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Moldboard Plowing Following Compost Application Significantly Reduces Nutrient Transport

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Abstract. *The excessive application of manure on cropland areas can cause nutrients to accumulate near the soil surface and increase nutrient transport by overland flow. Inverting soils with high surface nutrient content could reduce runoff nutrient transport. 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-hour intervals, were applied at an intensity of approximately 70 mm hr^{-1}. Dissolved phosphorus (DP), NO_3-N, NH_4-N, and total nitrogen (TN) content of runoff were measured from 0.75 wide x 2.0 m long plots. No significant differences in runoff and erosion were measured among experimental treatments as a result of the moldboard plowing operation. However, 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}. Consequently, concentrations of DP, NO_3-N, and TN in runoff decreased significantly on the moldboard plowed plots.*

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

INTRODUCTION

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 found 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 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 TP losses 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 on 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 TN 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 containing excessive amounts of P from long-term manure application were mixed with subsoil materials containing smaller amounts of P. The mixing process substantially reduced soil P levels near the surface.

Little et al. (2005) conducted a 3-yr 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, PP and TP in runoff from a Pohocco 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 by 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, NE. 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 permeability is moderately slow. For the control 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 by 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. Composted beef cattle manure was applied on September 24, 2002 at five selected rates that were replicated four times. A tillage variable was also included in the experimental design resulting in 20 moldboard plowed plots and 20 non-plow plots. Moldboard plowing occurred up and down 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 N that were added were 0, 0.62, 0.96, 1.30, and 1.63 Mg ha^{-1}, while 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. 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 x 2.7 m long area to provide more uniform application. Each of the 40 plots was disked up and down slope in the direction of overland flow to a depth of approximately 8 cm on September 26, 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 May 15 - 22, 2003 (233 - 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 slope to a depth of approximately 23 cm on May 27, 2003 (244 days following compost application). Finally, each of the 40 plots was disked up and down slope in the direction of overland flow on May 27, 2003 to a depth of approximately 8 cm. Soil samples were again collected on May 28 - June 4, 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. Soil NO_3-N and NH_4-N concentrations (extracted using a 2 molar KCl solution) were measured with a spectrophotometer (Lachat system from Zellweger Analytics, Milwaukee, WI).

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 June 2 to July 9, 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 between 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 hr^{-1} (NPRP protocol is 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-hr 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 volume. 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 determination of sediment. Centrifuged and filtered runoff samples (obtained using number 1 filter paper) were analyzed for DP (Murphy and Riley, 1962), NO_3-N and NH_4-N using a Lachat system (Zellweger Analytics, Milwaukee WI). 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, each for a 30-min duration, 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 Institute, 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 x compost application rate x soil depth interaction was significant for WSP and Bray-1 P. All 2-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 17.5 and 20.9 mg kg^{-1} determined at soil depths 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 48.0 mg kg^{-1}. After moldboard plowing, soil near the surface came from greater depths where soil test P levels were much less. The Bray-1 P content of 70.6 mg kg^{-1}, measured at the 5 - 15 cm depth after moldboard plowing, was significantly greater than the 17.5 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 is 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:

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

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}.

Table 1. Effects of soil depth, tillage, and compost 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.

			Variable			
Soil Depth	Tillage	Compost Rate	WSP	Bray -1 P	NO_3 -N	NH_4 -N
cm		Mg ha^{-1}	------------------mg kg^{-1}	--------------------		
0-5	Non-Plow	0	3.17	52.2	6.53	7.16
		68	24.7	230	8.54	4.14
		105	18.2	198	9.96	4.09
		142	18.2	201	8.92	5.69
		178	34.0	319	13.5	3.28
	Plow	0	1.42	36.0	3.06	6.59
		68	2.61	46.8	2.55	5.59
		105	1.56	37.4	1.99	4.74
		142	3.99	66.3	2.65	4.86
		178	2.43	53.6	2.38	4.82
5-15	Non-Plow	0	1.08	12.1	4.50	6.27
		68	0.98	21.3	9.89	3.84
		105	0.71	12.4	8.10	3.30
		142	0.46	13.4	10.8	7.38
		178	1.35	28.0	11.9	3.06
	Plow	0	2.05	42.1	3.33	4.86
		68	3.27	53.0	4.42	4.00
		105	2.82	84.3	4.80	4.52
		142	9.45	128	5.50	3.44
		178	2.34	45.4	5.45	4.15
15-30	Non-Plow	0	1.92	24.3	5.22	3.97
		68	0.67	18.1	14.3	3.79
		105	1.21	19.4	10.6	3.12
		142	0.77	18.7	14.1	7.53
		178	1.77	24.1	14.9	3.06
	Plow	0	1.07	20.8	2.67	4.79
		68	1.22	20.3	5.76	4.05
		105	2.74	56.0	4.82	4.43
		142	2.09	33.3	6.53	3.44
		178	2.34	21.4	7.77	3.62
LSD			5.15	46.1	2.05	1.97
		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 x compost rate	0.01	0.01	0.01	0.05
		Tillage x soil depth	0.01	0.01	0.01	0.27
		Compost rate x soil depth	0.01	0.01	0.01	0.23
		Tillage x compost rate x soil depth	0.01	0.01	0.16	0.29

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 (fig. 2). After moldboard plowing, the NO_3-N content of soil was reduced significantly at each of the three soil depths. The NO_3-N content of 2.52 mg kg^{-1}, measured at the 0 - 5 cm depth after moldboard plowing, was significantly less than the 4.70 and 5.51 mg kg^{-1} determined 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.

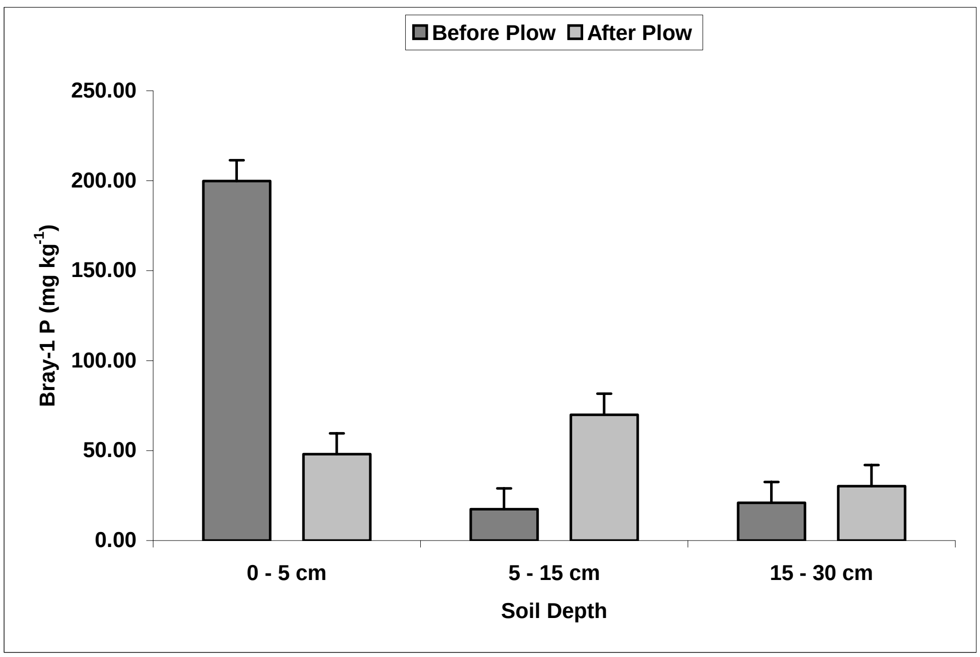

Figure 1. Bray-1 P content of soil as affected by tillage and soil depth. Vertical bars are standard errors.

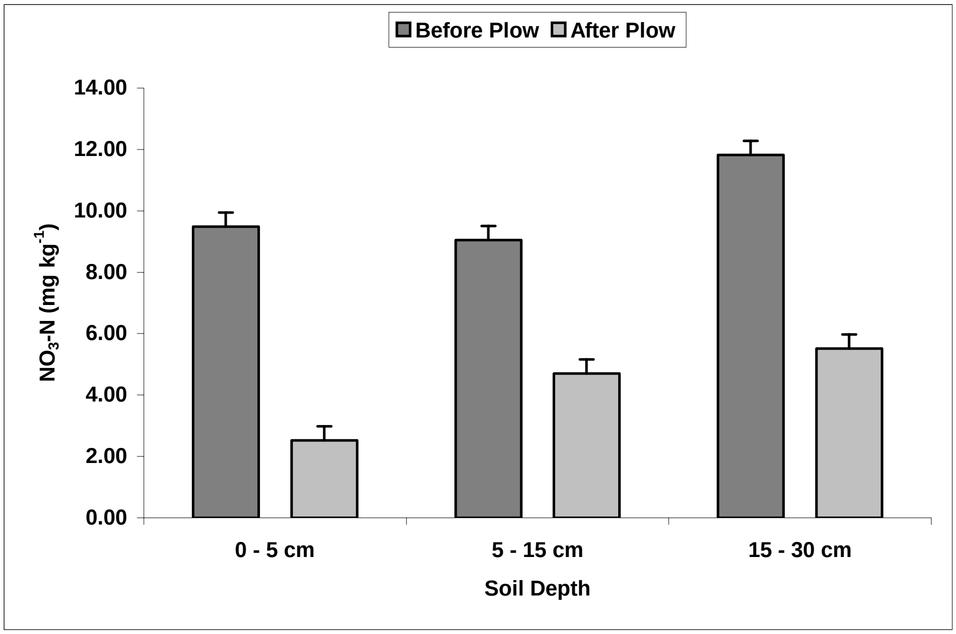

Figure 2. NO_3-N content of soil as affected by tillage and soil depth. Vertical bars are standard errors.

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

The tillage x 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, NO_3-N and TN were significantly affected by tillage.

Phosphorus Measurements

Concentrations of DP in runoff from the plots that were not moldboard plowed increased as 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:

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

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 plots (fig. 3). Thus, the concentration of DP in runoff was reduced significantly on the plots that were moldboard plowed.

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.

Tillage	Compost Rate	DP	NO3-N	NH4-N	TN	Runoff	Erosion
	Mg ha^{-1}	----------------------mg L^{-1}			----------------------	mm	Mg ha^{-1}
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 x compost rate		0.10	0.91	0.76	0.92	0.70	0.41

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 2.30 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

In this study, no significant differences in runoff rates were found 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.

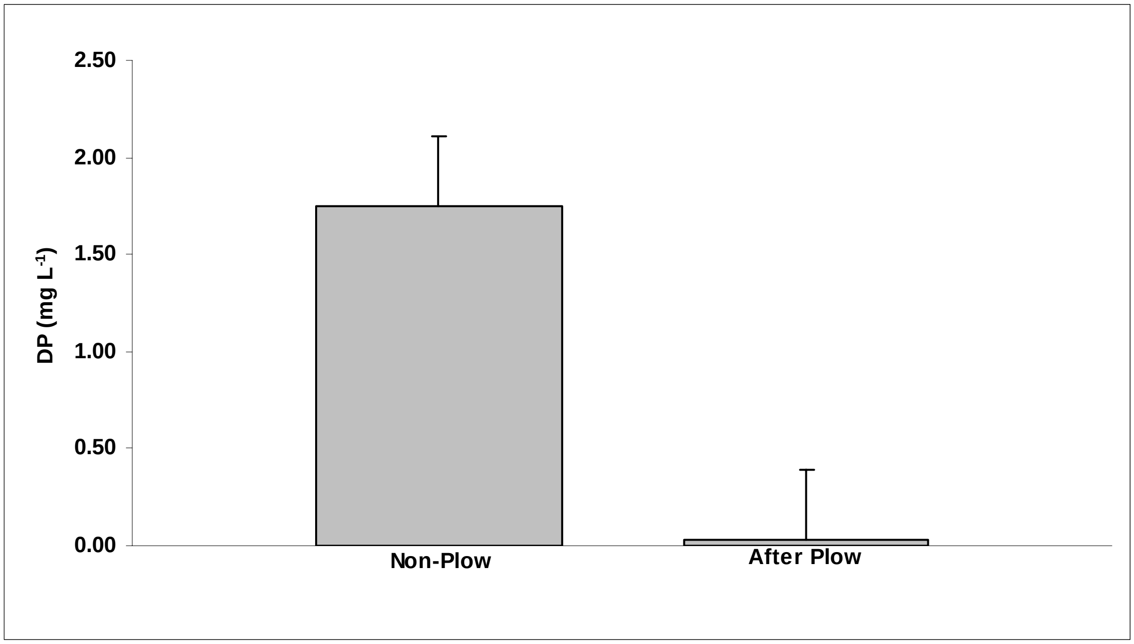

Figure 3. Mean concentration of dissolved phosphorus (DP) in runoff from the non-plow and moldboard plow plots. Vertical bars are standard errors.

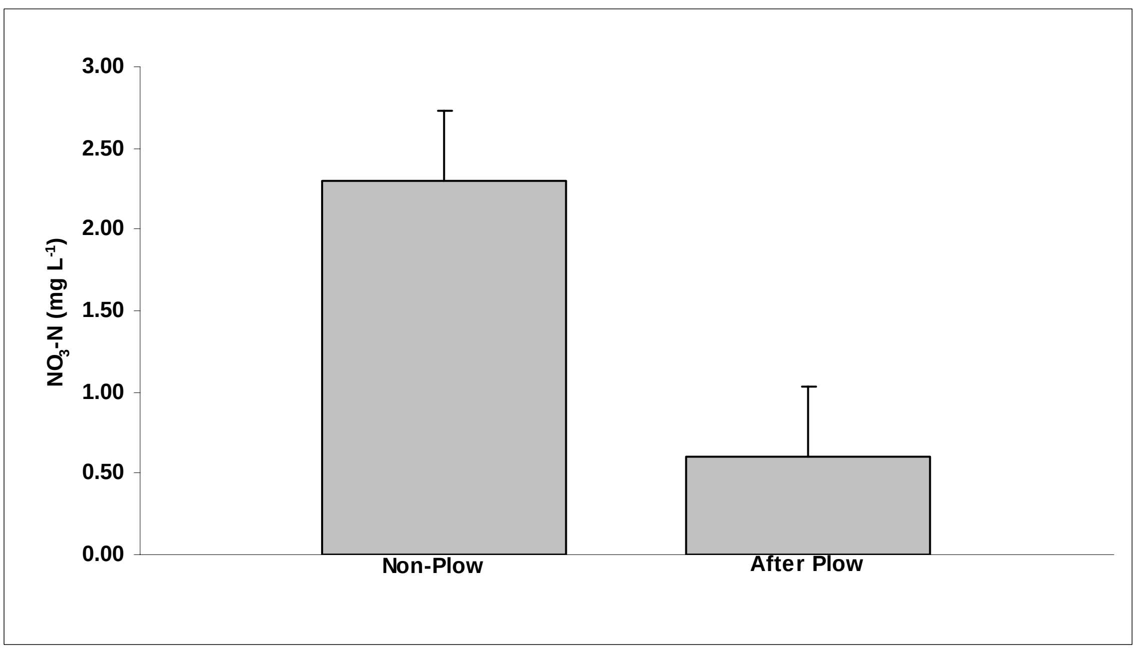

Figure 4. Mean concentrations of NO_3-N in runoff from the non-plow and moldboard plow plots. Vertical bars are standard errors.

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, 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, 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 environmental concerns.

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 test 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 soon 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, NO_3-N, and TN. Concentrations of DP in runoff from both the non-plow and moldboard plow plots increased substantially as 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 NH_4-N content of runoff.

Moldboard plowing should only 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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