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NITROGEN AND PHOSPHORUS CONCENTRATIONS OF RUNOFF AS AFFECTED BY MOLDBOARD PLOWING

J. E. Gilley, B. Eghball, D. B. Marx

ABSTRACT. *The excessive application of manure on cropland areas can cause nutrients to accumulate near the soil surface. This study was conducted to measure the effects of moldboard plowing on the redistribution of nutrients within the soil profile and nutrient transport by overland flow. Composted beef cattle manure was applied at dry weights of 0, 68, 105, 142, and 178 Mg ha^{-1} to a silty clay loam soil and then incorporated by disking. Selected plots were moldboard plowed 244 days later to a depth of approximately 23 cm. Soil samples for analysis of water-soluble phosphorus, Bray and Kurtz No. 1 phosphorus (Bray-1 P), NO_3-N, and NH_4-N were collected at depths of 0-5, 5-15, and 15-30 cm before and after moldboard plowing. Three 30 min simulated rainfall events, separated by 24 h intervals, were then applied. Dissolved phosphorus (DP), NO_3-N, NH_4-N, and total nitrogen (TN) content of runoff were measured from 0.75 wide × 2.0 m long plots. Bray-1 P content at the 0-5 cm soil depth was reduced from 200 to 48.0 mg kg^{-1} and NO_3-N content decreased from 9.49 to 2.52 mg kg^{-1} as a result of the moldboard plowing operation. Consequently, mean concentrations of DP and NO_3-N in runoff decreased from 1.76 and 2.29 mg L^{-1} under no-till conditions to 0.03 and 0.60 mg L^{-1} on the moldboard plow plots. Thus, the experimental results suggest that moldboard plowing can significantly reduce concentrations of DP and NO_3-N in runoff from land application areas.*

Keywords. *Eutrophication, Manure management, Manure runoff, Nitrogen movement, Nutrient losses, Phosphorus, Plowing, Runoff, Tillage, Water quality.*

The land application of manure at rates that exceed crop nutrient requirements can result in the accumulation of P within the soil profile (Sims et al., 1998). An increase in P content near the soil surface is especially pronounced when manure is applied under no-till conditions without incorporation (Daverede et al., 2003). Gilley and Eghball (2002) found that after four years of corn production following the last application of beef cattle compost, P content near the soil surface remained elevated.

Soil P content near the surface has been found to influence runoff P concentrations (Sharpley et al., 1996; Wortmann and Walters, 2006). Concentrations of P in runoff have been reported to increase with greater soil P test values (Pote et al., 1999; Andraski and Bundy, 2003). However, the amount of crop residue on the soil surface has been found to have a minimal effect on nutrient concentrations in runoff (Nicolaisen et al., 2007).

Research on conservation tillage systems has shown that stratification of P at the soil surface can increase nutrient runoff losses over time (Andraski et al., 2003). Nutrient concentrations in runoff following land application of beef cattle manure on cropland sites containing corn, sorghum, or wheat residue were found to be greater on no-till than tilled treatments (Eghball and Gilley, 1999; Eghball et al., 2000). Bundy et al. (2001), in their studies on the effects of dairy manure application on P losses in runoff from corn production systems, showed that tillage to incorporate manure generally lowered DP concentrations but increased total P (TP) concentrations due to increased sediment load. Reduced tillage can also decrease particulate P losses (Sims and Kleinman, 2005).

Gilley et al. (2007) measured nutrient transport in runoff as affected by tillage and time following the application of beef cattle or swine manure to a cropland site. Concentrations of DP, TP, and NH_4-N, in general, declined throughout the year on both the no-till cattle and no-till swine manure treatments. Under no-till and tilled conditions on both the cattle and swine manure treatments, the smallest concentrations of DP, NO_3-N, NH_4-N, and total N (TN) in runoff occurred on the final test date approximately one year after manure application.

Surface soil containing excessive nutrient levels can be inverted by plowing. Plowing has been shown to reduce soil nutrient content near the surface and to redistribute nutrients within the top 15 cm of soil (Pezzarossa et al., 1995; Rehm et al., 1995). A decrease in surface soil nutrient values could reduce N and P transport by overland flow.

Sharpley (2003) investigated the feasibility of redistributing surface stratified P within the top 15 cm of soil. Selected surface soils with excessive amounts of P from long-term manure application were mixed with subsoil materials containing smaller amounts of P. The mixing process substantially reduced P levels near the soil surface.

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Little et al. (2005) conducted a three-year study to measure nutrient and sediment losses with selected tillage methods including a moldboard plow for incorporation of beef cattle manure. On the moldboard plow treatment, runoff loads of TN and TP were reduced 95% and 79%, respectively. Sediment losses were not significantly different among tillage treatments.

Wortmann and Walters (2007) examined the effects of moldboard plowing on the concentration and load of DP, particulate P (PP), and TP in runoff from a silt loam soil on which low-P and high-P compost had been applied. Runoff from natural precipitation events was measured from 3.7 m wide × 11.0 m long plots. Moldboard plowing was found to greatly reduce P loss in runoff. The objective of the present study was to determine the effects of moldboard plowing on the redistribution of P and N stratified near the soil surface and nutrient transport by overland flow.

MATERIALS AND METHODS

STUDY SITE CHARACTERISTICS

This field study was conducted at the University of Nebraska Rogers Memorial Farm located 18 km east of Lincoln, Nebraska. The soil at the site developed in loess under prairie vegetation and had a mean slope of 7%. The Sharpsburg silty clay loam soil (fine, smectitic, mesic Typic Argiudoll) contained 11% sand, 54% silt, and 35% clay, and 18.5 g kg^{-1} of organic C in the top 15 cm of the soil profile. This soil is moderately well drained, and the permeability is moderately slow. For the plots on which compost was not applied and moldboard plowing did not occur, the content of water-soluble P (WSP), Bray-1 P, NO_3-N, and NH_4-N at the 0-5 cm soil depth was 5.02, 76.1, 4.90, and 3.31 mg kg^{-1}, respectively. Electrical conductivity and pH, measured in a 1:1 soil/water ratio, were 0.47 dS m^{-1} and 6.58. The site had been cropped using a grain sorghum (*Sorghum bicolor* (L.) Moench), soybean (*Glycine max* (L.) Merr.), winter wheat (*Triticum aestivum* L. cv. Pastiche) rotation, under a no-till management system. The study area was planted to winter wheat in September 2001 and harvested in July 2002. Herbicide was applied as needed between July 2002 and July 2003 to control weed growth.

EXPERIMENTAL DESIGN

Forty 0.75 m wide × 2 m long plots were established using a randomized block design. The larger plot dimension extended up and down the slope in the direction of overland flow. Manure was applied at five selected rates on 24 September 2002, and each of the plots was then disked to an 8 cm depth. One-half of the treatments were moldboard plowed to a 23 cm depth 244 days later, and the entire area was then disked to an 8 cm depth. This resulted in 20 moldboard-plowed plots and 20 non-moldboard plowed plots. Both disking and moldboard plowing occurred up and down the slope in the direction of overland flow.

Compost application rates, calculated on a dry weight basis, were 0, 68, 105, 142, and 178 Mg ha^{-1}. These rates were determined from previous mineralization studies (Eghball and Power, 1999; Eghball, 2000; Eghball et al., 2002). The equivalent dry rates of total N that were added were 0, 0.62, 0.96, 1.30, and 1.63 Mg ha^{-1}, while total P was applied at equivalent dry rates of 0, 0.36, 0.56, 0.76, and 0.95 Mg ha^{-1}. To meet estimated N requirement to achieve a target corn yield of 9.4 Mg ha^{-1}, compost would have been applied at a dry rate of 48 Mg ha^{-1}, assuming 40% N availability during the first year following manure application (Eghball and Power, 1999).

The composted beef cattle manure was obtained from the University of Nebraska Agricultural Research and Development Center near Ithaca, Nebraska. During the composting process, microorganisms help to stabilize nutrients into organic compounds that are released over time (Eghball and Barbarick, 2002). Concentrations of NO_3-N, NH_4-N, TN, and TP in the composted beef cattle manure, determined on a dry weight basis, were 1.22, 0.41, 9.45 and 5.32 g kg^{-1}, respectively. Electrical conductivity and pH, measured in a 1:5 compost/water ratio, were 17.2 dS m^{-1} and 7.2.

Soil may be transported from its original location during tillage. Therefore, the composted beef cattle manure was applied to a 2.4 m wide × 2.7 m long area to provide more uniform application. Each of the 40 plots was disked up and down the slope in the direction of overland flow to a depth of approximately 8 cm on 26 September 2002. The plots on which composted beef cattle manure was not applied were also disked to provide a standard tillage condition for the study area.

Soil cores were collected by hand from each of the 40 plots on 15 to 22 May 2003 (233 to 240 days following compost application) in 0-5, 5-15, and 15-30 cm depth increments using a 1.9 cm diameter probe. Twenty of the plots were then moldboard plowed up and down the slope to a depth of approximately 23 cm on 27 May 2003 (244 days following compost application). Finally, each of the 40 plots was disked up and down the slope in the direction of overland flow to a depth of approximately 8 cm on 27 May 2003. Soil samples were again collected on 28 May to 4 June 2003 at the three depth increments used previously to determine the redistribution of soil nutrients within the profile after plowing.

Soil samples were air dried and then analyzed for water-soluble P (WSP), Bray-1 P, NO_3-N, and NH_4-N. A modified version of the procedure identified by Pote et al. (1996), which involved shaking 2 g of soil for 5 min in 20 mL of deionized water, was used to extract WSP. As an index of P availability, the Bray-1 P procedure (Bray and Kurtz, 1945) provides a relative estimate of P concentration in the soil solution that limits the growth of plants. Concentrations of WSP and Bray-1 P were analyzed using the Murphy-Riley procedure (Murphy and Riley, 1962). Soil NO_3-N and NH_4-N concentrations (extracted using a 2 molar KCl solution) were measured with a spectrophotometer (Lachat system, Zellweger Analytics, Milwaukee, Wisc.).

RAINFALL SIMULATION PROCEDURES

Water used in the rainfall simulation tests was obtained from an irrigation well. Measured mean concentrations of DP, NO_3-N, NH_4-N, and TN in the irrigation water were 0.19, 16.8, 0.04, and 16.8 mg L^{-1}, respectively. The irrigation water had a mean EC value of 0.65 dS m^{-1} and a pH of 7.67. Reported nutrient values represent the difference between runoff measurements and concentrations of the irrigation well water.

Field rainfall simulation tests were conducted from 2 June to 9 July 2003 (251 to 288 days following compost application). Experimental procedures established by the National Phosphorus Research Project (NPRP) were employed in this study (Sharpley and Kleinman, 2003). A portable rainfall simulator based on the design by Humphry et al. (2002) was used to apply rainfall to paired plots. Two rain gauges were placed along the outer edge of each plot, and one rain gauge was located between the plots.

Water was first added to the plots with a hose until runoff began to provide more uniform antecedent soil water conditions among treatments. Burlap material was placed on the plot surface to reduce the kinetic energy of the added water. The period between the addition of water to the surface and initiation of rainfall simulator testing was only a few minutes.

The simulator was used to apply rainfall for 30 min at an approximate rate of 70 mm h^{-1} (NPRP protocols are for runoff to be collected for a 30 min period). Following the initial rainfall simulation event, plots were covered with tarps to prevent the input of natural rainfall. Two additional rainfall simulation tests were conducted for the same duration and intensity at approximately 24 h intervals.

Plot borders channeled runoff into a sheet metal lip that emptied into a collection trough. The trough extended across the bottom of each plot and diverted runoff into aluminum washtubs. After completion of a rainfall simulation event, the washtubs were weighed to determine total runoff mass. The stored runoff was then agitated to maintain suspension of solids. Two runoff samples were collected for water quality analyses, and two additional samples were obtained for sediment analyses. Centrifuged and filtered runoff samples (obtained using 11 μm filter paper) were analyzed for DP (Murphy and Riley, 1962), NO_3–N, and NH_4–N using a Lachat system (Zellweger Analytics, Milwaukee Wisc.). Non-centrifuged samples were analyzed for TN (Tate, 1994). The two samples obtained for sediment analysis were dried in an oven at 105°C and then weighed to determine sediment content.

Rainfall simulation procedures used by the NPRP represent an extreme condition. Three consecutive high-intensity storms, of 30 min duration each, would be unlikely to occur over a 72 h period under natural rainfall conditions. However, the rainfall simulation protocol allows comparison of results among selected experimental treatments. Since NPRP participants use the same rainfall simulation and data collection procedures, researchers are better able to compare and contrast the experimental data obtained at different geographic locations.

DATA ANALYSES

The effects of tillage, compost application rate, and soil depth on soil characteristics were determined using ANOVA (SAS, 2003). For a given plot, water quality measurements obtained from each of the three-rainfall simulation runs were included in the statistical analyses. The effects of tillage and compost application rate on selected water quality parameters were identified using ANOVA. The least significant difference test (LSD) was used to identify the effects of tillage, compost application rate, and soil depth on selected soil characteristics (table 1). The effects of tillage and compost application rate on concentrations of selected nutrients, runoff, and erosion were also identified using LSD procedures (table 2). A probability level < 0.05 was considered significant for both the ANOVA and LSD tests.

RESULTS AND DISCUSSION

SOIL CHARACTERISTICS AS AFFECTED BY MOLDBOARD PLOWING

The tillage × compost application rate × soil depth interaction was significant for WSP and Bray–1 P. All two-way interactions were significant for WSP, Bray–1 P, and NO_3–N (table 1).

Phosphorus Measurements

The Bray–1 P content of 200 mg kg^{-1} measured at the 0-5 cm depth before moldboard plowing was significantly greater than the 18 and 21 mg kg^{-1} measured at soil depths

Table 1. Effects of soil depth, tillage, and compost application rate on water-soluble phosphorus (WSP), Bray and Kurtz No. 1 phosphorus (Bray–1 P), NO_3–N, and NH_4–N content of the soil.

Soil Depth (cm)	Compost Rate (Mg ha^{-1})	Variable (mg kg^{-1})			
		WSP	Bray–1 P	NO_3–N	NH_4–N
0-5	Non-plow				
	0	3.2	52	6.5	7.2
	68	24.7	230	8.5	4.1
	105	18.2	198	10.0	4.1
	142	18.2	201	8.9	5.7
	178	34.0	319	13.5	3.3
	Plow				
	0	1.4	36	3.1	6.6
	68	2.6	47	2.6	5.6
	105	1.6	37	2.0	4.7
	142	4.0	66	2.7	4.9
	178	2.4	54	2.4	4.8
5-15	Non-plow				
	0	1.1	12	4.5	6.3
	68	1.0	21	9.9	3.8
	105	0.7	12	8.1	3.3
	142	0.5	13	10.8	7.4
	178	1.4	28	11.9	3.1
	Plow				
	0	2.1	42	3.3	4.9
	68	3.3	53	4.4	4.0
	105	2.8	84	4.8	4.5
	142	9.5	128	5.5	3.4
	178	2.3	45	5.5	4.2
15-30	Non-plow				
	0	1.9	24	5.2	4.0
	68	0.7	18	14.3	3.8
	105	1.2	19	10.6	3.1
	142	0.8	19	14.1	7.5
	178	1.8	24	14.9	3.1
	Plow				
	0	1.1	21	2.7	4.8
	68	1.2	20	5.8	4.1
	105	2.7	56	4.8	4.4
	142	2.1	33	6.5	3.4
	178	2.3	21	7.8	3.6
LSD		5.2	46	2.1	2.0
ANOVA (Pr > F)					
Tillage		0.01	0.01	0.01	0.78
Compost rate		0.35	0.37	0.01	0.33
Soil depth		0.01	0.01	0.01	0.04
Tillage × compost rate		0.01	0.01	0.01	0.05
Tillage × soil depth		0.01	0.01	0.01	0.27
Compost rate × soil depth		0.01	0.01	0.01	0.23
Tillage × compost rate × soil depth		0.01	0.01	0.16	0.29

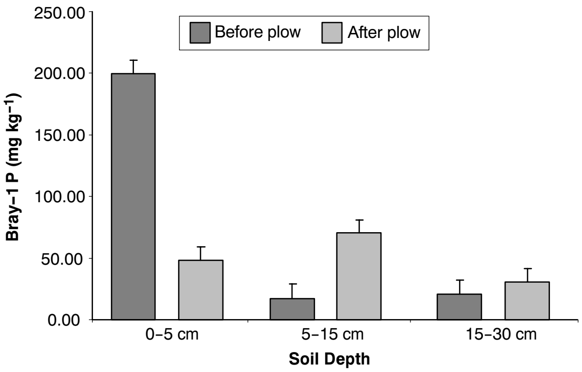

Figure 1. Soil Bray–1 P content as affected by tillage and soil depth. Nutrient content values are averaged across compost rates. Vertical bars are standard errors.

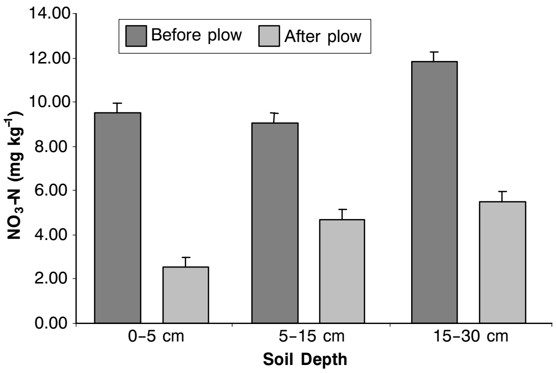

Figure 2. Soil NO_3–N content as affected by tillage and soil depth. Nutrient content values are averaged across compost rates. Vertical bars are standard errors.

of 5-15 and 15-30 cm, respectively (fig. 1). The moldboard plowing operation significantly reduced Bray–1 P content at the 0-5 cm depth from 200 to 48 mg kg^{-1}. After moldboard plowing, soil near the surface came from greater depths where soil test P levels were initially much less. The Bray–1 P content of 71 mg kg^{-1}, measured at the 5-15 cm depth after moldboard plowing, was significantly greater than the 18 mg kg^{-1} determined before plowing. Soil originally located near the surface was deposited at greater depths as a result of the moldboard plowing operation.

Significant differences in WSP and Bray–1 P values were found among compost application rates at the 0-5 cm soil depth on the non-plow treatment (table 1). However, soil test P values did not consistently increase with each incremental compost application. Variations in soil test P values among compost application rates are attributed to the non-uniform nature of the compost material.

The experimental results obtained for WSP and Bray–1 P were similar. The following regression equation ($R^2 = 0.89$), obtained from samples collected at the 0-5 cm soil depth before moldboard plowing, relates WSP content to Bray–1 P measurements:

$$\text{WSP} = 0.117(\text{Bray–1 P}) - 4.11 \qquad (1)$$

Equation 1 was derived using WSP values ranging from 1 to 51 mg kg $^{-1}$ and Bray–1 P measurements varying from 13 to 414 mg kg^{-1}.

Nitrogen Measurements

No significant differences in NO_3–N content of soil were found between the 0-5 and 5-15 cm depth increments prior to moldboard plowing (table 1 and fig. 2). Since NO_3–N is highly soluble, it likely leached from near the soil surface (0-5 cm) to lower depths (5-15 cm and 15-30 cm). After moldboard plowing, the NO_3–N content of the soil was reduced significantly at each of the three soil depths. The NO_3–N content of 2.5 mg kg^{-1}, measured at the 0-5 cm depth after moldboard plowing, was significantly less than the 4.7 and 5.5 mg kg^{-1} measured at soil depths of 5-15 and 15-30 cm, respectively

The incorporation of compost during the moldboard plowing operation likely enhanced the environment for microbial activity, resulting in rapid mineralization of organic N. Rainfall occurring after moldboard plowing but prior to soil sampling could have resulted in the leaching of much of the highly mobile NO_3–N below the 30 cm soil depth.

Neither tillage nor compost application rate significantly affected NH_4–N content of soil (table 1). However, soil NH_4–N content decreased significantly with soil depth.

NUTRIENT CONCENTRATIONS, RUNOFF, AND EROSION AS AFFECTED BY MOLDBOARD PLOWING

The tillage × compost rate interaction was not significant for any of the nutrient constituents, runoff, or erosion (table 2). The nutrient constituents, runoff, and erosion were also unaffected by rate of compost addition. Tillage did not significantly influence concentrations of NH_4–N, runoff, or erosion. However, runoff concentrations of DP and NO_3–N were significantly affected by tillage.

Phosphorus Measurements

Concentrations of DP in runoff from the plots that were not moldboard plowed increased as the Bray–1 P content of the soil at the 0-5 cm depth became greater. The following regression equation, with an R^2 value of 0.70, can be used to relate DP concentrations of runoff to Bray–1 P content of the soil before moldboard plowing:

$$\text{DP} = 0.0003(\text{Bray–1 P})^{1.63} \qquad (2)$$

Table 2. Effects of tillage and compost rate on concentrations of dissolved phosphorus (DP), NO_3–N, NH_4–N, total nitrogen (TN), runoff, and erosion averaged over the three rainfall simulation runs.

Compost Rate ($Mg\ ha^{-1}$)	Nutrient Concentrations ($mg\ L^{-1}$)				Runoff (mm)	Erosion ($Mg\ ha^{-1}$)
	DP	NO_3–N	NH_4–N	TN		
Non-plow						
0	0.41	1.40	0.05	10.2	14	0.25
68	1.27	2.43	0.06	11.0	11	0.11
105	1.01	2.20	0.04	10.3	17	0.33
142	2.72	3.63	0.05	11.8	16	0.15
178	3.37	1.81	0.05	11.1	17	0.21
Plow						
0	0.01	0.27	0.06	8.90	14	0.28
68	0.03	0.71	0.05	9.42	13	0.30
105	0.01	0.55	0.06	9.29	12	0.16
142	0.03	0.84	0.05	9.48	13	0.21
178	0.07	0.64	0.05	9.58	10	0.28
LSD	1.16	1.89	0.03	2.12	6	0.18
ANOVA (Pr > F)						
Tillage	0.01	0.02	0.45	0.01	0.26	0.56
Compost rate	0.09	0.69	0.98	0.59	0.90	0.89
Tillage × compost rate	0.10	0.91	0.76	0.92	0.70	0.41

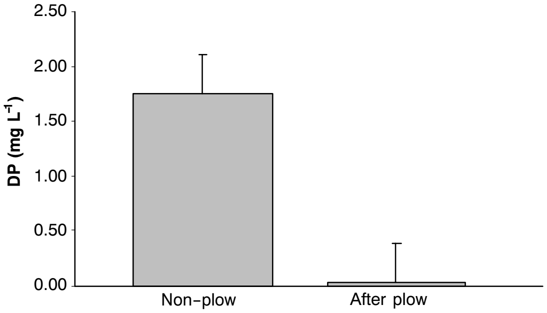

Figure 3. Mean concentration of dissolved phosphorus (DP) in runoff from the non-plow and moldboard plow plots. Nutrient concentration values are averaged across compost rates. Vertical bars are standard errors.

Equation 2 was derived using DP values ranging from 0.15 to 5.57 mg L^{-1} and Bray-1 P measurements varying from 53 to 301 mg kg^{-1}.

Concentrations of DP in runoff from the non-plow plots averaged 1.75 mg L^{-1}, compared to 0.03 mg L^{-1} on the moldboard plowed treatments (fig. 3). Thus, the concentration of DP in runoff was reduced significantly on the plots that were moldboard plowed.

Nitrogen Measurements

Concentrations of NO_3-N in runoff were related to soil NO_3-N content. A mean NO_3-N concentration in runoff of 2.3 mg L^{-1} was measured on the non-plow plots compared to 0.60 mg L^{-1} on the moldboard plow treatments (fig. 4). Neither tillage nor the application of varying amounts of compost significantly affected NH_4-N content of runoff (table 2). The mean concentration of NH_4-N in runoff from both the non-plow and moldboard plow treatments was 0.05 mg L^{-1}.

Runoff and Erosion Measurements

No significant differences in runoff rates were found in this study among experimental treatments (table 2). Thus, results reported for runoff concentration should also be applicable to nutrient load. The relatively large amounts of wheat residue at the study site prior to tillage are thought to have reduced runoff and erosion. After the final disking operation, surface cover on the non-plow and moldboard plow plots was 33% and 8%, respectively. Rainfall simulation tests were initiated in this investigation soon after the study area was moldboard plowed. Runoff and erosion rates would be expected to increase as the length of time following moldboard plowing became greater.

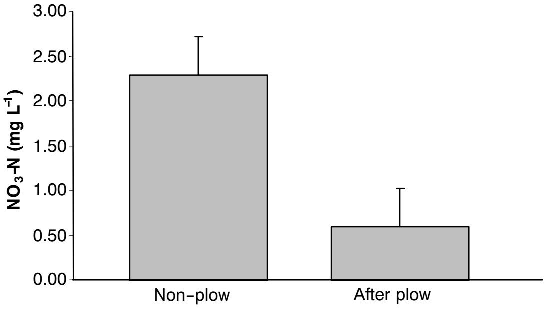

Figure 4. Mean concentration of NO_3-N in runoff from the non-plow and moldboard plow plots. Nutrient concentration values are averaged across compost rates. Vertical bars are standard errors.

Erosion has been reported to substantially increase after moldboard plowing (Siemens and Oschwald, 1978; Laflen and Colvin, 1981; Gilley et al., 1997). Therefore, moldboard plowing to reduce excessive soil nutrient levels near the surface should only occur when proper erosion control measures are implemented. Moldboard plowing should be utilized as a remedial measure to rectify former excessive land application practices, not as a means to allow continued addition of excess nutrients.

Following the moldboard plowing operation, cropping and management practices should be implemented to remove excess nutrients buried during the tillage operation. The extraction of high soil P by crop removal is a relatively slow process (Hooker et al., 1983; McCollum, 1991). If an additional moldboard plowing operation were to occur before the extraction of excessive nutrients, then soil with a relatively large nutrient content could be transferred to the surface.

Management practices used to control runoff include buffer strips, conservation tillage, contouring, strip cropping, and terraces (Gilley et al., 2002). The transport of nutrients by overland flow is influenced by manure characteristics, loading rates, incorporation, and the time between manure application and the first rainfall. When properly managed, manure can serve as a valuable nutrient source and soil amendment without causing adverse environmental impacts.

CONCLUSIONS

The moldboard plowing operation substantially reduced the content of WSP and Bray-1 P at the 0-5 cm soil depth. After moldboard plowing, soil near the surface originated from greater depths where soil P concentrations were much lower. Soil originally located near the surface was deposited at greater depths as a result of the moldboard plowing operation.

Soil NO_3-N content at each of the three sampling depths decreased substantially following tillage. The incorporation of compost during the tillage process is thought to have enhanced the environment for microbial activity. Rainfall occurring after moldboard plowing appears to have leached much of the highly mobile NO_3-N below the 30 cm soil depth.

Tillage significantly influenced runoff concentrations of DP and NO_3-N. Concentrations of DP in runoff from both the non-plow and moldboard plow plots increased substantially as the Bray-1 P content of the soil at the 0-5 cm depth became greater. Neither tillage nor the application of varying amounts of compost significantly affected the NH_4-N content of runoff.

Moldboard plowing should be used as a remedial measure to rectify former improper application practices, not as a means to allow continued excessive addition of nutrients. Appropriate soil erosion control procedures should be implemented following the moldboard plowing operation. Cropping and management practices should also be employed to remove excess soil nutrients buried during the tillage process.

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