Published online August 31, 2007

Residual Effects of Compost and Plowing on Phosphorus and Sediment in Runoff

Charles S. Wortmann* and Daniel T. Walters University of Nebraska–Lincoln

Manure application can lead to excessive soil test P levels in surface soil, which can contribute to increased P concentration in runoff. However, manure application often results in reduced runoff and sediment loss. Research was conducted to determine the residual effects of previously applied compost, plowing of soil with excessive soil test P, and application of additional compost after plowing on volume of runoff and loss of sediment and P in runoff. The research was conducted in 2004 and 2005 under natural rainfall events with plots of 11-m length where low-P and high-P compost had been applied during April 1998 to January 2001. During this initial application period, Bray-P1 in the surface 5-cm of depth was increased from 14 to 553 mg kg^{-1} for the high-P compost. Inversion plowing in the spring of 2004 greatly decreased P levels in the surface soil and over the following year reduced runoff by 35% and total P losses by 51% compared with the unplowed compost treatments. Sediment loss was increased with plowing compared with the unplowed compost applied treatments but less than with the no-compost treatment. The application of additional compost after plowing increased surface soil P and dissolved reactive P (DRP) in runoff but did not increase particulate P in runoff. Unplowed compost-amended soil continued to reduce sediment loss but exhibited increased DRP loss even 5 yr after the last application. Plowing to invert excessively high-P surface soil was effective in reducing runoff and DRP loss.

Beef feedlot cattle account for 80% of the livestock revenue in Nebraska, with 4.5 to 5.0 million animals fed in 2005 (NASS, 2006), resulting in the production of approximately 28 200 to 31 300 Mg yr^{-1} of manure P (Koelsch and Powers, 2005). Nutrients in manure are valuable to crop production, but nutrient pollution is a leading cause of eutrophication and impairment of water bodies due to excessive algal growth (USEPA, 2000). Phosphorus is often the most limiting factor to greater rates of aquatic algal growth, and P enrichment of surface waters is of particular environmental concern. Good management of land-applied animal manure is important to reducing P loading of surface water. Composting of feedlot manure is often used to reduce manure odor and volume of material to be transported and land-applied.

Runoff-P concentration has generally been found to be higher from soils with higher soil test P levels (Sauer et al., 2000; McDowell and Sharpley, 2001; Andraski and Bundy, 2003; Daverede et al., 2003; Klatt et al., 2003). Dissolved P and particulate P (PP) concentration in runoff can be significant even when soil test P is at an agronomically moderate level due to effects of the nonlabile soil P fraction (Eghball, 2002; Eghball and Gilley 1999; Wortmann and Walters, 2006).

Phosphorus loss in runoff generally increases as the volume of runoff and amount of sediment loss increase. Runoff and erosion losses are often reduced by manure application, presumably due to increased water infiltration and retention, and this effect can persist for several years after manure application (Gilley and Risse, 2000; Wortmann and Walters, 2006). Although manure application does not always result in reduced runoff and erosion (Gilley and Eghball, 1998), the effect is common enough to be considered as partly off-setting the effect of increased runoff P concentration on total P lost to surface water after manure application.

Feedlot manure is commonly applied to the soil surface with no or only shallow incorporation. Surface application may be most advantageous for improving water infiltration, but it results in very P high concentrations at the soil surface. The potential for P loss from such land may be reduced by one-time inversion plowing that mixes P-enriched surface soil with deeper low-P soil. The effect of plowing is one of effectively diluting surface soil P and increasing P sorption capacity of the surface soil (Sharpley, 2003).

Copyright © 2007 by the American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America. All rights reserved. No part of this periodical may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording, or any information storage and retrieval system, without permission in writing from the publisher.

Published in J. Environ. Qual. 36:1521–1527 (2007).
doi:10.2134/jeq2006.0404
Received 26 Sept. 2006.
*Corresponding author (cwortmann2@unl.edu).
© ASA, CSSA, SSSA
677 S. Segoe Rd., Madison, WI 53711 USA

Dep. of Agronomy and Horticulture, 279 Plant Science, Univ. of Nebraska, Lincoln, NE 68583-0915. Contribution of the Univ. of Nebraska-Lincoln Agricultural Research Division. This research was partly funded by the Hatch Act.

Abbreviations: DRP, dissolved reactive P in filtered runoff; PP, particulate P; RC, treatment with residual compost but left unplowed; RC-P04, treatment with residual compost and plowed in 2004; RC-P04-C05, treatment with residual compost plowed in 2004 with additional compost applied in 2005; TP, total P in unfiltered runoff.

Table 1. A timeline of events at a runoff research site in eastern Nebraska.

Year	Event
1998	Twenty-one natural runoff plots established with seven treatments and three replications .
1998–2001	Compost was applied annually over a 3-yr period with the last application in the winter of 2001 (Wortmann and Walters, 2006). Low-P and high-P composts were applied to each of three treatments reflecting methods of application. A total of 750 and 1150 kg ha^{-1} of P were applied as composted manure for the low-P and high-P composted treatments, respectively. One treatment was the control with no P applied. During this period the crop was continuous corn.
2004	The residual effects of the previously applied compost on runoff and losses of sediment and nutrients were determined, ending with an early spring runoff event in 2004 (Wortmann and Walters, 2006). Two each of the low-P and high-P compost treatments were plowed, leaving one treatment each of unplowed high-P and low-P compost-amended soil. Data were collected for runoff events that occurred on 25 May, 3 June, and 15 June.
2005	Compost was applied in April to one each of the plowed low-P and high-P plots in each block at the rate of 87 kg P ha^{-1}. Treatments then included the no-compost (control). For each of high- and low-P compost: unplowed (RC), plowed (RC-P04), plowed plus additional compost (RC-P04-C05). Data collection continued for runoff events that occurred on 27 April, 16 May, 6 June, and 6 July.
2006	Soil samples were taken to determine P distribution with depth in April 2006.

The objective of this research was to compare runoff sediment and P losses from highly P-enriched surface soil with runoff and sediment P losses from P-enriched surface soil subject to deep plowing with and without additional surface application of compost.

Materials and Methods

Study Site and Trial Management

The residual effects of previously applied composted feedlot manure were studied during 2004 and 2005 at a runoff facility established in 1998 at the University of Nebraska Agricultural Research and Development Center (42.1 N, 96.5 E, 345 m elevation) (Table 1). The runoff facility consisted of 21 natural runoff plots of 3.7 m × 11.0 m plus a V-shaped down-slope end to direct flow to an outlet pipe for runoff and sediment collection. The individual runoff plot area was 40 m^2 with an average slope of 6%. Plots were arranged in three complete blocks and analyzed as a randomized, complete-block design. The soil series was Pohocco silt loam derived from upland loess (fine-silty, mixed, mesic Typic Eutrochrepts; texture 280 g kg^{-1} sand, 580 g kg^{-1} silt, and 140 g kg^{-1} clay). Runoff was channeled to a 5-cm pipe that conveyed it to a 450-L tank connected to a second tank in case of overflow. The tanks were covered to keep out rainfall and irrigation water. Additional details are available in Wortmann and Walters (2006).

Low-P (0.20–0.36% P) and high-P (0.36–0.46% P) windrow-composted feedlot manure was applied annually to three compost treatments, each with different methods of application, for 3 yr before the 2001 crop season (Table 1) (Wortmann and Walters, 2006). Total P applied over this 3-yr period was 750 and 1150 kg ha^{-1} of P for the low-P and high-P compost treatments, respectively. The total quantity of compost applied was approximately 240 Mg ha^{-1}. Runoff P was affected by the P content of the compost during 2001 through 2003, but the application methods had no effect during that period (Wortmann and Walters, 2006).

For the purposes of this study, compost-plowed (RC-P04) treatments were created by plowing two each of the former low-P and the high-P compost treatments on 6 Apr. 2004 with a moldboard plow to a depth of approximately 20 cm to invert the P-enriched surface soil and reduce the P content of the immediate soil surface (Table 1). Compost-plowed-compost (RC-P04-C05) treatments were created when composted feedlot manure containing approximately 87 kg ha^{-1} of P was applied on 27 Apr. 2005 to one each of the low-P and high-P compost treatments that had been plowed in 2004; this compost application occurred before any runoff events in 2005. A series of original residual-composted runoff plots (RC) was preserved for comparison purposes.

Tillage for all plots consisted of pre-plant disk-tillage each year from 1998 to 2005. The crop from 2003 to 2005 was continuous soybean (*Glycine max* L.) planted in 0.76-m rows. No fertilizer was applied. The soybean varieties were glyphosate (N-(phosphonomethyl)glycine) tolerant, and weeds were controlled with the application of glyphosate as needed. The site was irrigated with a center pivot. All runoff events occurred from April through July and were associated with rainfall events (Table 1).

Soil and Water Sample Collection and Analysis

Surface soil was sampled in April 2006 at the 0- to 5-, 5- to 10-, 10- to 20-, and 20- to 30-cm depths. A total of 12 17.5-mm diameter cores were composited from each plot. Surface soil samples were analyzed for Bray-P1 (Bray and Kurtz, 1945) and total soil P by perchloric acid digestion (Olsen and Sommers, 1982).

Three runoff events occurred after the plow tillage in 2004, and four events occurred in 2005. The volume of runoff was determined after each runoff event by measuring the depth of collected runoff in the tank and calculating the volume using equations calibrated for this determination. A 1-L subsample was taken after thorough stirring of the runoff and sediment in the tank and stored at 4°C until P analyses were performed the following winter. Runoff volumes were highly variable within individual runoff events, and the ANOVA was run for the totals of runoff volume, sediment, and P loss within each year and mean annual runoff concentrations, which were calculated from these totals for each plot (Wortmann and Walters, 2006).

Sediment concentration was gravimetrically determined by drying 10 mL of unfiltered runoff sample at 104°C. Total P (TP) was determined on unfiltered runoff samples using perchloric/nitric acid extraction. Dissolved reactive P (DRP) in runoff was determined after filtration of a 100-mL sample to <0.45 μm (Pote and Daniel, 2000). The difference between TP and DRP was considered to be PP, although dissolved unreactive P was included in this difference (Pote and Daniel, 2000). All P fractions were measured colorimetrically according to Murphy and Riley (1962).

Statistical Analysis

Analyses of variance were conducted for soil P properties across depths. Runoff data were analyzed by year and combined for years for those treatments that were not modified in 2005. Variables were tested for homogeneity of variance using Bartlett's test. Response variables that displayed unequal variance across treatments were square-root transformed before ANOVA. Actual means are reported in tables. Contrasts were used to test for differences between sets of treatments in both years: plowing (n = 12 in 2004 and 6 in 2005) versus no plowing (n = 6), high-P (n = 3) versus low-P (n = 3) compost applied during 1998 to 2001 with no plowing, and no compost (n = 3) versus compost applied during 1998 to 2000 with no plowing (n = 3). The effect of application of additional compost (n = 6) versus no application in 2005 following plowing in 2004 (n = 6) was also tested. Treatment effects on runoff were considered to be significant at $P \leq 0.1$. Relationships between soil properties were evaluated using regression analysis.

Results and Discussion

Surface Soil Phosphorus

Bray-P1

Bray-P1 was of medium availability and ranged from 14 to 5 mg kg^{-1} for the 0- to 5-cm and the 20- to 30-cm depths, respectively, for the no compost treatment (Ferguson et al., 2000) (Fig. 1A). Bray-P1 was, however, extremely high for the RC treatments in the surface 10 cm of soil. Bray-P1 exceeded 400 mg kg^{-1} in the surface 5 cm of soil for the mean of the unplowed low-P (280 mg kg^{-1}) and high-P (553 mg kg^{-1}) RC treatments.

Plowing effectively redistributed extractable soil P to reduce P in the surface 10 cm of soil and enrich Bray-P1 extractable P below that depth (Fig. 1A). Application of an additional 87 kg ha^{-1} of P in compost in the spring of 2005 resulted in an increase in Bray-P1 by 133 mg kg^{-1} in the surface 5-cm of soil compared with the RC-P04 treatment. Bray-P1 was greater at the 20- to 30-cm depth for the RC-P04 and the RC-P04-C05 treatments when compared with the RC treatment, probably due to occasionally plowing deeper than the intended 20-cm depth. Bray-P1 was not affected at the 30- to 60-cm depth where the mean concentration was 8.4 mg kg^{-1} (data not shown).

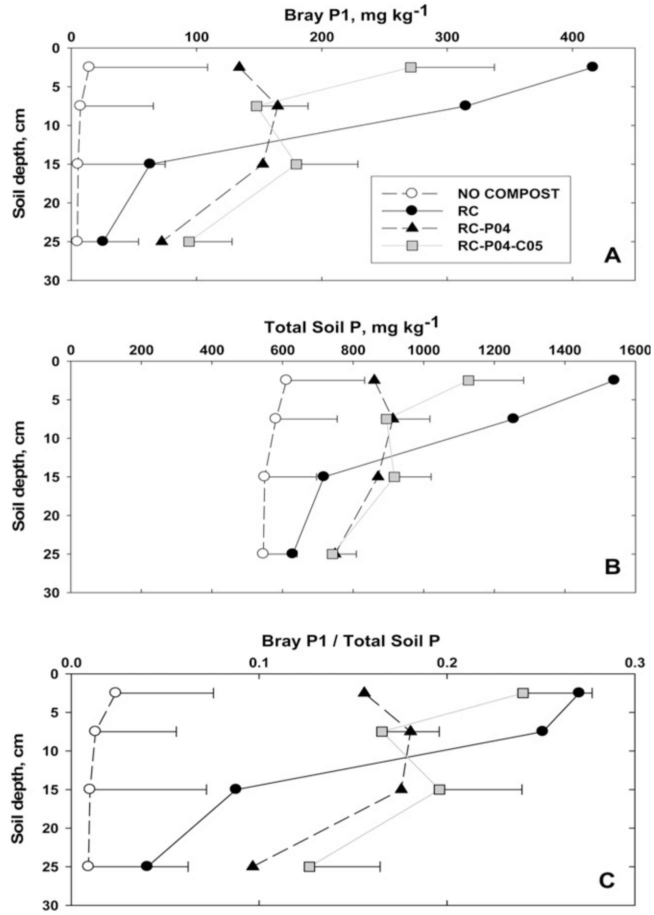

Fig. 1. Soil P distribution (0–30 cm) in April 2006 as affected by residual compost application, plowing, and compost applied after plowing. Compost treatments are means of the low-P and high-P compost. Horizontal bars on the No Compost treatment are LSD (*p* < 0.05) for within-depth comparison of control vs. compost-treated soil. Horizontal bars on the RC-P04-C05 treatment are LSD (*p* < 0.05) for within-depth comparison of compost-treated soil.

Total Soil Phosphorus

Total soil P concentration was similar throughout the soil depth for the no-compost treatment and was very stratified for the unplowed RC treatments (Fig. 1B). In compost-amended soil (RC), the concentration of total soil P was very high in the 0- to 5-cm and 5- to 10-cm depths. Below the surface 10 cm, there was very little accumulation of P. Plowing reduced total soil P in the surface soil while increasing the concentration below the 20 cm depth. The 2005 compost application resulted in a large increase in total soil P in the top 5 cm of soil compared with the RC-P04 treatments.

The Ratio of Bray-P1 to Total Soil Phosphorus

A greater proportion of TP was recovered as Bray-P1 extractable P for the RC treatments compared with no compost applied (Fig. 1C). The ratio of Bray-P1:total soil P ranged from 0.024 in the 0- to 5-cm depth to 0.009 at the 20- to 30-cm depth for the no-compost treatment. The ratio was 12 times as high in the 0- to 5-cm depth for the mean of the RC treatments compared with the no-compost treatment, but the ratio declined sharply with depth. Plowing greatly reduced this ratio

Table 2. Treatment means and ANOVA for 2004 losses of runoff, sediment (Sed.), dissolved reactive P (DRP), particulate P + dissolved nonreactive P (PP), and total P (TP) in runoff.

Treatments	Concentration				Quantity lost				
	Sed.	TP	PP	DRP	Runoff	Sed.	TP	PP	DRP
	kg m^{-3}	g m^{-3}			m^3 ha^{-1}	kg ha^{-1}			
1. Control	6.43	2.83	2.59	0.25	225.5	1502	0.599	0.536	0.063
2. High-P RC†	2.88	13.17	10.45	2.73	209.0	673	3.073	2.516	0.557
3 & 4. High-P RC-P04	5.62	9.27	8.04	1.24	250.9	1389	2.232	1.917	0.315
5. Low-P RC	1.41	7.75	5.31	2.43	222.0	310	1.724	1.232	0.491
6 & 7. Low-P RC-P04	5.49	6.35	5.25	1.09	183.2	937	1.151	0.955	0.195
Contrasts: significance and difference									
Plowed versus no plowing in 2004 where compost was applied in 1998–2000									
3, 4, 6, 7 vs. 2, 5	3.41*	NS	NS	–1.416***	NS	NS	NS	NS	–0.286***
High-P versus low-P compost applied during 1998–2000, no plowing in 2004									
2 vs. 5	NS‡	5.42*	5.14+	NS	NS	NS	1.349+	NS	0.066+
No compost versus compost applied during 1998 to 2000, no plowing in 2004									
1 vs. 2, 5	4.28*	–7.63**	–5.29+	–2.336***	NS	NS	–1.800+	NS	0.461***

+, *, **, ***, Significant at the 0.1, 0.05, 0.01, and 0.001 probability level, respectively.

† High-P and Low-P, high and low P compost; RC, unplowed residual compost; RC-P04, plowed residual compost.

‡ NS, not significant.

in the surface soil and resulted in a uniform ratio to a depth of 20 cm. The ratio was restored to a high level in the 0- to 5-cm depth with the single application of compost in 2005.

The relationship of Bray-P1 with total soil P for total soil P and Bray-P1 ranges of 600 to 1932 mg kg^{-1} and 3 to 584 mg kg^{-1} was accounted for by the following equation: Bray-P1 = –237 + 0.43* total soil P (r^2 = 0.90). According to this equation, total soil P increases 2.33 for 1 mg kg^{-1} increase in Bray-P1. With increasing soil P concentration, the soil is expected to reach a point of P saturation where the change in total soil P equals the change in Bray-P1. When total soil P was 500 to 600 mg kg^{-1}, Bray-P1 ranged from 3 to 29 mg kg^{-1} and was not related to total soil P.

The reduction in Bray-P1 in the surface soil with moldboard plowing was apparently due to dilution of the excessively P-enriched surface soil with the deeper low-P soil, which has a much greater P sorption capacity (Fig. 1A). The results agree with those of Garcia (2005), who also found that plow tillage was effective and disk and chisel plow tillage were ineffective at reducing this stratification. A reduction in the ratio of Bray-P1 extractable P to total P with inversion plowing was indicative of the effect of soil mixing on the dilution of labile P within the plow layer. Sharpley (2003) found that in P-stratified soils, mixing P-enriched surface soil with subsoil via plowing increased P sorption capacity of the soil surface, effectively reducing losses of DRP in runoff. Guertal et al. (1991) found less P sorption capacity for soil at the 0- to 2-cm depth as compared with the 2- to 20-cm depth for P-stratified, manure-amended soils. Plowing to reduce Bray-P1 in the surface soil resulted in reduced DRP concentration in runoff in proportion to the reduction in Bray-P1–extractable P. The relationship between extractable P and reactive P in runoff has been shown by others (Sauer et al., 2000; McDowell and Sharpley, 2001; Andraski and Bundy, 2003; Daverede et al., 2003; Klatt et al., 2003; Wortmann and Walters, 2006).

Runoff and Sediment Loss

Runoff was not affected by treatments in 2004 (Table 2). In 2005 and in the ANOVA for both years combined, runoff was less with the RC-P04 compared with the RC treatments (Table 3; Fig. 2), apparently due to a greater infiltration rate with the one-time plow tillage. Runoff was also less in 2005 for RC treatments compared with no compost applied. Runoff was not affected by the type of compost applied or by the 2005 application of compost.

Sediment concentration in runoff increased both years in RC-P04 compared with RC treatments (Table 2 and 3). Sediment concentration was also higher for the no compost treatment in 2004 compared with RC treatments; this effect was significant with the ANOVA combined across years. Sediment concentration was not affected by the 2005 application of compost.

Plowing caused increased sediment loss relative to the RC treatments but not relative to the no-compost treatment, which was not plowed (Fig. 3). Sediment loss was 165% greater for the no-compost treatment compared with the RC treatments in 2005; this effect was significant in the combined ANOVA. Sediment loss was not affected by compost type or by the application of additional compost in 2005.

The residual effects of compost on runoff and sediment loss were generally consistent with the results during the 3 yr before this study when runoff and sediment losses were 69% and 120% greater without the application of composted manure (Wortmann and Walters, 2006). The results also agree with the findings of Gilley and Risse (2000) that manure application caused a reduction in runoff and sediment loss. The reduced runoff and sediment loss may be due to an increase in water-stable aggregates with compost or manure application (McDowell and Sharpley, 2001). Celik et al. (2004) found that after 5 yr of annual application of 25 Mg ha^{-1} of manure or compost incorporated by moldboard plowing, the mean weighted diameter of water-stable aggregates was greater than

Table 3. Treatment means and ANOVA for 2005 losses of runoff, sediment (Sed.), dissolved reactive P (DRP), particulate P + dissolved nonreactive P (PP), and total P (TP) in runoff.

Treatments	Concentration				Quantity lost				
	Sed.	TP	PP	DRP	Runoff	Sed.	TP	PP	DRP
	kg m^{-3}	g m^{-3}			m^3 ha^{-1}	kg ha^{-1}			
1. Control	5.60	5.49	5.35	0.14	286.2	1396	1.61	1.57	0.041
2. High-P RC†	2.83	10.66	7.49	3.17	245.0	713	2.68	1.89	0.781
3. High-P RC-P04	8.07	7.97	7.25	0.72	104.2	539	0.63	0.58	0.046
4. High-P RC-P04-C05	5.97	10.72	8.82	1.87	93.7	597	1.09	0.88	0.210
5. Low-P RC	1.97	6.50	5.05	1.45	184.0	341	1.13	0.85	0.273
6. Low-P RC-P04	3.50	5.24	5.14	0.10	108.5	461	0.72	0.70	0.016
7. Low-P RC-P04-C05	4.27	9.06	7.02	2.03	136.8	440	0.91	0.69	0.213
Contrasts: significance and difference									
Plowed versus no plowing in 2004 where compost was applied in 1998–2000									
3, 6 vs. 2, 5	3.38*	−1.97+	NS‡	−1.89 ***	−108.1 **	NS	−0.73 *	NS	−0.496 ***
High-P versus low-P compost applied during 1998–2000, no plowing in 2004									
2 vs. 5	NS	4.16*	NS	1.72**	NS	NS	1.55*	1.04+	0.508**
No compost versus compost applied during 1998–2000, no plowing in 2004									
1 vs. 2, 5	NS	−3.09*	NS	−2.17 ***	71.7+	869*	NS	NS	−0.486 ***
Additional compost versus no compost applied in 2005, plowed in 2004									
4, 7 vs. 3, 6	NS	3.28**	NS	1.54***	NS	NS	NS	NS	0.180+

+, *, **, *** Significant at the 0.1, 0.05, 0.01, and 0.001 probability level, respectively.

† RC, unplowed residual compost; RC-P04, plowed residual compost; RC-P04-C05, plowed residual compost with additional compost applied in 2005.

‡ NS, not significant.

where no manure or compost was applied. They also observed reduced bulk density, increased macro- and microporosity, increased hydraulic conductivity, and increased available water-holding capacity with manure or compost application compared with the control. The effects of compost and manure were similar. Although manure application does not always result in reduced runoff and erosion (Gilley and Eghball, 1998), the effect is common enough to be considered as partly off-setting the effect of increased runoff P concentration after manure application.

Phosphorus Loss

Concentration of DRP in runoff was reduced by plowing in both years (Tables 2 and 3). Particulate P concentration was not affected in either year by the one-time plowing. Plowing decreased TP concentration in 2005 and in the combined ANOVA. When compared with P concentrations in runoff from plots that received no compost, the compost (RC) treatments increased DRP and TP concentrations in both years (Tables 2 and 3) and in the combined ANOVA (Fig. 4) and increased PP concentration in 2004. Compared with runoff from low-P compost, the high-P compost significantly increased concentrations of DRP in 2005 runoff and increased concentrations

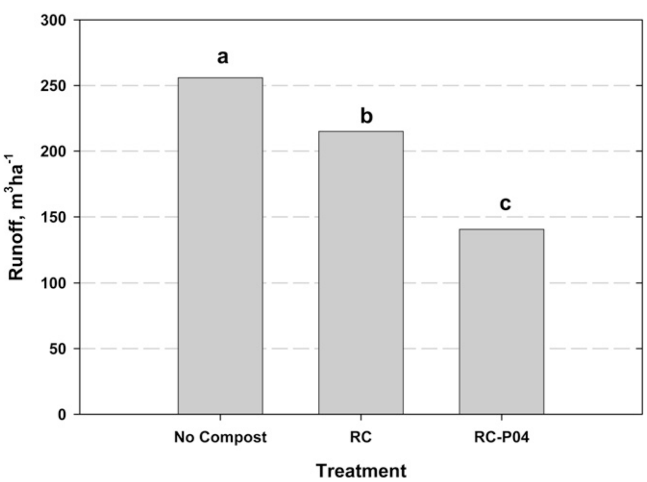

Fig. 2. The residual effect of compost application, with and without plowing, on runoff losses during 2004 and 2005. The letters indicate differences in runoff volume by ANOVA-protected LSD ($p < 0.1$) means separation.

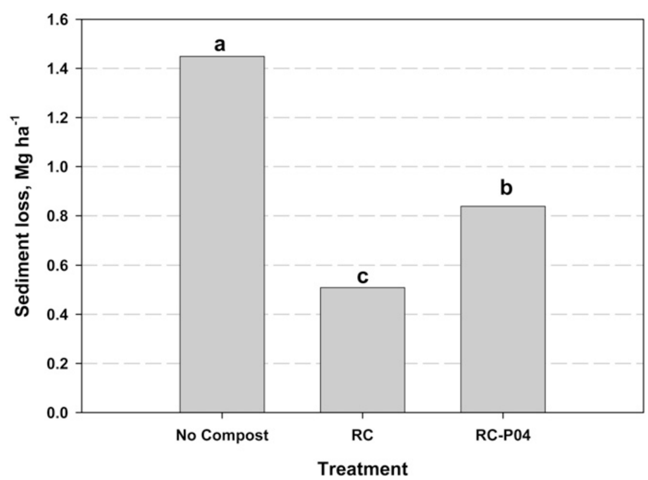

Fig. 3. The residual effect of compost application, with and without plowing, on sediment losses during 2004 and 2005. The letters indicate differences in sediment loss by ANOVA-protected LSD ($p < 0.1$) means separation.

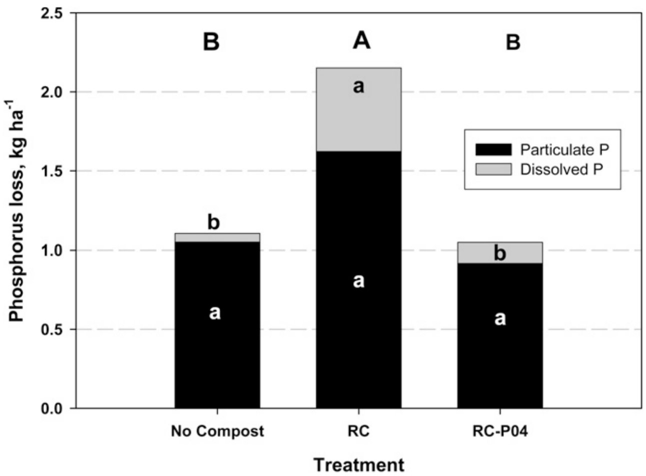

Fig. 4. The residual effect of compost application, with and without plowing, on particulate, including dissolved, nonreactive P (PP) and dissolved reactive P (DRP) in runoff during 2004 and 2005. Uppercase letters indicate differences in total P loss (DRP + PP) in runoff; Lowercase letters indicate differences in DRP and PP loss by ANOVA-protected LSD (*p* < 0.1) means separation.

of TP in both years. The application of additional compost in 2005 resulted in increased DRP and TP concentration.

Losses of DRP in 2004 and of DRP and TP in 2005 were reduced by plowing (Tables 2 and 3; Fig. 4). This was due in part to reduced runoff in 2005 and lower P concentration at the soil surface with plowing. Losses of TP and DRP were greater with the high-P compared with the low-P compost. This agrees with results from 2001 to the spring of 2004 at the same site (Wortmann and Walters, 2006) and was expected due to higher soil P levels associated with the high-P compost treatments. On average, 16% of the TP in runoff was DRP, but the percentage was less with the no-compost and the RC-P04 treatments. This raises the question of relative importance of PP compared with DRP entering water bodies for long-term P availability. Particulate P concentrations in runoff from agronomically modest soil test P levels can be significant and illustrate the importance of minimizing runoff and sediment loss to reduce P loading of surface waters.

Loss of DRP from compost-amended soils was significantly reduced by plowing to levels equal to the no-compost treatment. This effect was not observed for PP losses because of greater sediment and runoff from unamended treatments (Fig. 4). Reduced runoff and sediment loss with compost application were significant factors resulting in less P loss with the RC treatments than might be indicated by the Bray-P1 values. After plowing, the application of additional compost caused an increase in DRP loss but did not significantly increase PP and TP loss (Table 3).

Runoff P concentrations were in the ranges found at this site during the 3 yr before this study (Wortmann and Walters, 2006). Reduced total runoff over two growing seasons and the reduced surface soil P after one-time inversion plowing contributed to less runoff P loss compared with RC treatments. The effect of plowing on the reduction in runoff volume may be even greater for soils with generally slower infiltration rates. Single-inversion plowing resulted in increased sediment concentration in runoff for two consecutive years, with greater sediment loss than with RC but less than with the no-compost treatment. The potential of increased sediment loss where one-time plowing might not improve infiltration is of concern. Nonetheless, the long-term impact of reduced surface soil P enrichment from one-time plowing on runoff P loss should outweigh the short-term hazard of sediment loading immediately after plowing. Application of additional compost or manure after the one-time plowing may not be feasible for water quality protection because surface soil test P levels and DRP losses increased rapidly with the application of additional compost P.

Conclusions

Excessive surface soil P enrichment that resulted from repeated and heavy compost application persisted for five crop seasons after the application of composted manure was terminated. In this study, P concentration in runoff continued to be a function of surface soil (0–5 cm) P enrichment. The 5-yr residual effect of previous composted manure application effectively reduced sediment loss for five crop seasons and partly offset the effect of higher runoff P concentration on total P loss. One-time inversion plowing of P-enriched surface soil effectively reduced surface soil P concentration, runoff volume, and total P loss compared with disk tillage. Application of additional compost after plowing greatly increased surface soil P and resulted in increased DRP loss in runoff. Plowing of P-stratified soils with excessive P in the surface soil is a feasible practice for reducing the potential for P loss if it can be done without much increase in sediment loss, but the potential for P runoff can be quickly restored with additional compost P application.

References

Andraski, T.W., and L.G. Bundy. 2003. Relationships between phosphorus levels in soil and in runoff from corn production systems. J. Environ. Qual. 32:310–316.

Bray, R.H., and L.T. Kurtz. 1945. Determination of total, organic, and available forms of phosphorus in soils. Soil Sci. 59:39–45.

Celik, I., I. Ortas, and S. Kilic. 2004. Effects of compost, mycorrhiza, manure, and fertilizer on some physical properties of a Chromoxerert soil. Soil Tillage Res. 78:59–67.

Daverede, I.C., A.N. Kravchenko, R.G. Hoeft, E.D. Nafziger, D.G. Bullock, J.J. Warren, and L.C. Gonzini. 2003. Phosphorus runoff: Effect of tillage and soil phosphorus levels. J. Environ. Qual. 32:1436–1444.

Eghball, B. 2002. Soil properties as influenced by phosphorus and nitrogen-based manure and compost applications. Agron. J. 94:128–135.

Eghball, B., and J.E. Gilley. 1999. Phosphorus and nitrogen in runoff following beef cattle manure or compost application. J. Environ. Qual. 28:1201–1210.

Ferguson, R.B., G.W. Hergert, and E.J. Penas. 2000. Corn. p. 75–83. *In* R.B. Ferguson (ed.) Nutrient management for agronomic crops in Nebraska. Univ. of Nebraska Cooperative Extension EC 01-155-S, Lincoln, NE.

Garcia, J.P. 2005. The effects of occasional tillage in no-tillage systems on nutrient distribution and uptake, and on vesicular arbuscular mycorrhizal colonization. M.S. thesis. Univ. of Nebraska-Lincoln.

Gilley, J.E., and B. Eghball. 1998. Runoff and erosion following field application of beef cattle manure and compost. Trans. ASAE 41:1289–1294.

Gilley, J.E., and L.M. Risse. 2000. Runoff and soil loss as affected by the application of manure. Trans. ASAE 43:1583–1588.

Guertal, E.A., D.J. Eckert, S.J. Traina, and T.J. Logan. 1991. Differential

phosphorus retention in soil profiles under no-till crop production. Soil Sci. Soc. Am. J. 55:410–413.
Klatt, J.G., A.P. Mallarino, J.A. Downing, J.A. Kopaska, and D.J. Wittry. 2003. Soil phosphorus, management practices, and their relationship to phosphorus delivery in the Iowa Clear Lake agricultural watershed. J. Environ. Qual. 32:2140–2149.
Koelsch, R.K., and W. Powers. 2005. Integrating animal feeding decisions into CNMP processes. Available at http://www.lpes.org/Downloads/LPES_Update.doc (verified 21 May 2007).
McDowell, R.W., and A.N. Sharpley. 2001. Approximating phosphorus release from soils to surface runoff and subsurface drainage. J. Environ. Qual. 30:508–520.
Murphy, J., and J.P. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta 27:31–36.
NASS. 2006. Available at http://www.nass.usda.gov/Statistics_by_Nebraska/index.asp (verified May 24, 2006).
Olsen, S.R., and L.E. Sommers. 1982. Phosphorus. p. 403–430. *In* A.L. Page, R.H. Miller, and D.R. Keeney (ed.) Methods of soil analysis. 2nd ed. Agron. Monogr. 9, Part 2. SSSA, Madison, WI.
Pote, D.H., and T.C. Daniel. 2000. Analyzing for dissolved reactive phosphorus in water samples. p. 91–93. *In* G.M. Pierzynski (ed.) Methods of phosphorus analysis for soils, sediments, residuals, and waters. Southern Cooperative Series Bull. No. 396. SERA-IEG 17, USDA-CSREES Regional Committee.
Sauer, T.J., T.C. Daniel, D.J. Nichols, C.P. West, P.A. Moore, Jr., and G.L. Wheeler. 2000. Runoff water quality from poultry litter-treated pasture and forest sites. J. Environ. Qual. 29:515–521.
Sharpley, A.N. 2003. Soil mixing to decrease surface stratification of phosphorus in manured soils. J. Environ. Qual. 32:1375–1384.
USEPA. 2000. National Water Quality Inventory: 1998 Report to Congress. EPA841-R-00-001. Office of Water, Washington, DC.
Wortmann, C.S., and D. Walters. 2006. Phosphorus runoff during four years following composted manure application. J. Environ. Qual. 35:651–657.