RELATIONSHIPS BETWEEN SOIL P AND P IN SURFACE RUNOFF AND SUBSURFACE DRAINAGE: AN OVERVIEW OF ONGOING RESEARCH

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Introduction

Nonpoint source pollution from agricultural fields has the potential to accelerate eutrophication of freshwater ecosystems. In a report of water quality in the United States, the Environmental Protection Agency sited agriculture as the primary source of pollution in 60% of impaired river miles, 30% of the impaired lake acres and 15% of estuarine square miles (EPA, 1998). Phosphorus, in particular, has received much attention due to its role as limiting nutrient in many freshwater ecosystems (Correll, 1998). The application of P as inorganic fertilizers or manure is a common practice to maintain soil P at levels that optimize crop growth. However, soil P levels in many areas of the country are now above levels required to optimize crop production (PPI, 2001). This increase in soil P levels increases the risk of limnologically significant P concentrations reaching surface waters and accelerating eutrophication.

The purpose of agronomic soil P testing is to estimate the amount of P available for crop uptake. Different soil tests are used as indices of available P and are calibrated using several years of yield response experiments. From these experiments soil-test interpretations and nutrient recommendations are made. In recent years, an increasing concern about nonpoint source pollution from agriculture has prompted questions about the suitability of agronomic soil tests for environmental purposes. Several soil extraction procedures have been proposed as environmental soil P tests that in theory result in better estimates of potential P loss to water resources. For example, the iron-oxide impregnated strip test (Menon et al., 1989) uses a sink approach to extract dissolved and bound soil P that may be available to aquatic organisms. The water extraction test (Pote et al., 1996) provides an estimate of dissolved and very weakly bound soil P that may be lost when the soil comes into contact with rain water.

This presentation provides an overview of preliminary results of ongoing Iowa research that focuses on studying relationships between soil P (measured with both agronomic and environmental soil tests) and P concentrations in surface runoff and subsurface drainage.

Overview of Methods

Research is being conducted using a variety of methods, which include field trials under natural rainfall as well as indoor and outdoor rainfall simulations. In all studies, soil P was measured with the Bray-1 (BP), Olsen (OP), Mehlich-3 (M3P) agronomic tests and with the iron oxide-impregnated paper (FeP) and water (WP) environmental tests. The soil sampling depth varied across studies, and was 5 or 15 cm. The extracted P always was measured with a colorimetric determination method (Murphy and Riley). The P analyses in surface runoff and subsurface drainage varied depending on the study, and included one or more of total P (TP), total dissolved

P (TDP), bioavailable P (BAP) determined with the iron oxide-impregnated paper test, and dissolved reactive P (DRP) determined with the Murphy and Riley colorimetric method.

One ongoing study is based on three field trials located in central and northeast Iowa. These trials evaluate a variety of soil and nutrient management practices for the corn-soybean rotation and treatments include various application rates of P fertilizer, liquid swine manure, or poultry manure. All plots had subsurface drainage tiles installed through the center of each plot. Automated sampling devices collect water samples on a weekly basis from the onset of tile flow in early spring until water flow subsided in late summer or fall. Additionally, surface runoff capturing devices were installed on plots of one of the trials to collect all the runoff into large tanks. The treatments in this trial are nonfactorial combinations of three application rates of liquid swine manure, two placement methods, and three times of application. The manure is injected in the fall or spring of each year, or is broadcast during late winter before soil thawing. The runoff is analyzed for TP and TDP.

A second study was based on an indoor rainfall simulation technique, and examined the relationship between soil P and runoff for five typical Iowa soils. Bulk samples of the surface layer of the soil series Marshall, Nicollet, Fayette, Tama, and Harps with low soil P were incubated with different P fertilizer rates (mono-ammonium phosphate) for one month. The P treatments created a range of BP after the incubation period ranging from 3 to 530 mg kg^{-1}. Boxes with soil packed at a uniform density were rained on for 70 min. Soil samples were collected before the simulation, and surface runoff samples were collected throughout the simulation. The surface runoff was analyzed for TP, BAP, and DRP, and the drainage water was analyzed for DRP.

A third ongoing study is based on an outdoor rainfall simulation following the guidelines established by the National P Runoff Project to further examine the relationship between soil P and P in surface runoff. The simulations are conducted on plots of a field experiment that evaluates various application rates of poultry manure for the corn-soybean rotation. Microplots (1.5 x 2 m in size) delineated within large field plots are rained on at a rate of 70 mm hr^{-1} and surface runoff is collected during 30 min. The runoff was analyzed for BAP and DRP (TP analyses have not been completed at this time).

Relationship Between Soil Phosphorus and Phosphorus in Surface Runoff

Field Trials

Total dissolved P in surface runoff collected from the field experiment with liquid swine manure increased with increasing soil P measured by the five soil tests. Total dissolved P ranged from 0.03 to 3.9 mg L^{-1} across all treatments and runoff events (14 runoff events occurred during the season). As an example, Fig. 1 shows the relationships for TDP means for the season and for the M3P and WP tests for soil samples collected from a 0-5 cm depth. Total dissolved P increased at a higher rate at higher soil P values, and curvilinear trends explained a significantly (*$P<0.01$*) larger proportion of the variability compared with the linear trends for all soil tests. However, observation of the data points suggests that curvilinear trends were the result of one high data point. Total dissolved P concentrations in surface runoff for M3P values of 20 mg kg^{-1} or less ranged from 0.25 to 0.35 mg L^{-1}. These M3P values corresponded to 17 to 20 mg kg^{-1} at a 0-15 cm soil sampling depth, which is within the optimum range for crop production (16-20 mg kg^{-1} for the BP or M3P tests). Total P ranged from 0.07 to 15 mg L^{-1} across all treatments and runoff events. The mean seasonal TP concentration in runoff samples also increased with increasing soil P (Fig.1), and was two to eight times greater than TDP. This result indicates that sediment bound P was the dominant form of P leaving the field. Both TDP and TP in runoff were significantly greater for the broadcast treatments than for all other treatments. This result suggests that the injection process in our study did not create large increases in erosion and sediment-bound P loss with surface runoff, and that it markedly reduced P loss.

Indoor Rainfall Simulation

The indoor rainfall simulation study showed that TP, BAP, and DRP in runoff increased linearly with increasing soil P measured by all agronomic and environmental soil tests. The slopes of the relationships between BAP or DRP were similar for four of the soils independently of the soil P test used. However, the slope for the Harps soil was similar to the other soils for some tests and different for other tests. The BP and M3P agronomic tests and the FeP environmental test showed a slightly steeper slope for the Harps soil compared with other soils. The OP agronomic test and the WP environmental test showed either similar slopes for all soils or slightly smaller slope for the Harps soil compared with the others. As an example, Fig. 2 shows the relationship between BAP or DRP in runoff and soil P measured with the M3P or WP tests.

The steeper slopes for BP, M3P, and FeP seem to be the result of less P extraction by these tests in this calcium carbonate-affected soil. It is also noteworthy that BAP and DRP concentrations in runoff from the Harps soil were significantly greater than for the other soils at the higher soil P concentrations. The differences in relationships between soil tests and the larger BAP and DRP in runoff for the Harps soil likely are explained by the particular characteristics of this soil. This soil is calcareous and had the lowest extractable Fe and Al concentrations of all soils (not shown). Contrary to what we expected, the data suggest that extractable Fe and Al still dominate P reactions relevant to P loss measured as BAP and DRP in this calcareous soil.

Data from unfertilized controls showed that when soil P was in the optimum agronomic class or lower, DRP concentrations were less than 0.10 mg L^{-1} and that BAP ranged from 0.12 mg L^{-1} to 0.22 mg L^{-1} across soils. In most conditions, P concentrations greater than 0.10 mg L^{-1} are considered detrimental to freshwater ecosystems (Correll, 1998). The concentration measured for these low testing soils suggest that if soil P levels are around optimum levels, dissolved P will be near acceptable levels. However, the impact on surface water bodies will also be affected by larger loss of particulate P with sediment, which is not considered in this indoor rainfall simulation study.

Outdoor Rainfall Simulation

Results of the outdoor rainfall simulation study with plots that receive several application rates of poultry manure showed that both BAP and DRP in surface runoff increased linearly with increasing soil P measured by all soil tests. Figure 3 shows the relationships for the M3P test as an example. The DRP concentration in runoff at values near optimum soil P values for crop production usually were less than 0.05 mg L^{-1}. These results confirmed results of the indoor rainfall simulation study. Concentrations of BAP in runoff would be 0.10 to 0.11 mg L^{-1} for soil P concentrations near the optimum class.

Relationships Between Soil Phosphorus and Phosphorus in Subsurface Drainage

Study of the relationship between DRP in subsurface drainage water and soil P across all field studies is showing low DRP concentrations and no significant trend when the agronomic tests indicated soil P levels up to four times greater than needed for optimum crop production. All agronomic and environmental soil tests showed similar relationships between DRP and soil P. Figure 4 shows, as an example, relationships between mean seasonal DRP concentrations and soil P (0-15 cm) measured by the M3P or WP tests across plots of all trials. Phosphorus concentrations (less than 0.04 mg L^{-1}) were considerably lower for tile P compared with concentrations observed in runoff at high soil P concentrations, and there was no relationship with soil P up to concentrations as high as 80 to 100 mg P kg^{-1} (BP or M3P tests). These DRP concentrations in tile drainage are similar to those reported before from other research with tile drainage in Iowa (Baker et al., 1975). However, other researchers have reported significantly higher P concentrations in tile drainage. Sims et al. (1998) cited several studies in which higher P concentrations in tile water were related with sandy or organic soils. Hesketh and Brooks (2000) found increased P concentrations in tile water when OP tests were above 57 mg kg^{-1}. McDowell and Sharpley (2001) found a change point at 193 mg kg^{-1} of M3P above which the P concentration in subsurface drainage started to increase with increasing soil P. Ongoing research at higher soil P concentrations will provide additional information concerning relationships between soil P and DRP concentrations in tile water for Iowa conditions.

Conclusions

Ongoing research indicates that increasing soil P values above optimum levels for crop production increases P loss with runoff. Available data at this time suggest that both agronomic and environmental soil P tests are useful to describe these relationships and to approximately predict dissolved or bioavailable P loss. Discrepancies among soil tests were small and were observed only under particular conditions (such as in a highly calcareous soil). Available data do not allow for general conclusions concerning the shape of relationships between dissolved P loss and soil P (linear or curvilinear). Concentrations of dissolved P in subsurface drainage were considerably lower than concentrations in surface runoff. The data indicated low DRP concentrations in tile water and no significant relationship with soil P when soil-test P was up to four times greater than needed for optimum crop production. Ongoing research will provide additional information on relationships between soil P and P loss with surface runoff and subsurface drainage.

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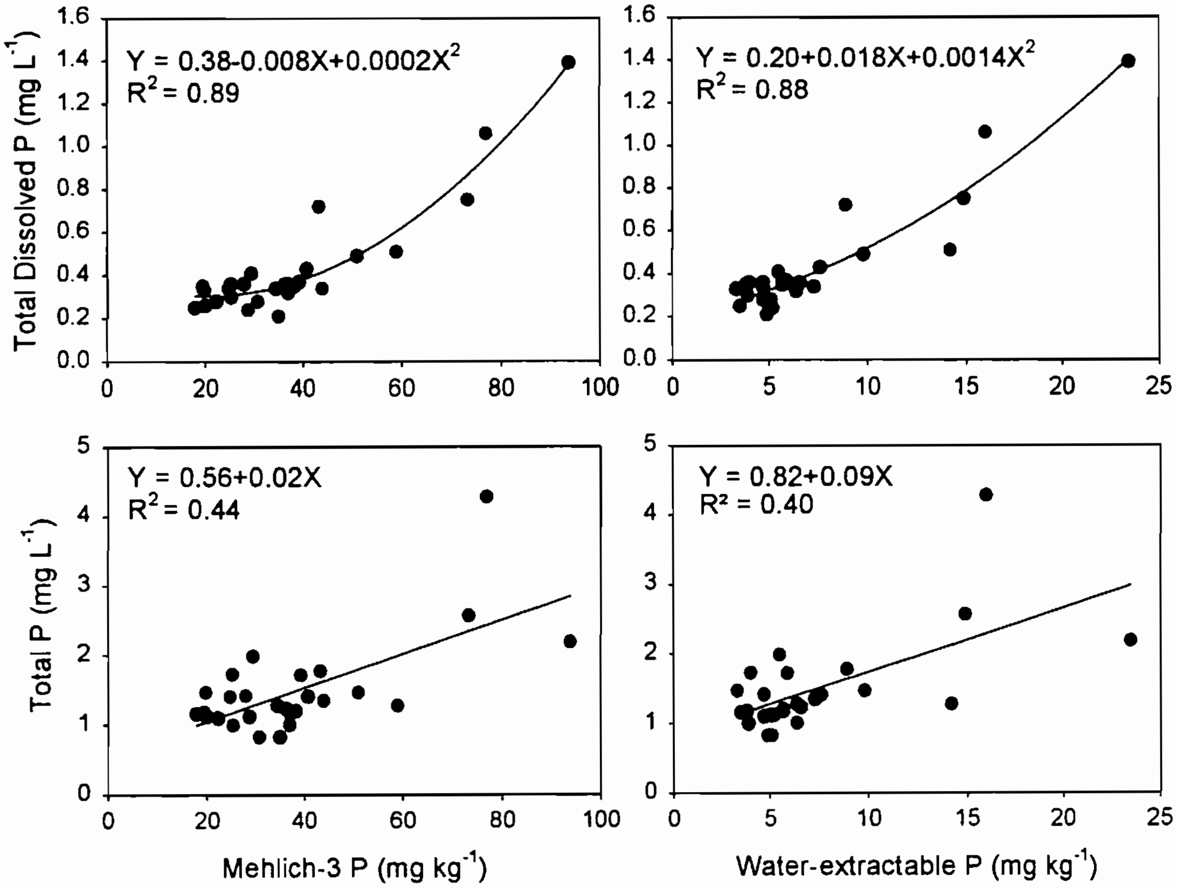

Fig. 1. Relationships between Mehlich-3 or water-extractable soil P and total dissolved P or total P in surface runoff from Nicollet-Webster soils under natural rainfall.

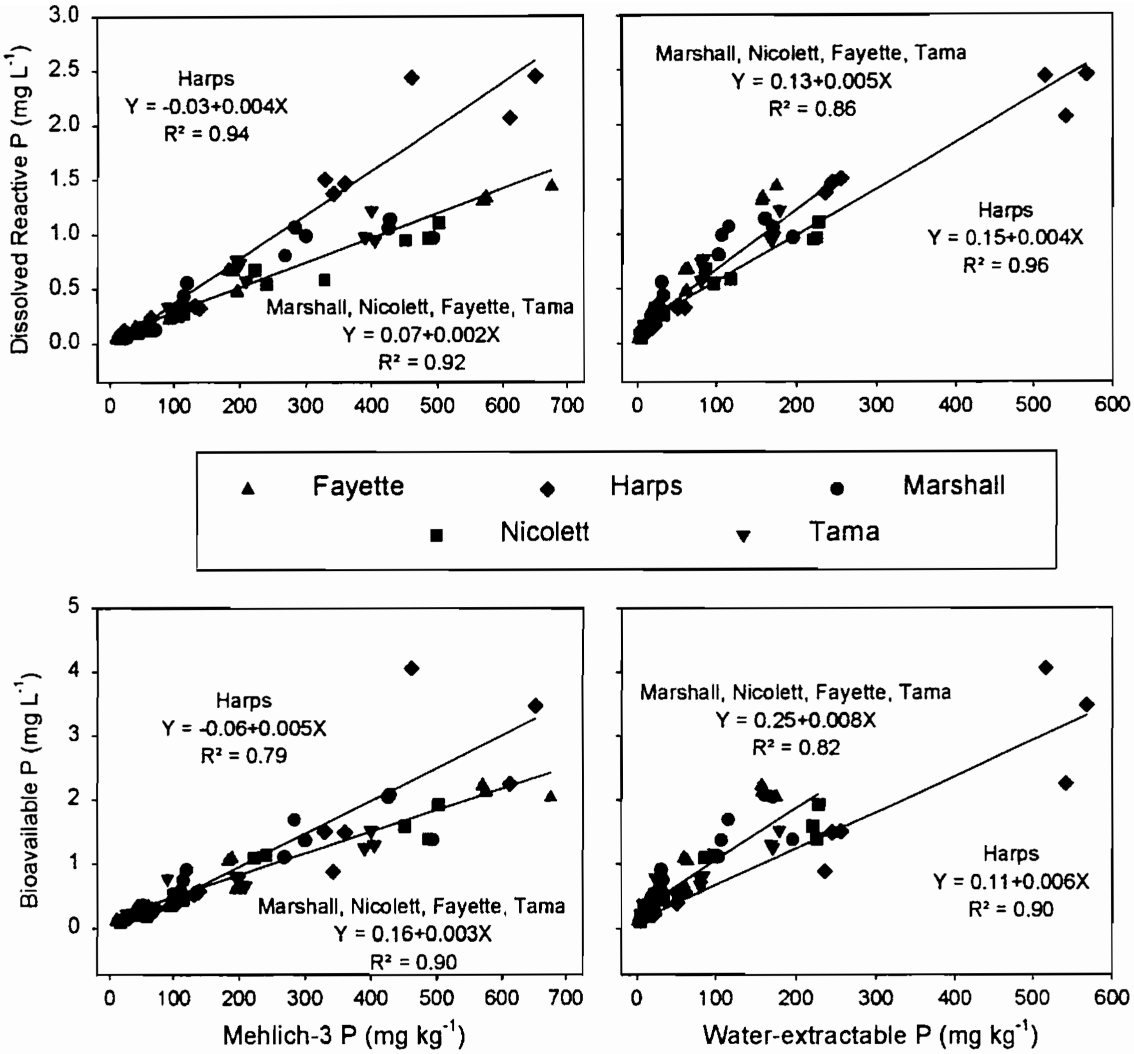

Fig. 2. Relationship between Mehlich-3 or water-extractable P and dissolved reactive P or bioavailable P in surface runoff from five typical Iowa soils assessed using an indoor rainfall simulation technique.

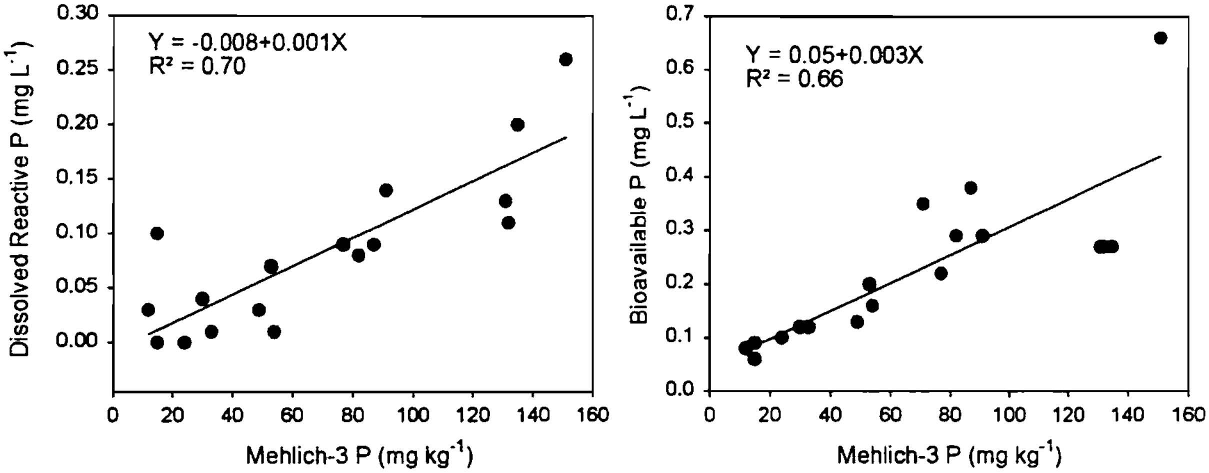

Fig. 3. Relationship between Mehlich-3 P and dissolved reactive P or bioavailable P in surface runoff from Clarion-Nicollet soils that received several rates of poultry manure the previous year (outdoor rainfall simulation).

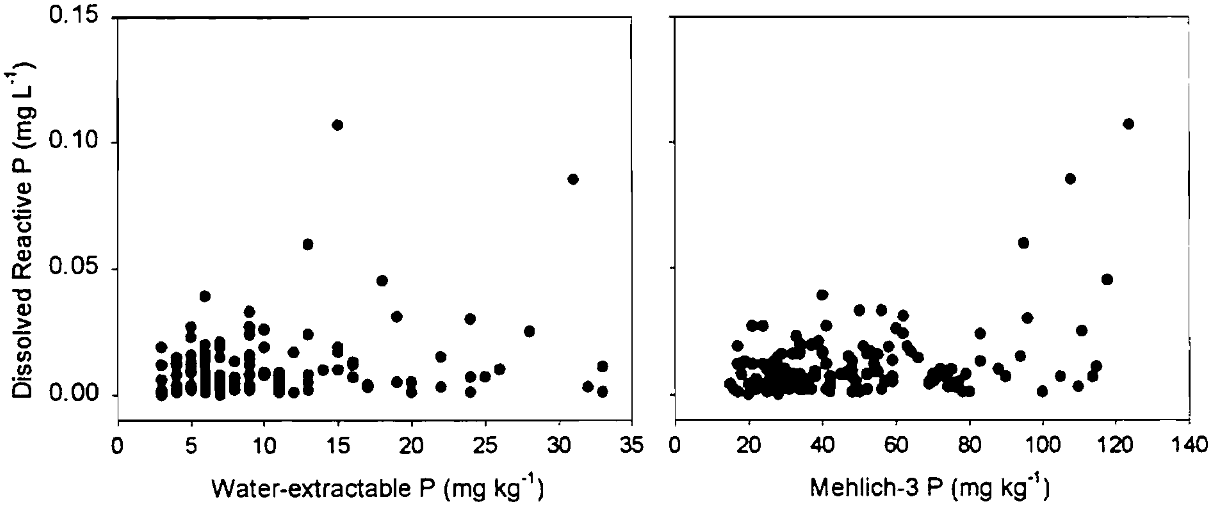

Fig. 4. Relationship between dissolved reactive P in tile drainage and Mehlich-3 or water-extractable soil P across three sites, three years, and various annual P fertilizer and manure treatments.

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