PHOSPHORUS RUNOFF FROM INCORPORATED AND SURFACE-APPLIED FERTILIZER AND MANURE

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Abstract

Continued inputs of fertilizer and manure in excess of crop requirements have led to a build-up of soil phosphorus (P) levels, creating an environmental rather than agronomic concern (Sharpley et al., 1994). The objective of this study was to evaluate the effects of soil test P level, source of P amendments, tillage, and manure application method on P runoff from agricultural soils. The treatments consisted of swine manure surface applied and injected at rates of 29 and 59 lb acre^{-1} of P, and triple super phosphate, broadcast and incorporated with a chisel plow at a rate of 48 lb acre^{-1} of P. Rainfall simulations were conducted in the fall, one month after P application, and in the spring, six months after P application. Runoff samples were collected and analyzed for dissolved reactive (DRP), total (TP), and algal-available P (AAP). For plots with surface applied P, concentrations and loads of DRP, TP and AAP in runoff were higher than those from control plots both in fall and spring rainfall simulations. In fall, the P concentrations and loads from plots with surface applied manure were also higher than those from plots with fertilizer applied P, while in spring the differences between plots with fertilizer and manure applied P were insignificant. Concentrations and loads from plots with incorporated manure or fertilizer generally did not differ from the controls.

Introduction

The transport of P occurs in dissolved and particulate forms. Particulate P (PP) encompasses all solid-phase forms and includes P sorbed by soil particles and organic matter eroded during runoff. While dissolved P is, for the most part, immediately available for biological uptake, PP can provide a long-term source of P for aquatic plant growth.

The main factors controlling P movement in surface runoff are transport (runoff and erosion) and source factors (surface soil P content and method, rate, and timing of fertilizer and animal manure applications), (Sharpley et al., 1993). High rates of P application either as fertilizer or manure, particularly if left on the soil surface, will increase the potential for movement of DRP from fields (Baker and Laflen, 1982; Mueller et al., 1984). Incorporation of P materials, either through tillage or injection, will generally reduce the potential for DRP runoff (Eghball and Gilley, 1999; Withers et al., 2001). On the other hand, tillage operations may enhance the potential for TP loss, especially in highly erosive sites.

Loss of P from experimental plots receiving inorganic and organic amendments has been shown to be highly variable. Eghball and Gilley (1999) observed that the concentrations of DRP and AAP were significantly greater for the inorganic fertilization than for two rates of cattle manure when all were surface-applied before an initial rainfall event. However, in the second rainfall event, increased

DRP and AAP in runoff resulted from the highest manure rate. When comparing different inorganic and organic amendments, Withers et al. (2001) observed that P runoff from triple superphosphate was similar to that with liquid cattle manure, regardless of whether surface-applied or incorporated with a rotovator.

Sixty percent of the swine production in the US is centered in the midwest region. This generates an enormous quantity of manure, which must be managed correctly to avoid water pollution. Unfortunately, little research has been conducted to determine the relative importance and intensity of the factors affecting P transport on Corn Belt agricultural soils.

The objectives of this study were to (i) compare the effects of incorporation to surface application of P-containing materials on the concentration and loads of DRP, AAP and TP loss, (ii) determine the effects of two different rates of swine manure and a typical P fertilizer rate on the DRP, AAP and TP load and concentration in runoff, (iii) determine the effects of a range of soil test levels on P loss in runoff, and (iv) evaluate P loss immediately following the treatment applications in fall and after six months, in spring.

Materials and Methods

The study was conducted from 1999 to 2001 at the Northwestern Illinois Agricultural Research and Demonstration Center, Monmouth, IL, on a Tama silt loam soil (fine-silty, mixed, mesic Typic Argiudoll).

The experimental design was a randomized complete block with two replications. The blocks contained thirty-four 6.5 by 5 ft plots, with a 5.5% average slope. Treatments consisted of four soil amendments; two swine (*Sus scrofa domestica* L.) manure rates (29 and 59 lb acre^{-1} P), a commercial fertilizer (48 lb acre^{-1} P as triple superphosphate), and a control with no P applied; two application methods (surface application and incorporation); and a range of four soil P levels. Manure was incorporated by injection and fertilizer P and control treatments were chisel-plowed. To obtain a range of soil P levels, each plot was soil sampled in May 1999 from 0 - 1 in and 0 - 7 in. Triple superphosphate was broadcast to every plot based on the soil test results. Then a field cultivator was used to mix and prepare the soil, and soybean [*Glycine max* (L.) Merr.] was planted. In early October 1999 and late September 2000, after the soybean crop was harvested, soil samples were collected from around the plots and analyzed for Bray and Kurtz P1 (Bray P1). Soil P levels were divided into 4 categories and every treatment combination was randomly assigned to each soil P level category, which resulted in an average of 47, 126, 257 and 862 mg kg^{-1} P (mg kg^{-1} x 2 ≈ lb acre^{-1}).

In mid October 1999 and early October 2000, swine manure was surface-applied and injected at rates of 5000 and 10000 gallon acre^{-1} and simultaneously triple superphosphate (TSP) was broadcast. The fertilizer and control incorporated treatments were then chisel-plowed 10 in deep, perpendicular to the slope. Manure was injected in a horizontal band at a 4 in depth using an injector with disk-sweeps. Plots with injected manure were not chisel-plowed.

Rainfall simulations were conducted at each of the plots in mid November 1999 and mid May 2000. The trial was repeated in late October 2000 and early May 2001 on an adjacent site. Rainfall simulators (Humphry et al., 2002), were used to simulate a 3.7 in hr^{-1} +/- 0.5 in hr^{-1} intensity rainfall, which is equivalent to a 10-year storm in Western Illinois (Huff and Angel, 1989).

Runoff samples were collected from each experimental unit 2.5, 7.5, 17.5 and 27.5 minutes following the onset of runoff. Composite samples were analyzed for DRP, AAP and TP concentration. Phosphorus load (kg ha^{-1}) was calculated by multiplying the total volume of runoff in 30 minutes by the composite sample concentration.

Within 12 hours after the sample collection, portions of the runoff samples were filtered (0.45 µm), stored at 4 °C and analyzed the next day for DRP using the ascorbic acid method (APHA, 1995). Unfiltered portions of samples were stored at 4 °C until analyzed for AAP. Algal-available P was measured on unfiltered runoff samples using an iron oxide strip method (Sharpley, 1993). Unfiltered samples were also analyzed for TP by a Kjeldahl digestion method (Patton and Truitt, 1992). Sediments were measured by drying 10 mL of unfiltered water sample at 110 °C until constant weight. The Bray and Kurtz P1 test for extracting soil P was used (Frank et al., 1998).

Results were analyzed with SAS (SAS Inst., 1999). The data were log-transformed to obtain near normal distributions. PROC GLM was conducted to analyze the effects of P sources, season, and methods of P application on DRP, TP and AAP concentrations and loads with Bray P1 soil test levels as a covariate.

Results and Discussion

Dissolved reactive phosphorus

High DRP concentrations and loads were observed for runoff from no-till plots with surface-applied triple superphosphate (TSP) or manure. This occurred in the fall rainfall simulation event, shortly after the treatments had been applied. (Fig.1 and 2). When these amendments were incorporated, DRP concentrations and loads were greatly reduced, showing no difference from the control plots. The differences among surface-applied and incorporated treatments were still significant for DRP concentrations during the second rainfall simulation in spring (Fig. 1), but not for DRP loads (Fig. 2). Dissolved reactive P loads were more variable than concentrations since DRP loads are related to runoff volumes, which depend on residue cover, slope, and surface roughness, all of which tended to vary from plot to plot.

Concentrations of DRP from surface-applied amendments in fall 2000 (Fig. 1b) were more than double those measured in fall 1999 (Fig. 1a). This was attributed to the prewetting of the plots in fall of 1999 because of the very dry soil conditions. Some runoff was observed in the buckets after prewetting, and evidently part of the amendments were lost in this manner. Concentrations and loads of DRP in runoff tended to be higher for the highest manure rate (HM) than for the low manure rate (LM), but the differences were not significant. Dissolved reactive P concentrations and loads in runoff from surface-applied TSP were smaller than LM only in the first year. Dissolved reactive P concentrations and loads from surface-applied TSP were always smaller than HM (*P*=0.01). The incorporated treatments showed no differences in DRP concentrations or loads between years, seasons or sources.

Total phosphorus

In the fall, surface-applied manure produced greater TP concentrations and loads in runoff, as compared to injected manure (Fig. 3 and 4). In fall of the second year (Fig. 3b), the difference in average TP concentrations between no-till and incorporated treatments was more than twice the difference in the first year (Fig. 3a) . This was also observed for DRP and AAP, and the cause was attributed to the prewetting of the plots in the first year, after the treatments had been applied. In spring, no differences were found for TP concentrations or loads in runoff between surface-applied and incorporated treatments.

No differences were found for TP concentration between surface-applied and incorporated TSP in the first year (Fig. 3a). Ninety percent of the TP from chisel-plow plots was PP, whereas only 33% of the TP from surface-applied TSP was PP. So evidently what caused the high TP concentrations in runoff was the erosion coming off the chisel-plow treatments in the first year. The chisel-plow treatments, however, did not produce greater TP loads in runoff as compared to the surface-applied TSP (Fig. 4). This can be attributed to the very low runoff volumes coming off chisel-plow plots, which were only about one-fifth the runoff volumes from no-till plots.

Total P concentration and load in runoff did not differ between the two surface-applied manure rates, except for fall of 2000, where TP concentrations from HM treatments were greater than the concentrations from LM treatments (P=0.1). Higher TP concentrations and loads resulted from the HM rate compared to the TSP treatment in fall for both years, and the LM rate only produced greater TP concentrations and loads compared to TSP in the first year (P=0.1).

Total P concentrations and loads in runoff from incorporated treatments showed no differences between years, seasons or sources. However, sediments and Bray P1 levels had an effect on TP concentrations from all of the incorporated treatments (Fig. 5). Total P load in runoff was also affected mainly by sediment concentration, and to a smaller extent by Bray P1. However, the model explained little variability ($R^2 = 0.34$).

Algal-available phosphorus

Algal-available P concentrations and loads in runoff followed the same trends as DRP concentrations and loads in runoff (data not shown). For surface-applied amendments, the average percentage of DRP was 81% of AAP, while for incorporated treatments, DRP was 55% of AAP. So the AAP concentration for the incorporated treatments were almost double the DRP concentrations, and the mean AAP concentrations for the surface-applied treatments were 19% greater than the DRP concentrations. Sediment concentration in runoff and Bray P1 were the only variables that affected the AAP concentrations in runoff from incorporated treatments (Fig. 6). The R^2 was 0.73 (P=0.001).

Algal-available P contained a high DRP fraction due to the incorporation of amendments. The AAP fraction consisted of 55 and 70% DRP for injected LM and HM, respectively, and 41% for incorporated TSP . In contrast, the DRP fraction in AAP concentration for the control treatments was only 27%. The greater influence of DRP in AAP was evidently the cause for a smaller influence of sediments in explaining AAP when all the incorporated treatments were considered.

Algal-available P load in runoff was affected by both sediment concentration and Bray P1 levels. Although the model was significant ($P = 0.001$), it had a poor predictive value ($R^2 = 0.34$).

Conclusions

Injection of manure was very effective in reducing DRP, TP and AAP concentrations and loads in runoff. The same trends were observed when inorganic fertilizer was incorporated with a chisel-plow. However, in one year, chisel-plowing produced more erosion and therefore the TP concentration from surface-applied triple superphosphate (TSP) equaled the TP runoff from incorporated TSP. Therefore, when chisel-plowing to incorporate fertilizers, it is very important to keep erosion at minimum levels to avoid high sediment loads and consequently high P loads.

The mean concentrations of DRP, TP and AAP were generally higher for the high surface-applied manure rate than for the low surface-applied manure rate, but the differences were not always significant. Runoff volumes introduced variability when calculating P loads in runoff, so no differences were observed between manure rates for any P fraction load.

The highest rate of surface-applied manure tended to produce more DRP, TP and AAP concentrations and loads in runoff than did inorganic fertilizer P, whereas the P concentrations in runoff from fertilizer P were similar and sometimes smaller than the lowest manure rate. Since the P rate applied in the fertilizer was greater than the one applied with the lowest manure rate, P transport in runoff appears to occur more readily with manure than with fertilizers, and would therefore pose a greater threat to the environment.

Phosphorus losses immediately following the surface treatment applications were much greater than the P losses after six months, in spring, where small differences were observed between surface-applied and incorporated treatments for DRP and AAP concentrations. Therefore, the residual effect of the surface-applied amendments for this worst case scenario was very small.

Soil test levels and sediments had an effect on the P losses from incorporated treatments. Bray P1 had a linear effect on DRP concentration and load in runoff, and Bray P1 and sediments were significantly related to TP and AAP concentrations and loads. Using the models derived from the results of this study, values of 100 mg kg^{-1} Bray P1 and 2 g L^{-1} sediments would produce DRP concentrations of 0.12 mg L^{-1}, TP concentrations of 1.3 mg L^{-1} and AAP of 0.22 mg L^{-1}.

Incorporating organic and inorganic amendments was shown to be an acceptable technique to reduce P losses from agricultural fields. In this study, injecting manure and chisel-plowing inorganic fertilizer on the contour was not only effective in reducing P losses, but also in reducing the time to runoff and runoff volumes. However, this practice will be effective only if Bray P1 levels are kept below 100 mg kg^{-1} and residue coverage is adequate to control sediment losses.

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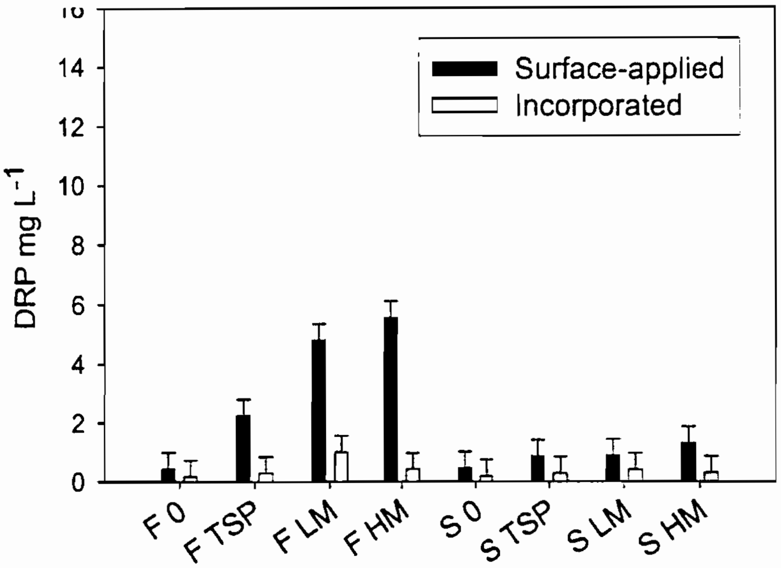
a) Year 1999/2000



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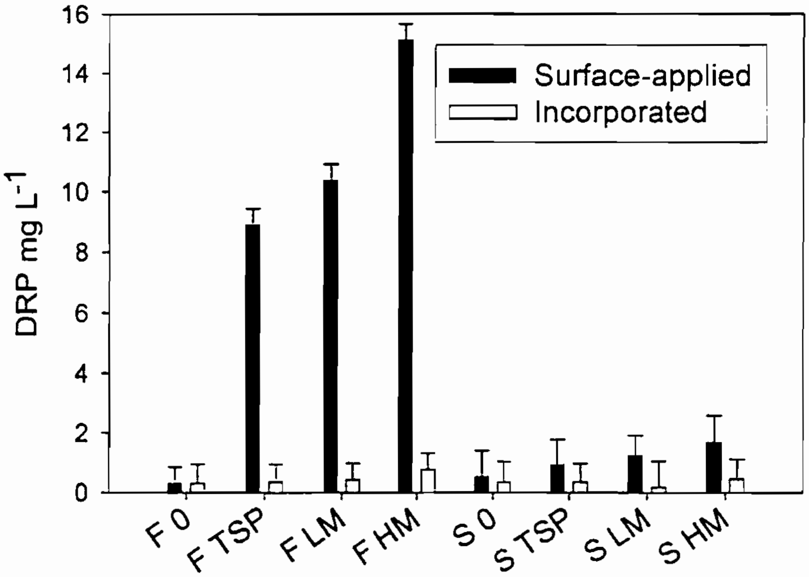
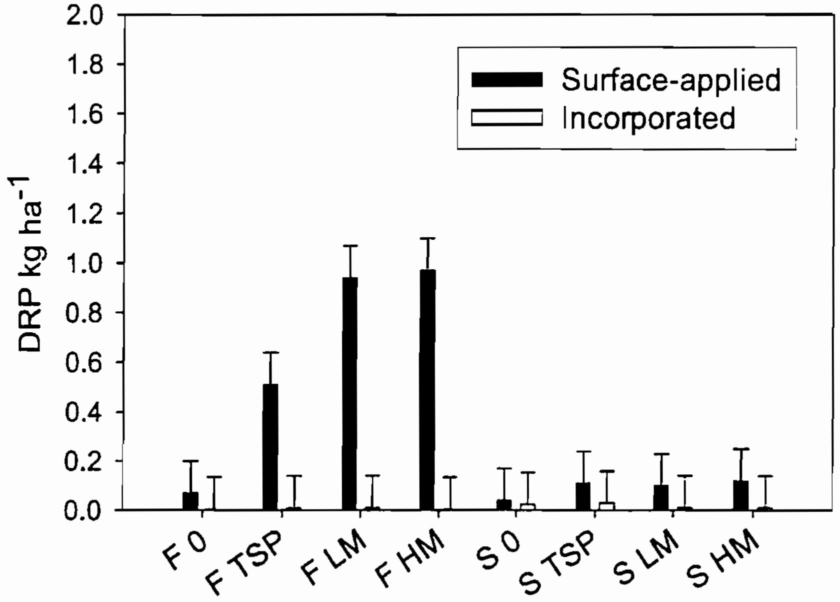


Fig. 1. Effects of P sources (O = control, TSP = 48 lb P acre^{-1} triple superphosphate, LM = 29 lb P acre^{-1} swine manure, HM = 59 lb P acre^{-1} swine manure), tillage (surface-applied and incorporated) and season of rainfall simulation (F = fall, S = spring), on the dissolved reactive P (DRP) concentration in runoff. Error bars represent standard errors.

a) Year 1999/2000



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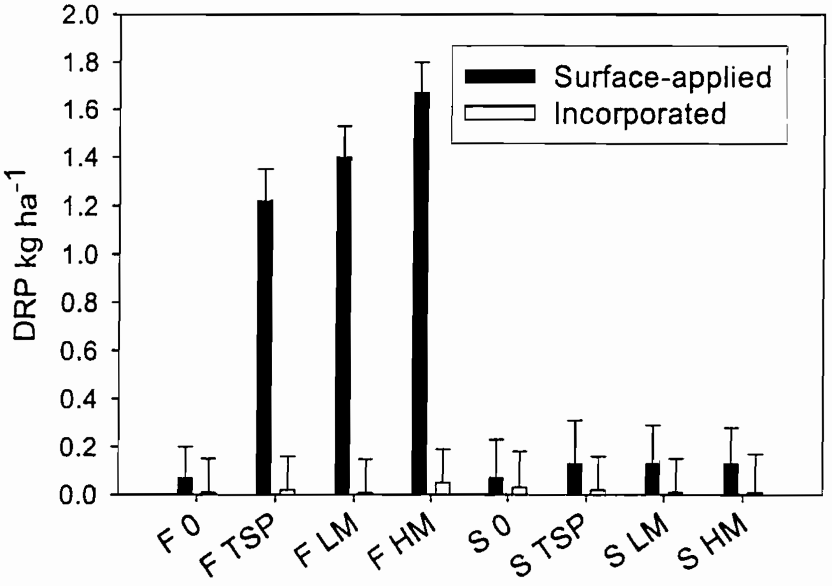
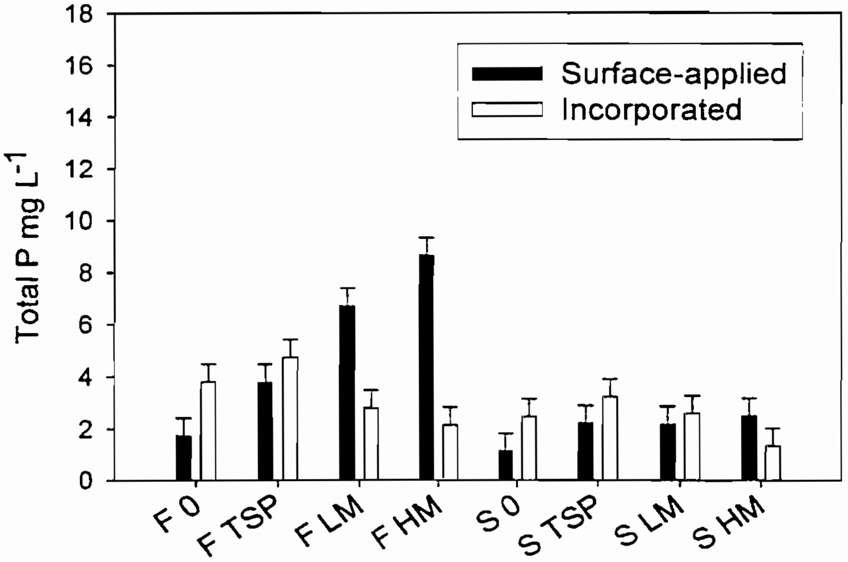


Fig. 2. Effects of P sources (O = control, TSP = 48 lb P acre^{-1} triple superphosphate, LM = 29 lb P acre^{-1} swine manure, HM = 59 lb P acre^{-1} swine manure), tillage (surface-applied and incorporated) and season of rainfall simulation (F = fall, S = spring), on the dissolved reactive P (DRP) load in runoff. Error bars represent standard errors. Unit conversion: kg ha^{-1} x 0.893 = lb acre^{-1}.

a) Year 1999/2000



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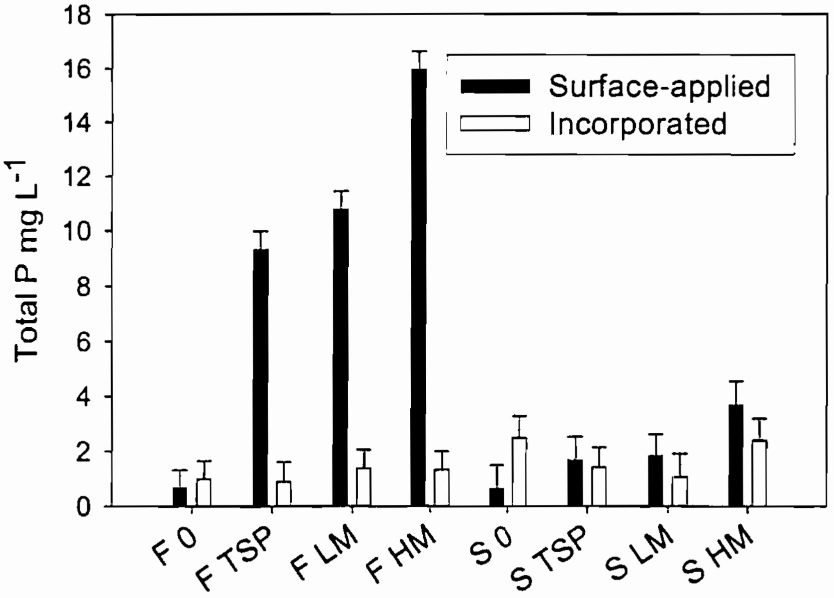

Fig.3. Effects of P sources (O = control, TSP = 48 lb P acre^{-1} triple superphosphate, LM = 29 lb P acre^{-1} swine manure, HM = 59 lb P acre^{-1} swine manure), tillage (surface-applied and incorporated) and season of rainfall simulation (F = fall, S = spring), on the total P concentration in runoff. Error bars represent standard errors.

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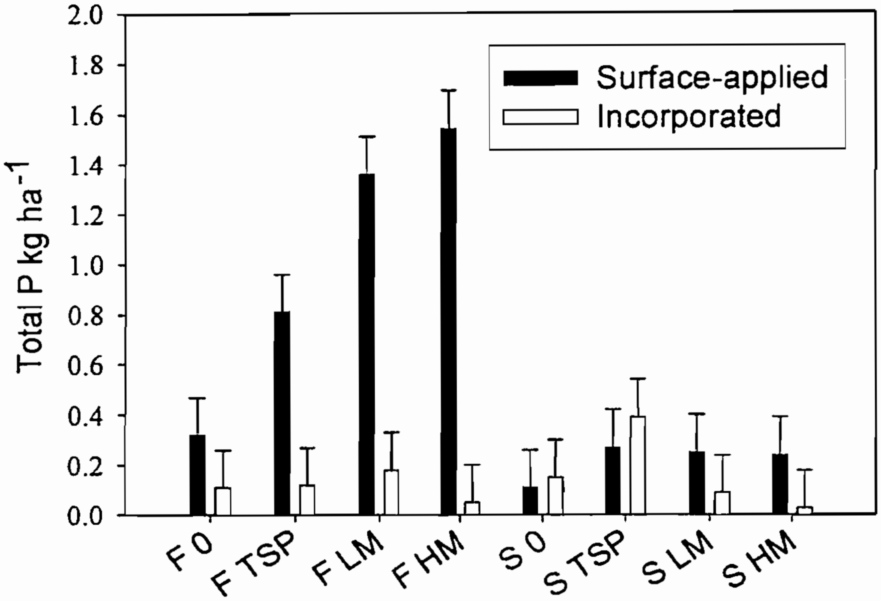

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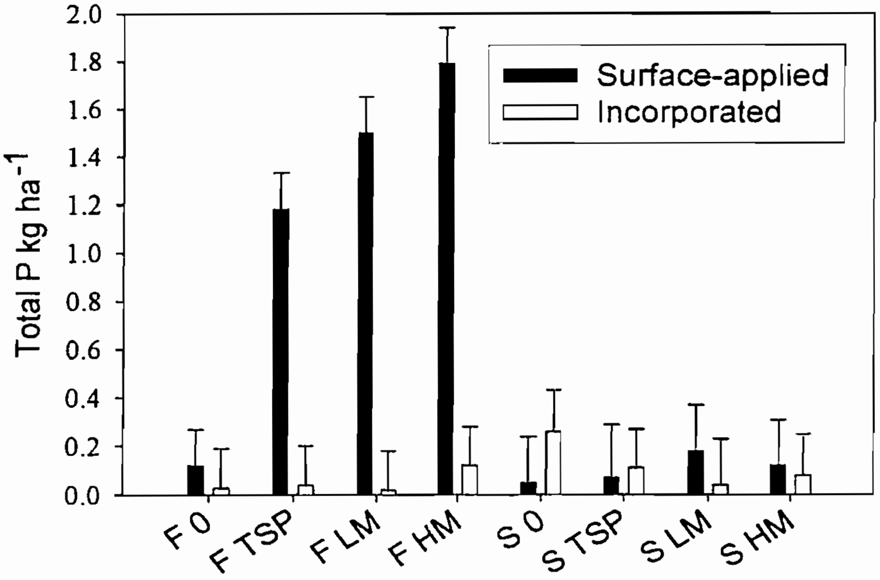

Fig.4. Effects of P sources (O = control, TSP = 48 lb P acre^{-1} triple superphosphate, LM = 29 lb P acre^{-1} swine manure, HM = 59 lb P acre^{-1} swine manure), tillage (surface-applied and incorporated) and season of rainfall simulation (F = fall, S = spring), on the total P load in runoff. Error bars represent standard errors. Unit conversion: kg ha^{-1} x 0.893 = lb acre^{-1}.

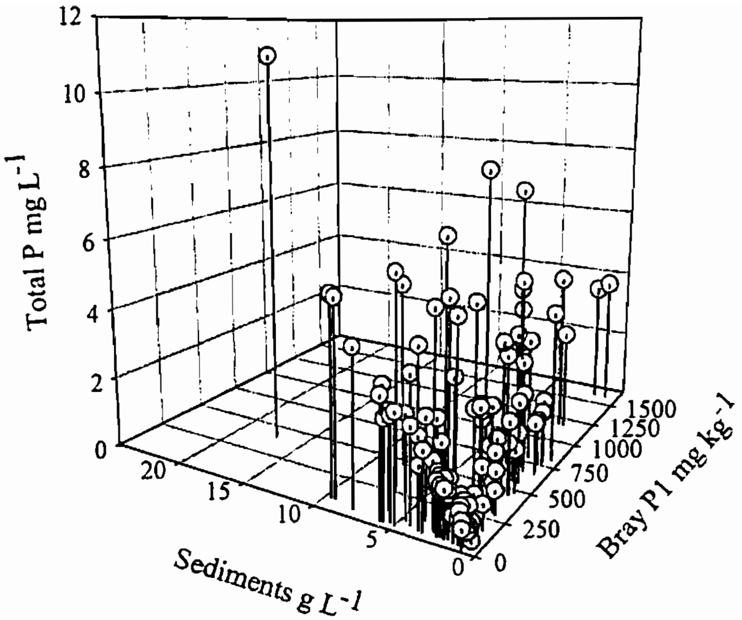

Fig. 5. Relationship between total P concentration (TPC) in runoff (mg L^{-1}) from incorporated treatments (including control), sediment concentration in runoff (g L^{-1}) and Bray P1 soil test levels (mg kg^{-1}). Unit conversion: mg kg^{-1} x 2 ≈ lb $acre^{-1}$.

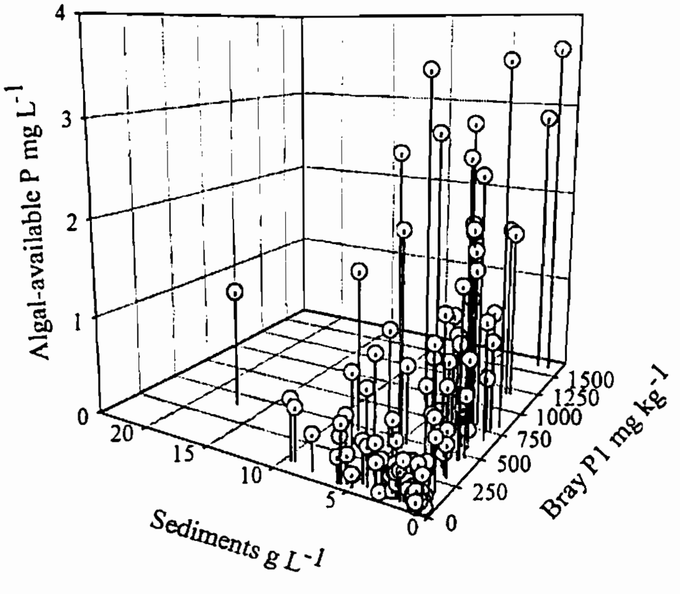

Fig. 6. Relationship between algal-available P concentration in runoff (mg L^{-1}) from incorporated treatments (including control), sediment concentration in runoff (g L^{-1}) and Bray P1 soil test levels (mg kg^{-1}). Unit conversion: mg kg^{-1} x 2 ≈ lb $acre^{-1}$.

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