux and apparent changes in soil nitrate over the same time period, but was ineffective as a nitrate scavenger because of late establishment and because of poor winter survival.

In summary, manure was as effective as fertilizer as a source of N in continuous corn culture. However, spring manure N resulted in less residual soil nitrate and lower concentrations of nitrate in leachate than did fertilizer N. At the rates used, there was little evidence for reduced N availability and greater N loss where a surface application of manure was used in combination with no-tillage. The data do suggest that spring manure applications will result in greater N use by the crop than will fall manure applications. Water quality was not improved commensurately, probably because of the much greater rate of manure applied in the spring, as compared to the fall, in this study. Fall manure application did result in greater levels of soil nitrate the following spring, indicating that some of the manure N was mineralized over the winter months. Water quality over the winter was well related to the disappearance of soil nitrate found after corn harvest, but leached nitrate generally exceeded apparent soil nitrate losses. Leached nitrate was generally small in relation to the amounts of manure and fertilizer N applied, suggesting that other N loss/conversion pathways for nitrate are significant.

Table 4. Nitrate concentration of percolating water collected in the pan lysimeters.

Tillage System	Manure Application Timing	Fertilizer N Rate	Nitrate Conc. by Period: 1	2	3	4
		lb N/acre	ppm N			
Experiment I: Main Effect of Tillage						
No-tillage			6.2a*	4.9a*	10.1a	13.1a
Chisel/disk			7.7a	4.6a	7.6a	9.1a
Experiment I: Main Effect of Manure						
	None		4.2b*	2.8b	7.3a	7.7b
	Spring only		9.8a	6.7a	10.4a	14.6a
Experiment I: Main Effect of N Rate						
		0	5.0b*	2.2b	4.9b	6.9b
		150	8.9a	7.3a	12.8a	15.3a
Experiment II: Interaction Between Times of Manure Application						
—	None	0	3.4b*	2.5b	8.3a	6.1b
All	Fall only	0	10.2a	1.7b	4.4a	9.7ab
No-till	Spring only	0	5.3b	2.2b	5.2a	11.9ab
—	Fall + spring	0	12.8a	5.2a	5.8a	14.9a

* Means within a sub-column followed by the same letter are not significantly different at the 90% level of confidence by the LSD method.

Table 5. Quantity of nitrate-nitrogen leached into the pan lysimeters.

Tillage System	Manure Application Timing	Fertilizer N Rate	Leached Nitrate by Period: 1	2	3	4	total
		lb N/acre	lb N/acre				
Experiment I: Main Effect of Tillage							
No-tillage			1.4a*	0.5a	2.6b	10.9a	15.4b
Chisel/disk			2.3a	0.8a	8.3a	16.5a	27.7a
Experiment I: Main Effect of Manure							
	None		0.7a*	0.4a	5.5a	13.8a	20.3a
	Spring only		3.0a	0.9a	5.3a	13.6a	22.8a
Experiment I: Main Effect of N Rate							
		0	0.8a*	0.4b	2.9b	11.2a	15.3b
		150	2.8a	0.9a	8.0a	16.1a	27.8a
Experiment II: Interaction Between Times of Manure Application							
—	None	0	0.1a*	0.3a	2.2a	13.7c	16.3b
All	Fall only	0	3.3a	0.4a	3.7a	18.4b	25.8a
No-till	Spring only	0	1.5a	0.6a	4.6a	20.4ab	27.1a
—	fall + spring	0	3.2a	1.0a	2.0a	23.0a	29.1a

* Means within a sub-column followed by the same letter are not significantly different at the 90% level of confidence by the LSD method.

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