Tillage, cropping, harvest, and nutrient management systems impacts on phosphorus loss with surface runoff: A research update

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Introduction

Eroded soil and phosphorus (P) impair several Iowa lakes and streams, and exported P contributes to hypoxia in the Gulf of Mexico. Most of the sediment and P originate from agricultural fields and stream banks. Phosphorus is lost from fields mainly by surface and subsurface transport processes, although delivery through water erosion and surface runoff accounts for the vast majority of the P reaching surface water bodies. The P lost with runoff can be classified into particulate P, dissolved reactive P (DRP), and bioavailable P (BAP). Particulate P includes forms in or attached to soil mineral and organic particles (sediment-bound P), and has been reported to account for 60 to 90% of P transported with surface runoff. Dissolved reactive P includes mainly orthophosphate P that was desorbed from soil, leached from plant residues, and dissolved from recently applied fertilizer or manure. Bioavailable P is an estimate of P available to algae and aquatic plants over a short period of time, and includes dissolved P and P weakly retained by soil constituents. A significant portion of the sediment-bound P becomes available to algae over a longer period of time.

Sustained too high P application rates that increase soil P concentration to levels much higher than optimum levels for crops increase the risk of P loss. Incorporating P into the soil without significantly increasing soil erosion reduces P concentration at or near the soil surface and may reduce runoff P loss. Livestock production results in the generation of large quantities of manure that is a valuable nutrient source for producing high biomass yield. Manure can be used to minimize use of inorganic fertilizers and enhance production efficiency. Field rainfall simulations conducted in Iowa by Dr. Mallarino and collaborators during the last decade (see references) evaluated P loss shortly after applying fertilizer, poultry manure, or liquid swine manure P. The results showed that incorporation of P rates of about 100 lb P_2O_5 or higher into the soil significantly reduces P loss for runoff events shortly after application but not necessarily for delayed runoff events. Other short-term field rainfall simulation studies have shown that the P source also may impact relationships between manure P rate and runoff P. For example, a study conducted in 21 farmers' fields showed that P loss for beef and poultry manure were less than for liquid swine manure or fertilizer P for runoff events within one to two days after applying P without incorporation in to the soil.

This article summarizes recent short-term research and preliminary results of ongoing long-term research that has addressed or is addressing issues that were not investigated before in Iowa. A long-term study was established in Northwest Iowa to investigate effects of corn and soybean production, tillage, and fertilizer or manure P management system on crop yield and loss of soil and P with runoff. This research is important because field rainfall simulations are useful to study potential differences between management practices affecting P loss but estimate poorly long-term differences and total P loss. Another study used field rainfall simulations to evaluate in central Iowa the impacts of several crop and corn biomass harvest systems on P loss with surface runoff as affected by management based on fertilizers or liquid swine manure. Cellulosic biomass is being promoted for use in future bioenergy production systems as a better alternative to current grain-based systems. Cropping systems and partial or total corn biomass removal in addition to grain harvest changes crop P needs, crop residue, and P recycling. Both sediment and water losses may also be altered and these changes could result in increased P loss from fields.

Runoff P as affected by crop, harvest, and nutrient management systems

A rainfall simulation technique was used on 0.05-acre plots of an ongoing field study in the Agronomy and Agriculture Engineering Research Farm. The soil at the site is Clarion loam with 2 to 3 % slope. Treatments replicated three times are listed in Table 1.

Table 1. Crop, harvest, and nutrient management treatments for the runoff phosphorus rainfall simulation study in central Iowa.

Treatment Abbreviation	Cropping System	Nutrient Management	Harvest
CCgr-F	Continuous corn	Fertilizer N and P	Grain
CCst-F	Continuous corn	Fertilizer N and P	Grain + cornstalks
CCtot-F	Continuous corn	Fertilizer N and P	Total Biomass
CCgr-M	Continuous corn	Manure N and P	Grain
CCtot-M	Continuous corn	Manure N and P	Total Biomass
CSgr-M	Corn/soybean	Manure N and P to corn	Grain
SW-F	Switchgrass	Fertilizer N and P	Total Biomass
SW-Mh	Switchgrass	Fertilizer N/manure history	Total Biomass

Initial soil-test P was optimum (16 to 20 ppm by the Bray-1 test) for all treatments with the only exception of plots for the SW-Mh treatment, which tested very high (100 ppm or higher) because these plots had a long history of high liquid swine manure application. Both crops of the corn-soybean rotation were planted each year. The corn biomass was harvested at the same time of grain harvest (at 17 to 20% moisture). For the Cst-F treatment, cornstalks were baled immediately after grain harvest and chopping stalks. The nutrients were applied before spring tillage. The fertilizer management system (F) applied triple superphosphate (broadcast) and dribbled urea-ammonium nitrate (UAN) at rates recommended in Iowa (Sawyer et al, 2008). Manure management systems (M) applied N-based injected liquid swine manure from an underground pit. The spring tillage involved chisel-plowing and disking. The fertilizer or manure N rates for corn were 150 lb/acre for corn after soybean and 200 lb/acre for continuous corn. Fertilizer P was applied as needed to maintain an optimum soil-test P level (16 to 20 ppm by Bray-1 or Mehlich-3 tests) in the fall (first year) or spring (second year). We measured residue cover and soil P from depths of 0-2 and 2-6 inches. Rainfall was applied at 3 inches/hour to 30 sq-ft plots. Surface runoff was collected during 30 minutes, weighed, and analyzed for total solids, DRP, BAP, and total P.

Crop grain yields (not shown) in 2008 were very low due to delayed planting as a result of excessive rainfall in the spring. Yields were much higher in 2009, when the continuous corn plots managed with commercial fertilizer consistently yielded more (168 to 185 bu/acre) than continuous corn or corn after soybean with manure (115 to 147 bu/acre).

The concentration in runoff of DRP and BAP were higher in fall than in spring for all treatments (Fig. 1). Similar seasonal trends were observed for DRP and BAP loss per unit area (Fig. 2). Data in these two figures show that seasonal differences were not so consistent for total runoff P, however. The total P concentration in runoff was somewhat higher in spring for most treatments, but the total P loss was higher in the fall for most treatments. These results might be explained by the spring tillage, because soil disturbance increased soil loss and the loss of sediment-bound P. However, other factors such as different hydrological soil conditions and both greater residue cover and P leaching from residues in the fall may have contributed.

A clear result was that the concentrations of the three runoff fractions were consistently highest for CC managed with N-based manure and total biomass harvest (Fig. 1). In the fall, the second highest concentrations were for CC harvested for grain and with N-based manure. These results were explained by differences in applied P, soil-test P levels, residue cover, and sediment loss (not shown). Other treatment differences were small and often statistically not significant. The P concentrations tended to be lower for crops managed with fertilizer and for switchgrass, however, especially for total runoff P. Management system differences for runoff P loads were less consistent across seasons and statistically less significant than for P concentrations (Fig. 2), probably due to highly variable runoff across plots. In the fall however, loads for all runoff fractions were highest for continuous corn (CC) harvested for total biomass with N-based manure management, as was the case for concentrations. Runoff P loads tended to be lowest for grain crops managed with fertilizers and for switchgrass.

The management systems resulted in a wide range of soil-test P levels, which resulted in significant relationships between soil-test P and runoff P. As an example, Fig. 3 shows relationships for DRP and BAP concentrations in runoff. There were clear differences between seasons in the relative impact of a soil P increase on runoff P. This is demonstrated by steeper slopes of the linear trends in the fall. Runoff P loads showed similar trends but were more variable. Seasonal differences can be explained by spring tillage and higher proportions of DRP and BAP in the fall runoff. The tight relationships across all systems suggest that management system effects on runoff P were largely explained by the soil P levels associated with the different practices used.

Runoff P as affected by tillage, crop, and phosphorus management systems

This ongoing study is evaluating five systems listed in Table 2 at the Northwest Iowa State University Research and Demonstration Farm. The crop rotations and tillage systems were first established in 2006 and the nutrient management systems were first applied for the 2007 crops. Corn and soybean of Systems 1 through 4 are grown each year on separate plots, and the rotation over time is achieved by switching crops each year. All systems are replicated three times. Therefore, the study includes 27 plots that measure 20 feet wide by 100 feet long.

Table 2. Cropping and nutrient management treatments for the runoff phosphorus study with natural rainfall in northwest Iowa.

Treatment Abbreviation	Cropping System	Tillage System	Nutrient Management	Harvest System
FP-CH	Corn/soybean	Chisel-Disk	Fertilizer N and P	Grain
FP-NT	Corn/soybean	No-Till	Fertilizer N and P	Grain
MP-CH	Corn/soybean	Chisel-Disk	P-based Manure + Fertilizer N if needed	Grain
MP-NT	Corn/soybean	No-Till	P-based Manure + Fertilizer N if needed	Grain
MN-CH	Continuous corn	Chisel-Disk	N-based Manure	Grain+cornstalks

The P needed by crops of the corn soybean rotations is determined by soil testing and estimated P removal with harvest, and it is applied only once in the fall before corn. Initial Bray-1 soil-test P was 17 ppm (Optimum), and a rate of 100 lb P_2O_5/acre as fertilizer or manure has maintained soil P levels. Triple superphosphate is broadcast for all fertilizer P treatments but is incorporated in the spring only for the tilled systems. Liquid swine manure from an underground pit is injected into the soil in the fall for all plots of the manure-based systems. Fertilizer N (28% UAN solution) is injected in spring as needed for corn after soybean so that the total N applied is at least 150 lb N/acre and equal for all four systems. For System 5 (continuous corn), manure is applied at 200 lb total N/acre each fall. The crops of the corn-soybean rotations are harvested only for grain, and the continuous corn is harvested for grain and cornstalks by baling immediately after grain harvest.

Soybean yields have been statistically similar across systems (Table 3) except in 2008, when yields were highest for the two fertilizer-based systems (FP-CH and FP-NT). Soybean yield has not been impacted by tillage, which agrees with results from the long-term tillage and fertilizer placement study at this farm. The lower yield for the manure P-based systems in 2008 is not likely explained by P applied or P availability because in fall 2007 and 2008 soil-test P was similar for the fertilizer and manure systems. Corn yields often differed between systems. Yield of continuous corn managed with tillage (MN-CH) always was the lowest, being 20 and 13 bu less than FP-CH and MP-CH. Yield differences for corn after soybean were less frequent. Apparent small differences due to tillage or P management in

2007 and 2008 were not statistically significant. But in 2009, yield was highest for FP-CH, intermediate for FP-NT, and lowest for the two manure-based systems.

Table 3. Management systems effects on grain yield for the runoff phosphorus study with natural rainfall in northwest Iowa.

Management System †			Grain Yield		
Crop	Source	Till	2007	2008	2009
			-------------- bu/acre --------------		
Cs	FP	CH	184	166	194
Cs	FP	NT	180	160	177
Cs	MP	CH	177	175	170
Cs	MP	NT	177	158	170
CC	MN	CH	169	152	163
Sc	FP	CH	51	48	46
Sc	FP	NT	50	48	47
Sc	MP	CH	50	41	46
Sc	MP	NT	49	44	48

† Crop: Cs, corn after soybean; Sc, soybean after corn; CC, continuous corn. Source: FP, fertilizer P; MP, manure P; MN, manure N. Tillage: CH, chisel/disk; NT, no-till.

There were six runoff events with measurable water or soil loss for most plots in 2007, six in 2008, and only one in 2009. We are summarizing the 2010 results at this time. Figure 4 shows that average runoff P concentrations were lowest for DRP, intermediate for BAP, and highest for total runoff P. The P concentrations were higher for the corn years (soybean residue in corn-soybean rotations) than for the soybean years (corn residue). In the corn years the systems ranked similarly for DRP and BAP, with statistically higher concentrations for the fertilizer-based systems (FP-CH and FP-NT), intermediate for MP-CH, and lowest for the other systems. Total runoff P concentration (which reflects soil loss more than DRP or BAP) was highest for FP-CH and lower with small differences for the other systems. In the soybean years (corn residue), DRP and BAP concentrations were low and did not differ. The total runoff P concentrations were higher, however, and were much higher for the tilled systems than for no-till.

Figure 5 shows the P losses, which integrate treatment effects on runoff (water and soil losses) and runoff P concentrations. In the corn years, DRP and BAP losses were highest for the no-till and fertilizer-based system (FP-NT) and lowest for MP-NT, with no statistical differences between the other intermediate systems. The TP losses were highest for FP-CH and MP-CH, lowest for MP-NT, and intermediate with no statistical differences for the other two systems. In the soybean years, there were no statistical differences between systems for DRP and BAP, although losses of both fractions seemed highest for MP-CH. The total P loss was much larger with tillage than with no-tillage for fertilizer- or manure-based systems. The P loss data in Fig. 2 must be interpreted with care because the corn and soybean crops alternate over time but there is corn every year for the continuous corn. We do not show or discuss sums of P loss over years across crops because we do not have two complete corn-soybean rotation cycles for all plots. The available results suggest, however, that the P loss over a 2-year period was about similar for the systems managed with tillage, with small or no difference between the P-based and manure-N based systems.

Conclusions

Rainfall simulation harvest/cropping/nutrient management systems study

The P loss with surface runoff was highest for continuous corn harvested for total biomass in combination with N-based swine manure management. This result was explained by less residue cover, higher P application rates, and higher soil-test P than for other systems. Differences among other systems were smaller, inconsistent, and often not statistically significant.

Natural rainfall tillage/phosphorus sources study

The runoff P results for the early years of this study should be interpreted with caution because the systems had been established recently. Two clear and consistent results were that there was a much higher total P loss with tillage than with no-till with small or no differences between fertilizer and manure management systems, and that losses of all runoff P fractions were much higher for the corn year than the soybean year. Another clear result was that dissolved and bioavailable P losses were the highest for the no-till and P fertilizer based system in the corn years, which was explained by broadcast fertilizer application before no-till corn. The differences with the other systems were smaller, however, and this result was not observed in the soybean years. On the other hand, the total P loss was two to three times higher than the dissolved and bioavailable P losses.

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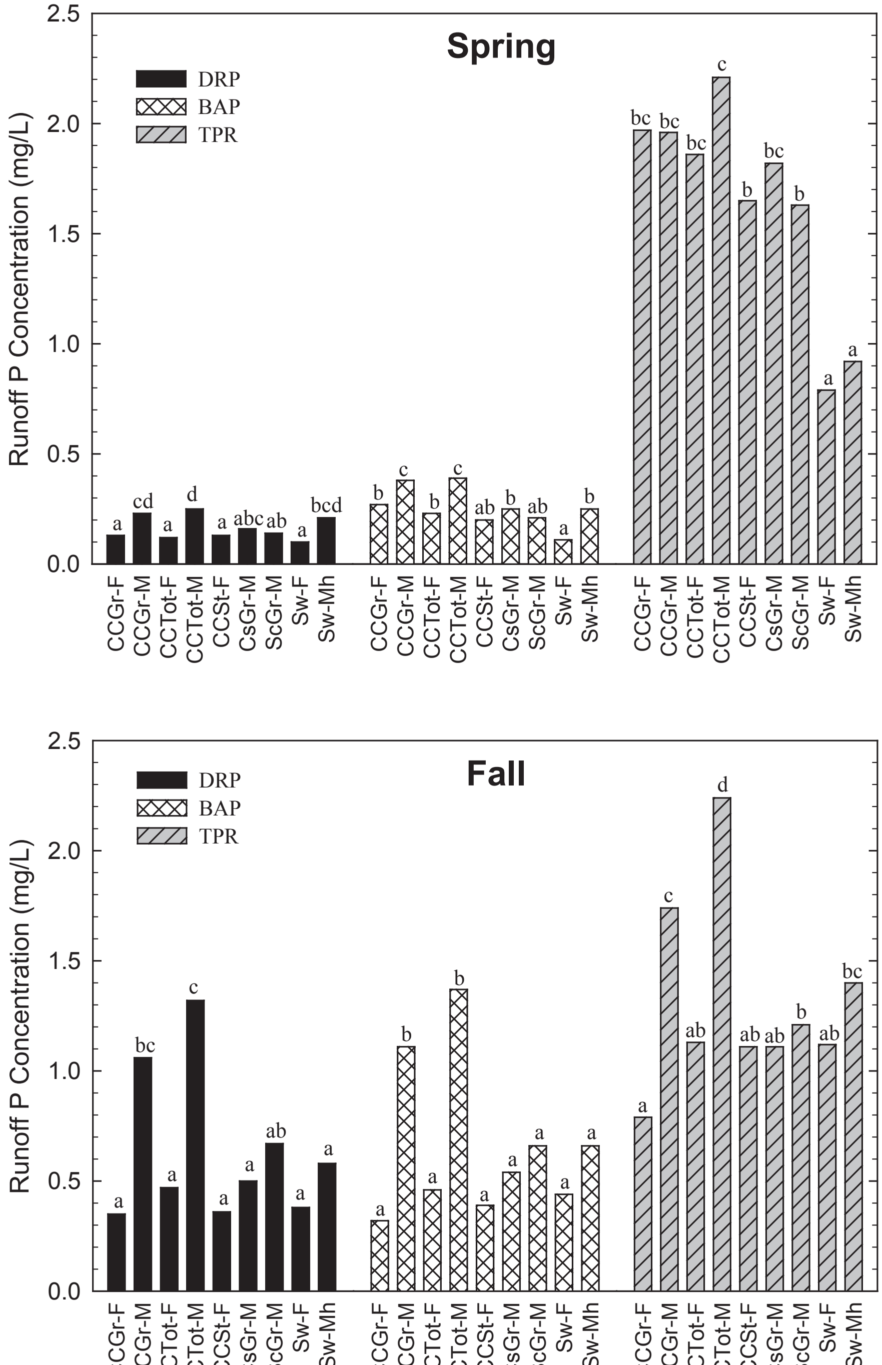

Figure 1. Surface runoff P concentrations by season for the central Iowa study. Bars with different letters differ statistically. Crop names indicate the residue to which simulated rainfall was applied. CC, continuous corn; Gr, grain harvest; Cs, corn after soybean; Sc, soybean after corn; Tot, total biomass harvest; St, grain plus stover harvest; Sw, switchgrass; Mh, manure history; F, fertilizer application; M, N-based manure.

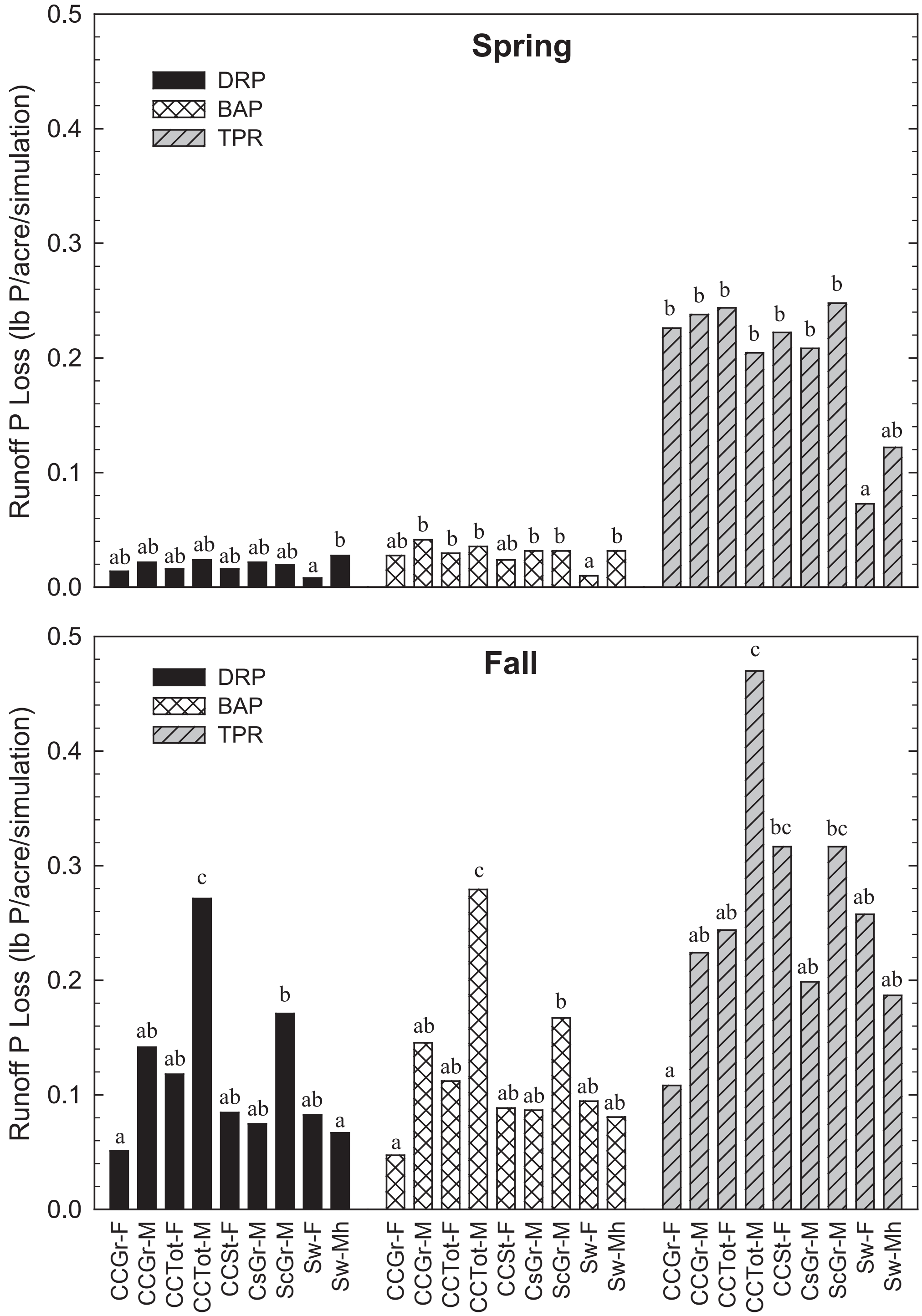

Figure 2. Surface runoff P loads by season for the central Iowa study. Bars with different letters differ statistically. Crop names indicate the residue to which simulated rainfall was applied. CC, continuous corn; Gr, grain harvest; Cs, corn after soybean; Sc, soybean after corn; Tot, total biomass harvest; St, grain plus stover harvest; Sw, switchgrass; Mh, manure history; F, fertilizer application; M, N-based manure.

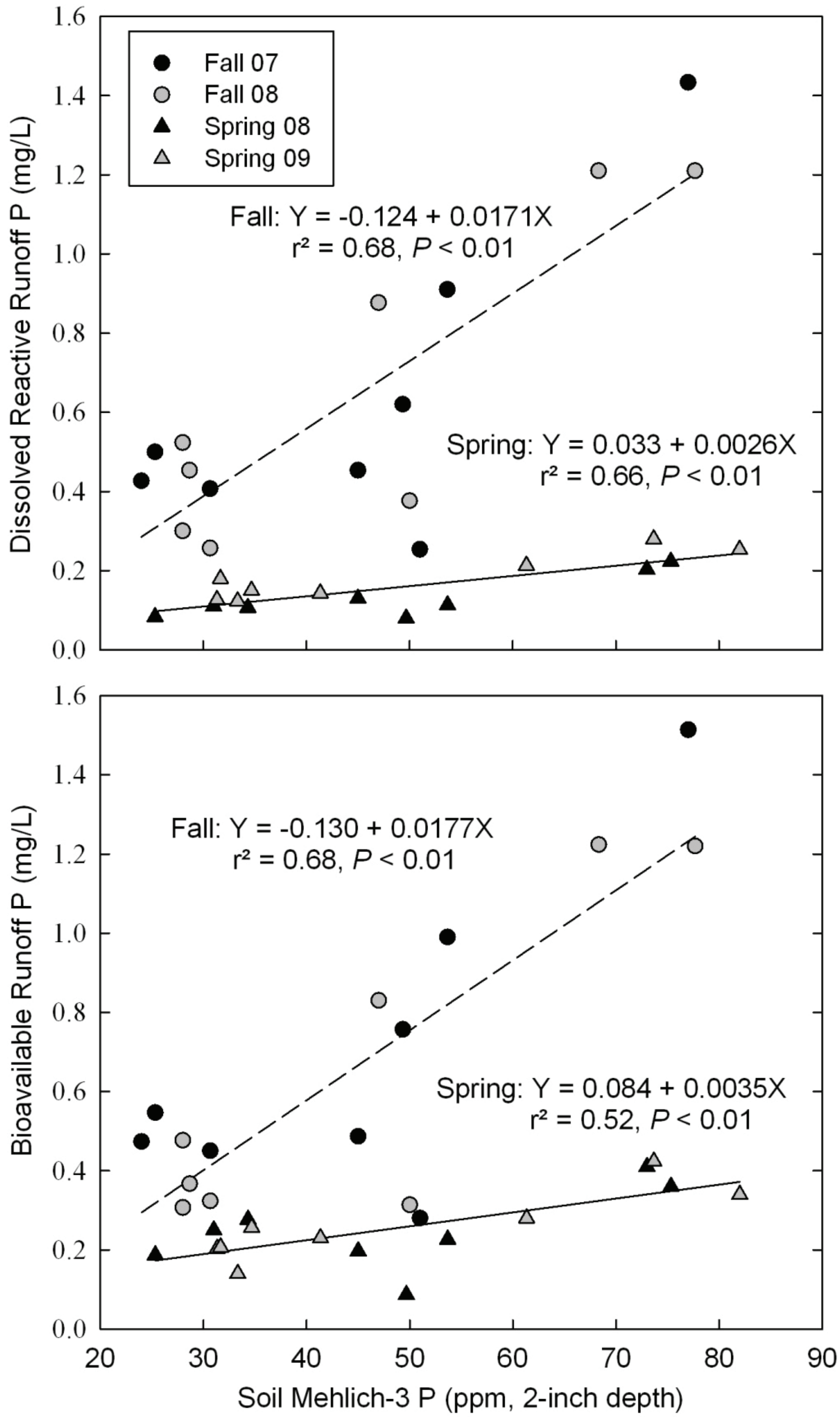

Figure 3. Relationships between soil P and dissolved and bioavailable P concentrations in surface runoff for the central Iowa study.

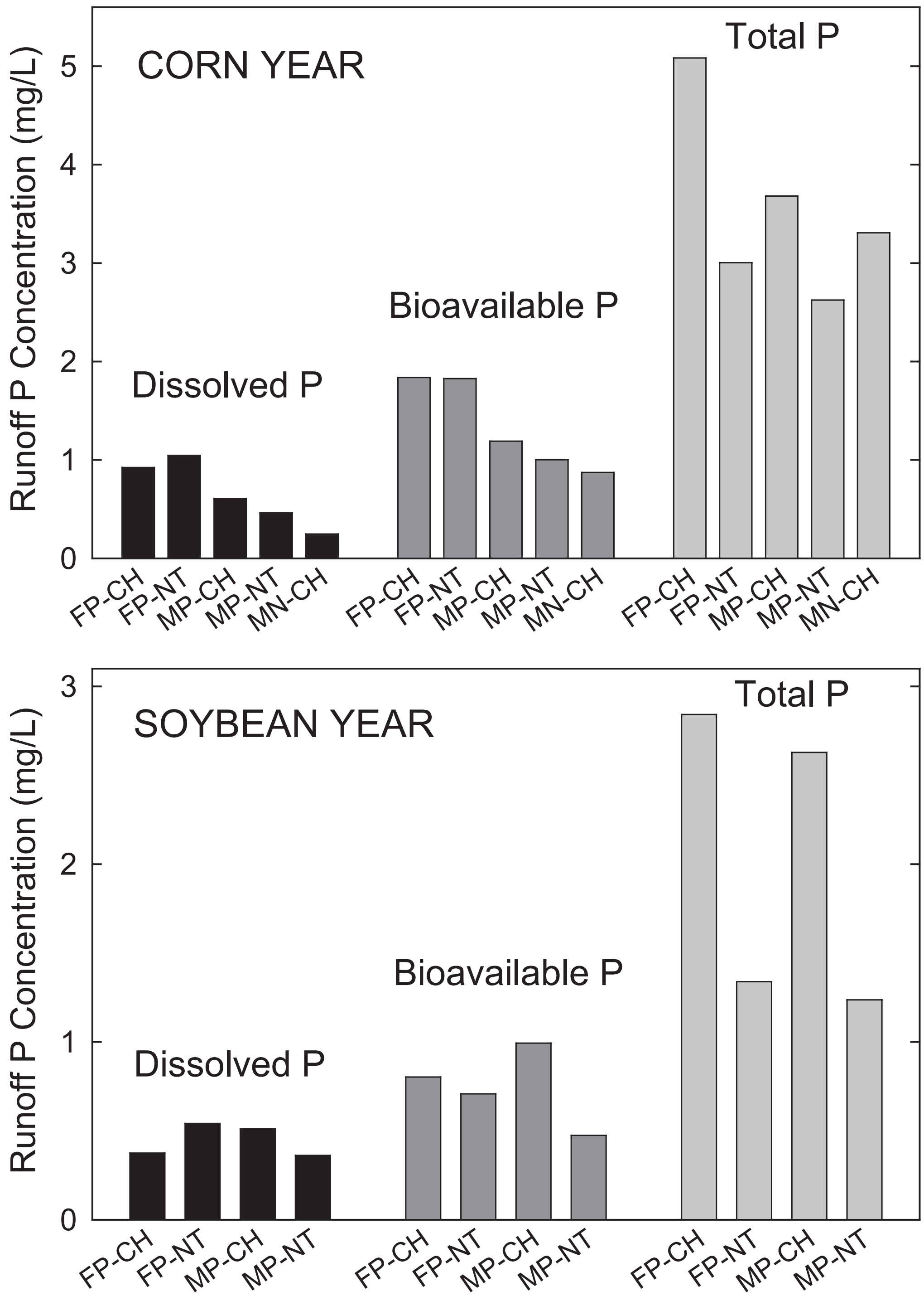

Figure 4. Runoff P concentrations for the northwest Iowa study (annualized averages across the entire length of the project). CH, chisel/disk tillage; FP, fertilizer P and N; MN, swine manure N for continuous corn; MP, swine manure P and N as needed; NT, no-till.

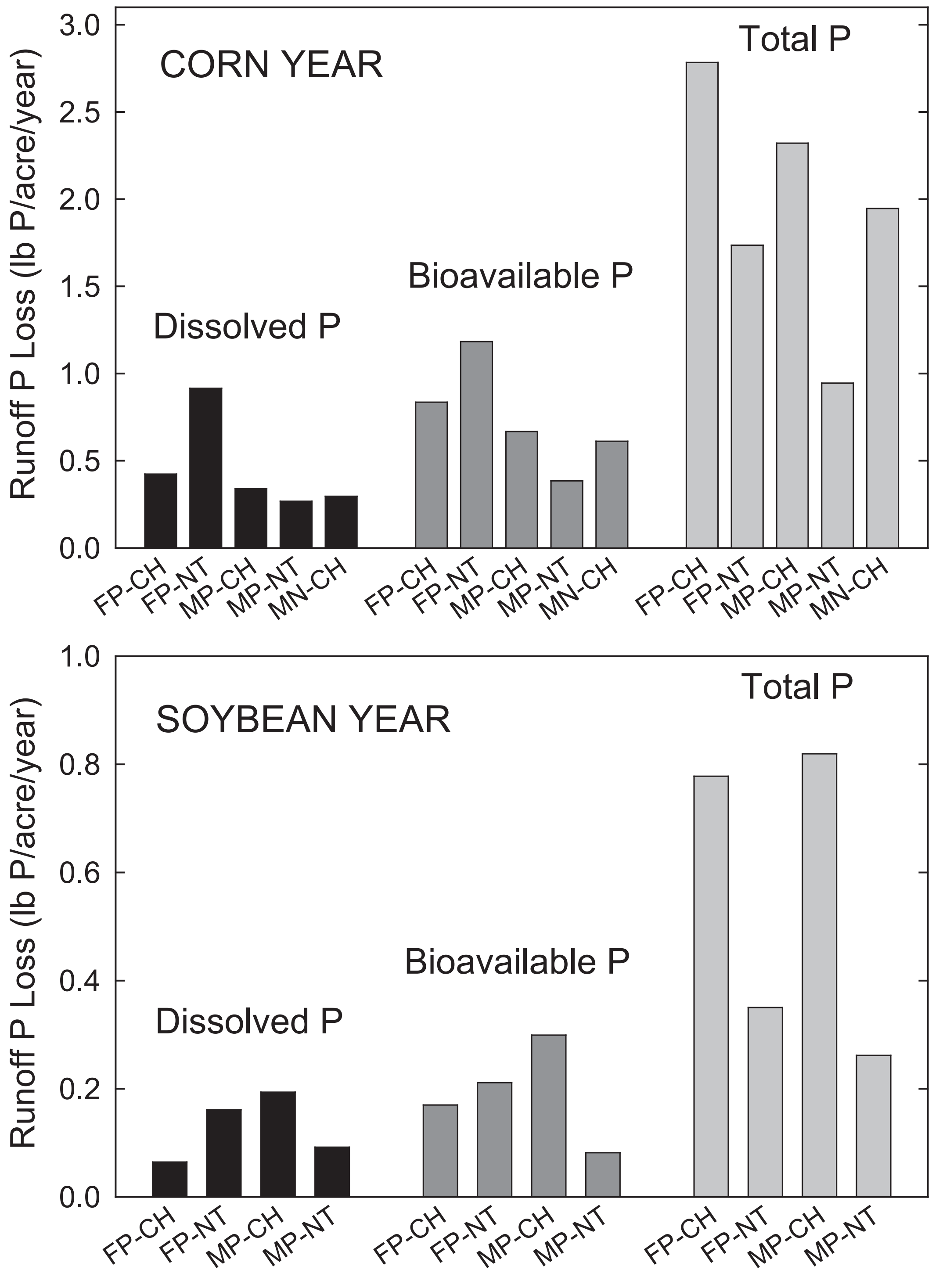

Figure 5. Runoff P loss for for the northwest Iowa study (annualized averages across the entire length of the project). CH, chisel/disk tillage; FP, fertilizer P and N; MN, swine manure N for continuous corn; MP, swine manure P and N as needed; NT, no-till.