MANURE AND TILLAGE EFFECTS ON PHOSPHORUS IN RUNOFF [1]

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Introduction

Phosphorus (P) loss in runoff from cropland is an environmental concern because this P often promotes weed and algae growth in lakes, rivers, and streams. Water bodies with a large supply of nutrients (well nourished) are termed eutrophic. Eutrophic conditions can result in excessive algae and plant growth and when these weeds and algae die and decompose, dissolved oxygen levels in the water is depleted resulting in odors, fish kills, and a general degradation of the aesthetic and recreational value of the environment such as reduced water clarity, unpleasant swimming conditions, poor boating conditions, and a polluted appearance potentially resulting in significant economic implications.

Concerns about P losses from agricultural land are also increasing because soil test P values that reflect the amounts of plant-available P in soils have increased substantially over the past 25 years. Average soil test P levels in Wisconsin exceed the levels needed for optimum crop production because long-term P additions in manure and/or fertilizer have exceeded P removals in the harvested portion of crops (Bundy, 1998; Bundy and Sturgul, 2001). However, continued land application of manure often is the only practical management option for livestock operations. This emphasizes the need to identify the effects of management practices for controlling P losses in runoff from corn production systems.

Recent Wisconsin research suggests that tillage and manure management can have a strong influence on the forms and amounts of P in runoff from corn production systems (Bundy, et al., 2001). In general, this work showed that tillage to incorporate manure greatly increased total P losses in runoff compared to surface applications of manure, mainly due to increased sediment loss in the tilled treatments. The added residue from surface applications of manure increased water infiltration rates and thus reduced runoff volume and total P loss. Mueller et al. (1984) also found lower sediment losses and generally lower total P losses in runoff where manure was applied in an earlier Wisconsin study. Unincorporated manure significantly increased soluble P concentrations in runoff and tended to increase runoff soluble P loads. However, soluble P represented only 1-3% of the total P in fall runoff measurements.

The objectives of this study were to determine the effects of tillage and manure management practices on the forms and amounts of P lost in runoff from the major agricultural soil groups in Wisconsin. This paper reports results from the study conducted on the loess-derived, unglaciated soils in southern and western Wisconsin (NRCS Major Land Resource Area 105, Northern Mississippi Valley Loess Hills). The representative soil series used for these studies is Rozetta silt loam (fine, silty, mixed, mesic Typic Hapludalf) located on the University of Wisconsin Agricultural Research Station at Lancaster (42° 51'N; 90° 42'W).

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Materials and Methods

Runoff generated from simulated rainfall applications was measured and analyzed in May and September, 2000 on a field study established in 1993 at the University of Wisconsin Agricultural Research Station at Lancaster on a Rozetta silt loam soil. This site provided the opportunity to evaluate established tillage and manure treatments as well as current year manure treatments on P losses in runoff. Since 1993, corn was planted and grain was harvested annually with all corn residue returned to the field. Main plot treatments (1993 to present) consist of two annual tillage methods, no-till (NT) and fall chisel plow (CP). Subplot treatments (1993 to 1997), referred to as long-term manure history, consisted of with and without annual fall manure applications at an approximate rate of 40 tons/acre (89.6 Mg/ha) of dairy manure. Fall chisel plowing was done immediately following manure application from 1993 to 1997. Sub-subplot treatments (spring 2000), referred to as spring manure, consisted of with and without a 32 ton/acre (71.7 Mg/ha) application of dairy manure applied on 18 April 2000. All treatment combinations included four replications for a total of 32 plots. In 2000, all fall chisel plow treatments were disked immediately following manure application and again on 2 May to prepare the seedbed. Field corn was planted at 30,000 seeds/acre (74,000 seeds/ha) without starter fertilizer on 2 May 2000. Inorganic N fertilizer (ammonium nitrate) was broadcast surface applied to all treatments in June to achieve a uniform available N rate of 160 lb N/acre (179 kg/ha) adjusted for manure N credits.

Simulated rainfall was applied following corn planting in May and following whole-plant (silage) harvest in September using techniques similar to those described by Zemenchik et al. (1996). A portable, multiple intensity rainfall simulator (Meyer and Harmon, 1979) equipped with a Veejet 80150 nozzle (Spraying Systems, Wheaton, IL) located 3 m above the soil surface delivered an application rate of 75 mm hr^{-1} with a corresponding energy of 0.278 MJ ha^{-1} mm^{-1}. This rainfall intensity has a recurrence interval of about 50 years (Huff and Angel, 1992). Steel plot frames (91 cm L x 91 cm W x 30 cm H) were set in the soil at a 15-cm depth before simulated rain was applied. Runoff was collected at the down-slope side of the plot frame and continuously removed by a 0.02 MPa vacuum (Dixon and Peterson, 1968) and placed in a holding tank.

Runoff was collected for a 60-min period following the onset of simulated rainfall, and the total volume of runoff from each plot was recorded. After mixing to resuspend sediment, subsamples of the runoff were obtained for sediment, dissolved reactive P (DRP), bioavailable P (BAP), and total P (TP) determinations. A subsample for DRP field-filtered through a 0.45-um cellulose nitrate filter. Samples were frozen until the analyses were performed.

Slope and surface residue cover were determined for each plot prior to simulated rainfall application. Soil samples (0-2, 2-5, and 5-15 cm) were obtained from the outside perimeter of each frame. In September, corn plants within each plot frame were cut near the base and removed. Sediment concentration in runoff, antecedent soil moisture content, and antecedent soil bulk density was determined by drying and weighing samples. Dissolved reactive P (DRP) in runoff filtrate samples was determined using the ascorbic acid method (Murphy and Riley, 1962). Bioavailable P (BAP) in unfiltered runoff samples was determined using the iron-oxide paper strip method (Sharpley, 1993). Total P was determined by ammonium persulfate and sulfuric acid digestion on aliquots of unfiltered runoff suspension (USEPA, 1993).

Soil samples obtained prior to simulated rainfall application were dried at 32°C, ground to pass a 2-mm sieve, and extracted for P using several methods. For the 0-2 cm soil samples, soil test P extraction methods included distilled water (Pote et al., 1996), Bray-Kurtz P1 (Frank et al., 1998), Mehlich III (Mehlich, 1984), iron-oxide strip (Sharpley, 1993). All P analyses were performed colorimetrically using the ascorbic acid method (Murphy and Riley, 1962). Ammonium oxalate P, iron (Fe), and aluminum (Al) (Pierzinski, 2000) was also determined using an inductively coupled plasma optical emission spectrometer (ICP–OES, Iris Plasma Spectrometer, Thermo Jarrell Ash Corp., Franklin, MA), and P saturation percentage was calculated as the oxalate-extractable P divided by the sum of the oxalate-extractable Fe and Al content, and multiplied by 100 (Pote et al., 1996). Soil samples from the 2-5 and 5-15 cm depth increments were also extracted for P using the Bray P1 method only. Only the Bray P1 data is included in this paper.

An analysis of variance was performed for treatment effects on all measured variables using PROC ANOVA (SAS Institute, 1992). Significant differences among treatment means were evaluated using a protected least significant difference (LSD) test at the 0.05 probability level. Where main treatment effect interactions were significant, LSD tests were performed at each level of the interacting factor. Regression analysis procedures were performed to determine the relationships between variables using PROC REG.

Results and Discussion

Table 1 summarizes the analysis of variance for the effects of tillage, long-term manure history, and current year (2000) spring manure applications on selected variables measured during May and September simulated rainfall events.

Surface residue cover in both spring and fall were significantly affected by tillage, long-term manure, and spring manure treatments. As expected, surface residue cover was lower in chisel plow than in no-till while long-term and spring manure treatments increased residue cover. In September, spring manure had no effect on residue cover with chisel plow tillage while spring manure increased residue cover in no-till. Long-term tillage and manure history had similar effects on soil test P (Bray P1) in May and September, and the September data is shown in Fig. 1. Long-term manure history increased 0-2 cm soil test P from 59 to 102 mg/kg while spring manure treatments increased soil test P from 75 to 88 mg/kg. Tillage did not affect 0-2 cm soil test P, but greater stratification of P with soil depth is apparent in no-till.

Sediment concentrations and loads in runoff were strongly influenced by tillage and spring manure treatments. In May and September, sediment loads were 15 to 30 times greater in chisel plow than in no-till (Table 2). In chisel plow tillage, spring manure additions reduced sediment load but had no effect on the lower sediment loads observed in no-till.

Dissolved reactive P (DRP) or soluble P concentrations in May runoff were higher in no-till than in chisel plow tillage, especially where spring manure was applied to the soil surface (Fig. 2). By September, the tillage did not affect runoff DRP concentrations, but these values were higher where either long-term manure or spring manure was applied. This effect is possibly due to the higher soil test P levels where long-term and current year manure treatments were applied.

Tillage and manure treatments had no effect on DRP load in either May or September runoff measurements.

Total P (TP) concentrations in both May and September runoff were higher with chisel plow tillage than with no-till, and long-term manure history increased TP concentrations at both measurement times (Fig. 3). In May only, spring manure increased TP concentration in no-till but not in chisel plow tillage. These observations are likely due to increased sediment loss in chisel plow tillage, increased soil test P with the long–term manure history, and the presence of unincorporated manure on the soil surface with spring applications in no-till.

Total P loads in runoff were higher in chisel plow than in no-till at both measurement times (Fig. 4). This is probably due to lower sediment loss in the no-till system (Table 2). May and September TP loads in chisel plow tillage were much lower where spring manure was applied, likely due to increased residue cover and water infiltration rates and lower sediment losses where manure was added. In September, spring manure reduced TP loads across all tillage and manure history treatments (Fig. 5).

In chisel plow tillage, DRP usually accounted for less than 15% of the May TP load. In no-till, where TP loads were much lower, most of the TP load was DRP where spring manure was applied and about one-third of the TP load was DRP where spring manure was not applied. In September, DRP accounted for less than 5% of TP load in chisel plow tillage and 16 to 45% of the substantially lower TP loads in no-till. These results suggest that sediment-bound P is a major contributor to TP loads in tilled systems. Data in Fig. 6 illustrate the close relationship between sediment load and TP load in May runoff.

Much of the work relating soil P and manure effects on P concentrations in runoff has been done in grass pasture systems (Sharpley et al., 1994; Daniel et al., 1994; Pote et al., 1996; 1999) where nearly all of the P in runoff is in the dissolved form and little sediment/particulate P loss occurs due to high soil surface cover. Consequently, total P loss in runoff is relatively unimportant in these systems. Measurement of the forms and amounts of P in runoff in this work emphasize the importance of TP loads in assessing the potential environmental impacts of P losses from row crop production systems. This study also supports recent research (Bundy et al., 2001) on other Wisconsin soils indicating that 97% of total P loss in runoff under simulated rainfall in tilled systems was sediment bound and that use of tillage to incorporate manure may increase total P losses in runoff. A recent review on P in lake sediments and waters (Correll, 1998) suggests that sediment/particulate P has a significant effect on algal growth in water bodies due to re-equilibration with the receiving water's dissolved P concentration. This review reflects the prevalent view of limnologists about the importance of runoff total P for assessing environmental impact and is consistent with the USEPA lakes and streams nutrient criteria based on total P rather than dissolved P.

Summary

This study evaluated the effects of tillage, manure history, and current year manure applications on the forms and amounts of P lost in runoff under simulated rainfall in corn production systems on soils typical of southwestern Wisconsin. Surface residue was decreased by tillage and increased by long-term and current year manure applications. Surface soil P test levels were increased by manure additions, but were not affected by tillage. Runoff sediment concentrations and loads were generally increased by tillage, and spring manure additions reduced sediment load in chisel plow tillage. Soluble P (DRP) concentrations in May runoff were highest in no-till with spring-applied manure. DRP loads were not affected by tillage and manure treatments. Total P (TP) concentrations in runoff were increased by tillage and long-term manure history. Total P loads were higher in chisel plow than no-till likely due to higher sediment losses with chisel plowing. Tillage increased total P loads in runoff consistent with increased sediment losses. Spring manure applications lowered TP loads. DRP usually accounted for a small percentage of TP load, especially in tilled treatments, suggesting that sediment-bound P accounted for most of the TP load. A close relationship was found between sediment load and TP load in runoff. Results emphasize the importance of managing tillage, manure, and residues to minimize sediment loss, the major contributor to total P load in runoff. Incorporation of manure may not control runoff P losses because tillage is likely to reduce residue cover and increase sediment loss leading to higher TP losses in runoff.

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Table 1. Analysis of variance summary for the effects of tillage, long-term manure history (1993-1997), and spring manure (2000) on several variables at Lancaster, Wisconsin, May 2000 and September 2000.

Variable	Tillage (T)	Long-term manure history (LTM)	T x LTM	Spring manure (SM)	T x SM	LTM x SM	T x LTM x SM	CV
	P > F							%
Results from May 2000								
Surface residue	<0.01	0.01	0.17	<0.01	0.73	0.20	0.73	14.3
Time to runoff	0.08	0.06	0.06	0.10	0.12	0.41	0.43	111
Runoff amount	0.03	0.01	0.40	<0.01	0.02	0.97	0.97	35.9
Sediment concentration	<0.01	0.44	0.16	0.02	0.17	0.64	0.85	36.6
Sediment load	0.01	0.30	0.59	<0.01	0.01	0.99	0.92	65.4
Soil test P								
Bray (0-2cm)	0.04	<0.01	0.03	<0.01	0.34	0.48	0.39	13.0
Bray (2-5 cm)	0.56	<0.01	0.19	0.11	0.02	0.92	0.67	18.8
Bray (5-15 cm)	<0.01	<0.01	0.18	0.19	0.07	0.06	0.03	12.9
P in runoff								
DRP concentration	0.02	0.29	0.21	<0.01	<0.01	0.68	0.87	56.8
BAP concentration	0.11	<0.01	0.07	<0.01	<0.01	0.87	0.74	50.6
TP concentration	0.02	0.02	0.37	0.20	<0.01	0.68	0.64	40.7
DRP load	0.84	0.06	0.01	0.07	0.08	0.10	0.36	107
BAP load	0.14	0.45	<0.01	0.54	0.01	0.08	0.61	85.2
TP load	0.01	0.47	0.18	0.07	0.02	0.73	0.79	67.5
Results from September 2000								
Surface residue	<0.01	0.05	0.49	<0.01	0.03	0.21	0.28	17.1
Runoff amount	<0.01	<0.01	0.49	<0.01	0.01	0.27	0.25	24.5
Time to runoff	0.39	0.70	0.64	0.15	0.21	0.20	0.23	164
Sediment concentration	<0.01	0.20	0.13	0.14	0.41	0.98	0.82	53.5
Sediment load	<0.01	0.89	0.76	<0.01	0.01	0.87	0.67	69.8
Soil test P								
Bray (0-2cm)	0.16	<0.01	0.11	0.01	0.30	0.53	0.96	16.0
Bray (2-5 cm)	0.67	<0.01	0.15	0.06	0.28	0.68	0.47	25.6
Bray (5-15 cm)	0.82	0.06	0.19	0.96	0.92	0.45	0.95	41.3
P in runoff								
DRP concentration	0.15	0.03	0.25	0.03	0.08	0.63	0.88	65.5
BAP concentration	0.39	<0.01	0.76	0.06	0.32	0.72	0.92	43.3
TP concentration	<0.01	0.02	0.07	0.90	0.54	0.55	0.98	36.7
DRP load	0.28	0.70	0.26	0.46	0.07	0.26	0.65	57.0
BAP load	<0.01	0.12	0.04	0.04	0.04	0.34	0.34	52.6
TP load	<0.01	0.54	0.27	<0.01	<0.01	0.49	0.39	51.1

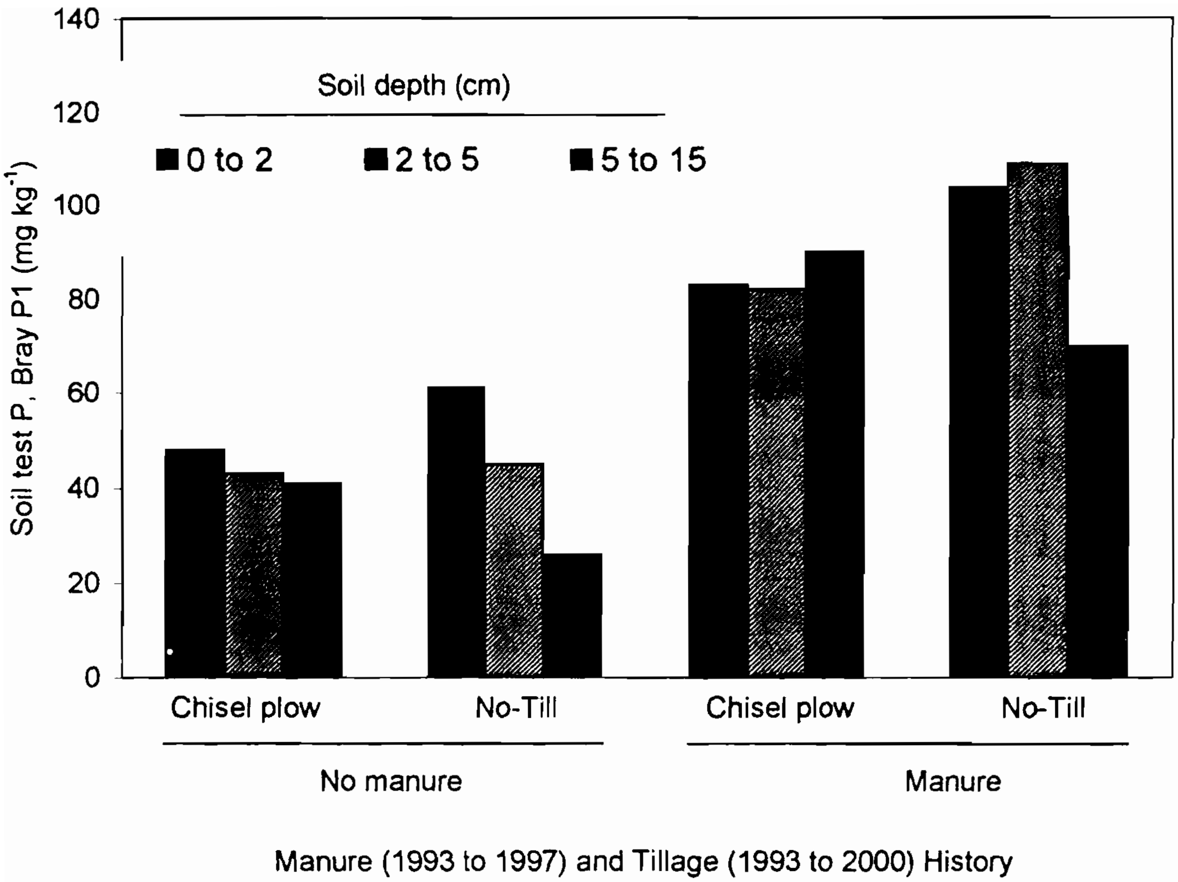

Fig 1. Effect of long-term manure on soil test P level at several depth increments in two long-term tillage systems at Lancaster, September 2000.

Table 2. Effect of tillage, long-term manure history (1993-97), and spring manure (2000) on sediment load in runoff at Lancaster, WI, September 2000.

		Tillage	
Long-term manure history	Spring manure	Chisel plow	No-till
		-------- sediment load, kg ha^{-1} -------	
None	None	4493	467
	Manure	1779	127
Manure	None	4833	214
	Manure	1582	52

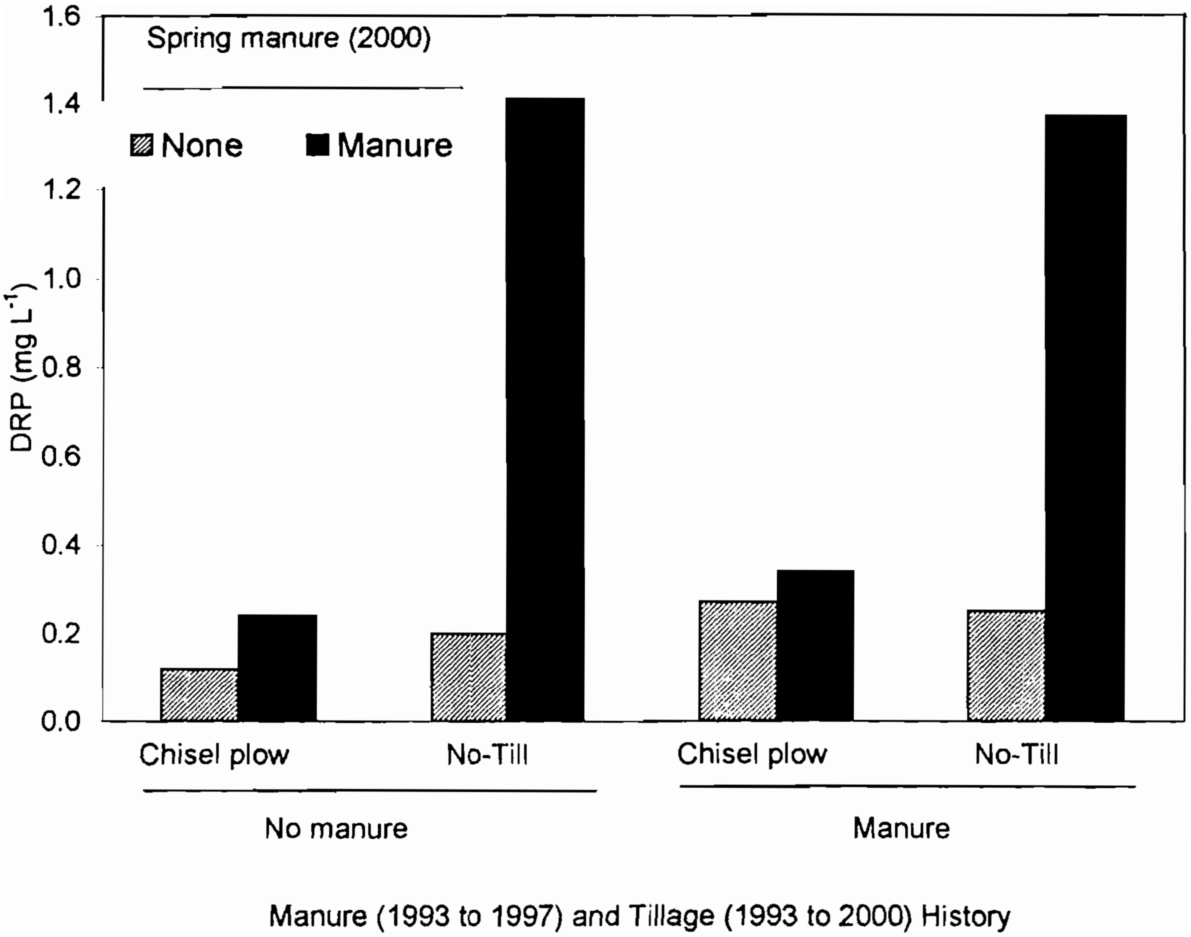

Fig. 2. Effect of long-term manure history, long-term tillage, and spring-applied manure on DRP concentration in runoff at Lancaster, May 2000.

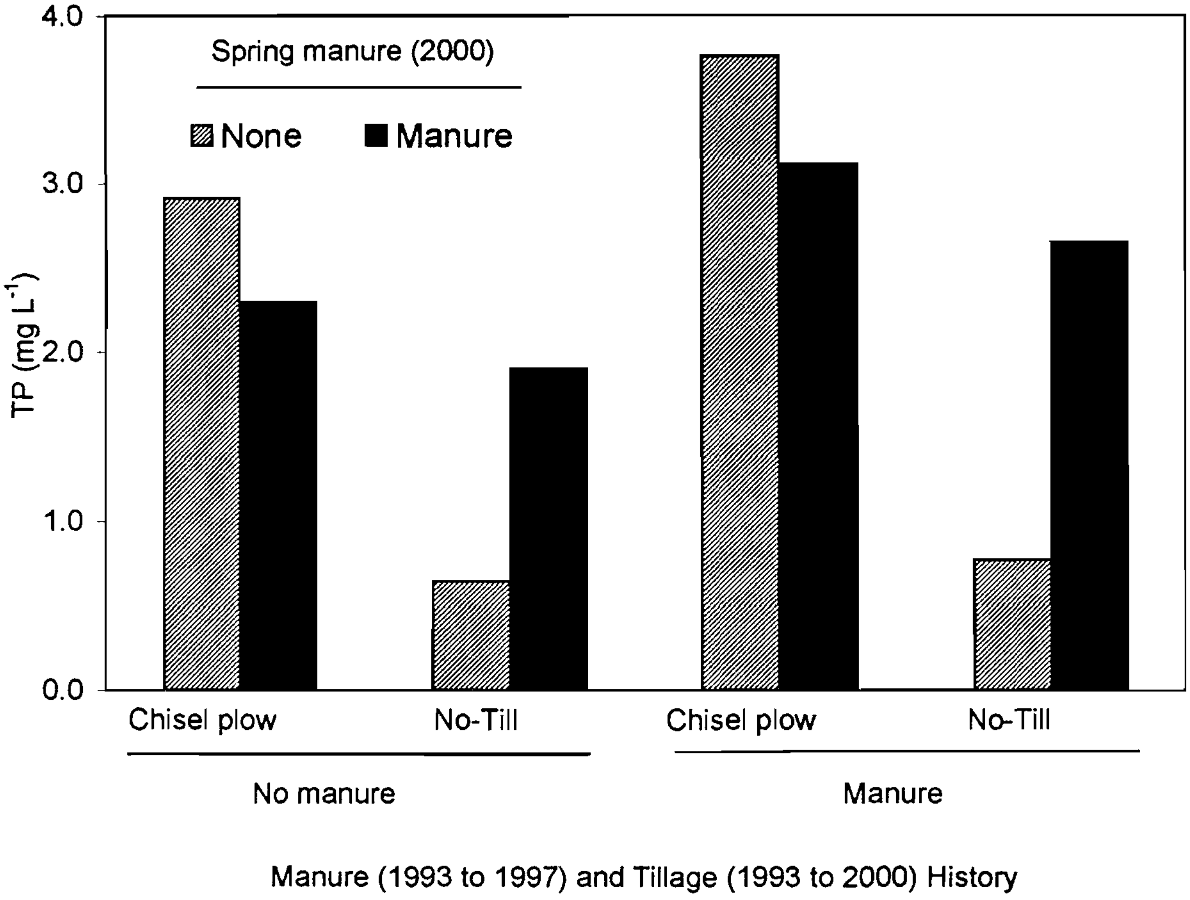

Fig. 3. Effect of long-term manure history, long-term tillage, and spring-applied manure on TP concentration in runoff at Lancaster, May 2000.

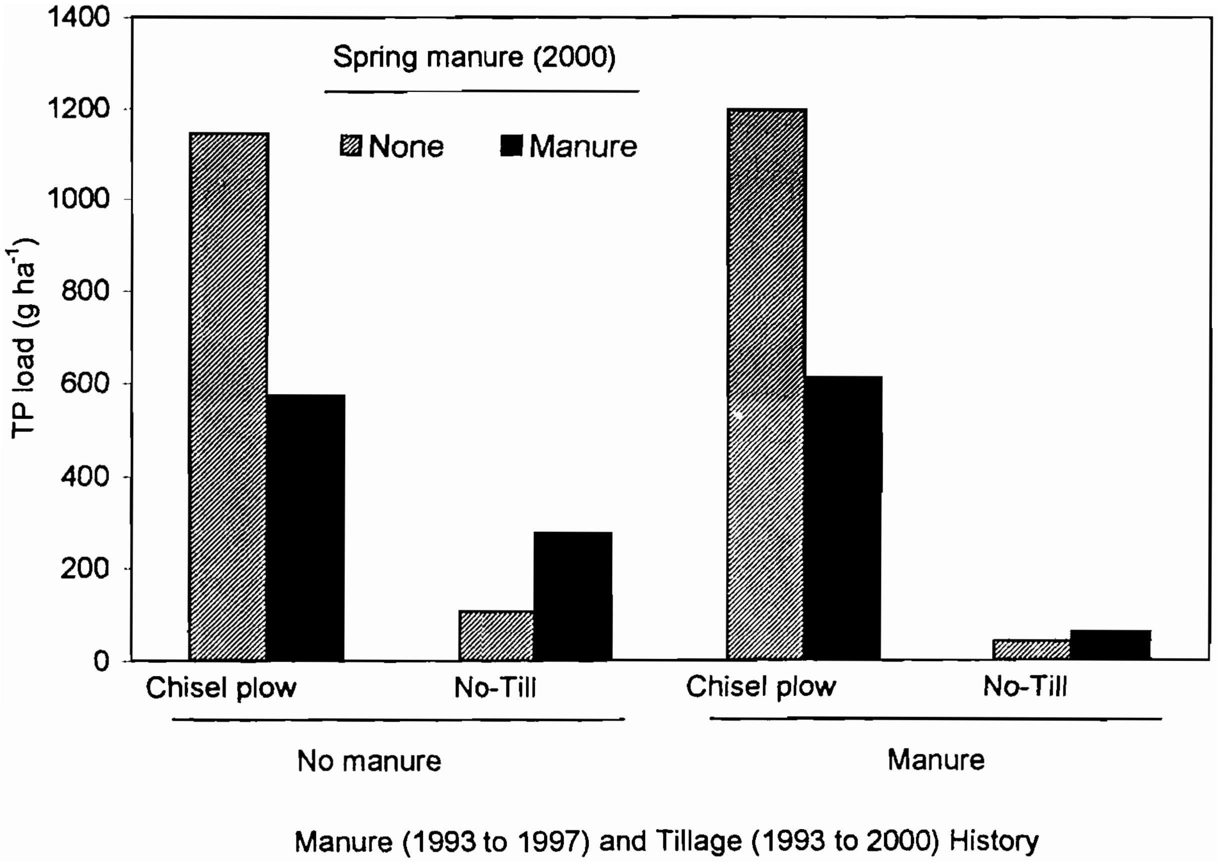

Fig. 4. Effect of long-term manure history, long-term tillage, and spring-applied manure on TP load in runoff at Lancaster, May 2000.

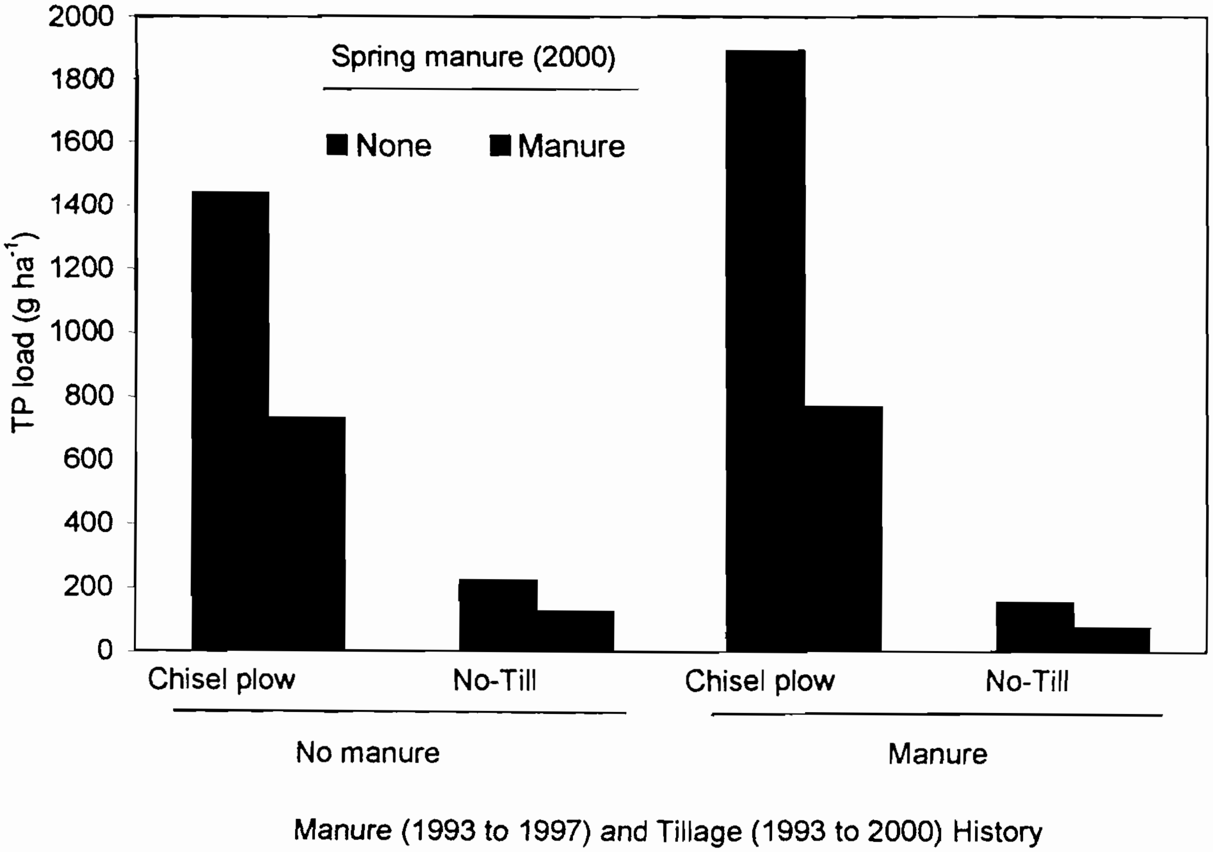

Fig 5. Effect of long-term manure history, long-term tillage, and spring-applied manure on TP load in runoff at Lancaster, September 2000.

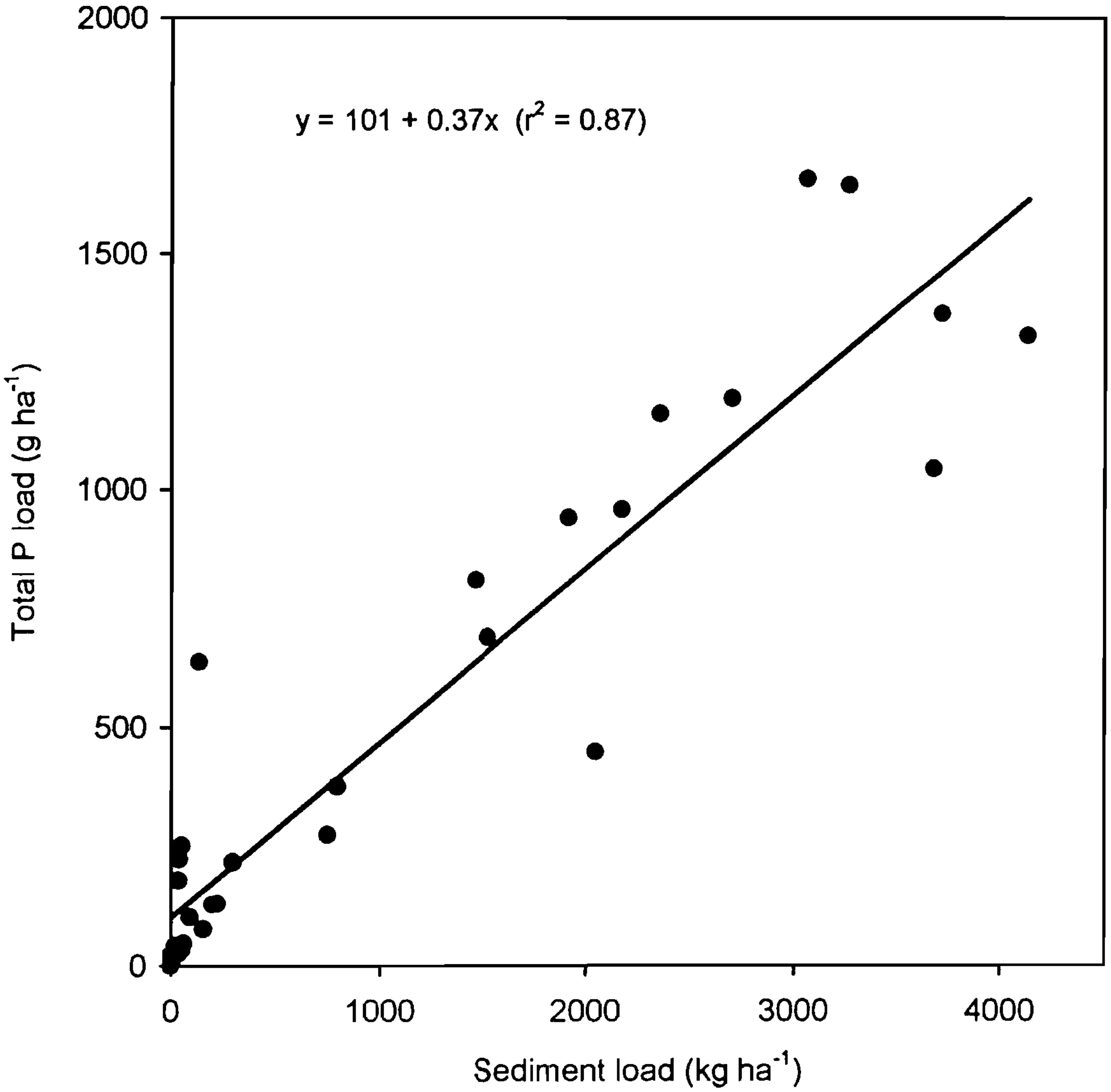

Fig. 6. Relationship between sediment load and total P load in runoff at Lancaster, May 2000 (n = 32).

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