IMPACTS OF MANAGEMENT, MOISTURE AND PHOSPHORUS FORM ON PHOSPHORUS LOSS POTENTIAL

A.S. Berg[1], C.A. Baxter[2], D.L. Nussbaum Wagler[3], and B.C. Joern[1]
[1]Purdue University, West Lafayette, Indiana
[2]University of Wisconsin-Platteville, Platteville, Wisconsin
[3]Madison, Wisconsin

Abstract

Phosphorus (P) is considered one of the major nutrients contributing to degradation of water quality in the United States. Our objectives were to examine P loss potential associated with: 1) high moisture conditions, 2) application (surface and incorporated) of manure from animals fed different diets and 3) sorption dynamics of inorganic and organic P compounds. The study of high moisture conditions evaluated the effects of near surface moisture conditions (wet and saturated), time (up to 28 days incubation), and an incorporated manure application on: 1) redox potential (Eh) measured at 2 and 10 cm from the soil surface, 2) porewater chemical composition, 3) sediment and chemical composition of runoff, and 4) the distribution of soluble P, plant-available P, and oxalate-extractable P, Al, and Fe in surface soil. The objective of the manure application study was to determine the effectiveness of phytase and high available phosphorus (HAP) corn on reducing P concentrations in animal manure and their subsequent effects on runoff P losses from three benchmark soils (Creldon silt loam, Cecil clay loam, and Sleeth silt loam) receiving these manures as either a surface or incorporated application. The final study investigated P sorption dynamics when P was added as inorganic P ($NaH_2PO_4*H_20$) or organic P (inositol hexaphosphate, IP_6; or adenosine triphosphate, ATP). We also determined whether these organic P sources compete with inorganic P for soil sorption sites in these three soils. A summary of the results and implications of these studies is presented in this paper.

Introduction

Water quality impairment from runoff phosphorus (P) losses continues to affect agriculture in the United States. Recent regulations to improve manure management on concentrated animal feeding operations (CAFOs) should reduce P losses from agricultural land (USEPA, 2001). To optimize the land base needed for manure application and minimize the potential losses of nutrients to surface waters, several states have developed nutrient loss risk indices. These indices allow producers to determine the best areas for manure application based on a variety of soil properties and management factors, instead of just one factor such as soil test P level. The development and implementation of management practices that reduce future losses of sediments and nutrients is dependent on a better understanding of the mechanisms by which these materials are transferred from agricultural soils to surface waters. Dissolved and particulate forms of P may be present in runoff, and both runoff volume and sediment losses can be impacted by soil moisture. In the Midwestern U.S., the majority of runoff occurs during spring when soils are partially frozen, wet, or saturated. Therefore, a better understanding of sediment P losses under high-moisture conditions is important for developing and implementing management practices that will minimize runoff losses of sediment and nutrients during this time period.

In some areas, land application of manure occurs regardless of soil test P values. Balancing P on the farm by improving animal diet P inputs to reduce manure P excretion will benefit livestock producers. However, little is known about the effects of these diets on runoff P losses when manures are applied to soils on a nitrogen basis. Improving our understanding of the relative impacts of diet manipulation compared to manure application method will further our ability to develop optimum management strategies to reduce P losses from soils to surface waters.

Phosphorus loss potential may also depend on the specific P form(s) added to a soil, as not all P compounds are sorbed to soil equally. This issue may be especially important when manures that contain a mixture of P compounds are added to soils. Determining the P sorption capacity of soils for different P compounds when applied either individually or as a mixture will improve our understanding of how these P compounds interact in soils. This information may help us better understand how to manage or treat livestock manures to minimize P loss potential.

Materials and Methods

Moisture Effects Study

This experiment consisted of 12 runoff boxes (31 cm wide x 45 cm long x 40 cm deep) packed with a Chalmers silt loam soil (20 cm deep) and acid washed sand (15 cm deep) to a bulk density of 1.3 g cm^{-3} arranged randomly beneath a rainfall simulator. Two soil treatments were used: 1) swine slurry applied at a rate of 200 kg N ha^{-1} (SS) and 2) Control with no added P. Six runoff boxes were prepared for each treatment. Three boxes from each treatment were subjected to a saturated (SAT) condition where the water table was maintained 2 cm from the surface (matric potential = -0.2 kPa), while the remaining three were subjected to a wet but not saturated (WET) condition where the water table was maintained 18 cm from the soil surface (matric potential = -1.8 kPa). These two moisture conditions were chosen to provide differences in aeration and redox potential, and neither condition allowed free drainage to occur. The soils were incubated under the two moisture conditions for 28 days. Soil redox potential was measured daily throughout the 28 day incubation period at depths of 2 and 10 cm from the surface. At 1, 7, 14, and 28 days, porewater (SAT boxes only) and runoff samples were collected. At the end of the 28 day incubation, the boxes were allowed to drain freely and samples were collected from 0-5, 5-10, 10-15, and 15-20 cm and analyzed for various soil P parameters. Rainfall simulations were conducted with deionized water using a Teejet nozzle (HH-SS-50WSQ), mounted 3.05m (10 feet) above the soil surface. A target rainfall intensity of 75 mm h^{-1} was used and runoff was collected for 30 minutes.

Diet and Manure Application Study

The surface 20 cm of three benchmark soils (Table 1) were sieved (< 2 cm), thoroughly mixed, and stored in plastic containers. Manure for this project was collected from swine and broiler chickens fed either a standard industry diet (High P) formulated to match current National Research Council nutrient recommendations or a low P diet (Low P) formulated with low phytic acid corn and the phytase enzyme. Soils were packed into runoff pans (20 cm wide x 100 cm long x 5 cm deep) at a bulk density of 1.3 g cm^{-3}. Surface manure was applied after soil pans had been packed. Incorporated manure was mixed with soil using a portable cement mixer on a weight basis, then packed into pans. Manure was applied at a rate to provide 224 kg N ha^{-1} (200 lbs acre^{-1}), and the manure rate remained constant throughout the experiment to ensure a consistent P-rate. The incorporated manure rate was 50% of the surface applied manure rate since an incorporation depth of 10 cm (4 in) was assumed and the soil pan depth was 5 cm (2 in). Twenty-four hours following the manure applications, pans were brought to 5% slope, covered with a permeable membrane to minimize rainfall impact, and exposed to a 5 min. pre-wet rainfall event at an intensity of 75 mm hr^{-1} using deionized water. Twenty-four hours after the pre-wet the first rainfall was applied for a duration sufficient to collect 30 min of runoff; two more rainfall simulations were conducted with 24 hr between each rainfall event. Soil and runoff samples were analyzed for various P parameters.

Phosphorus Sorption Study

Phosphorus sorption by benchmark soils was determined when P was added as inorganic P ($NaH_2PO_4*H_20$, P_i) or organic P (inositol hexaphosphate, IP_6; or adenosine triphosphate, ATP). A 24-hour P sorption isotherm (0.01 M NaCl, 1:25 m:v, 25°C) was performed with six P concentrations (0, 6.45, 16.13, 32.26, 161.3, and 323 µmol P L^{-1}) for all P sources. To determine competitive sorption between inorganic P and the organic P sources, a similar isotherm was completed with seven P concentrations (0, 6.45, 16.13, 32.26, 161.3, 323, and 646 µmol P L^{-1}) with equimolar P contributions from inorganic and organic P. Solutions were corrected for ionic strength differences using NaCl, and the pH was adjusted to the soil-water pH of the soil. Isotherm supernatants were filtered (0.45 µm) and analyzed for pH and total P using standard protocols, while orthophosphate and the organic P compounds of interest were assayed using ion chromatography.

Summary and Implications

Moisture Effects Study

This study allowed several observations to be made regarding the effects of soil moisture, swine slurry applications, and time on P dynamics in porewater, runoff and soil. Soil redox potentials were strongly influenced by moisture conditions at both the 2 cm and 10 cm electrode depths (Figure 1). Application of swine slurry resulted in lower Eh measured at 10 cm under the WET condition, but did not significantly change Eh under other moisture-electrode depth combinations. Porewater Eh decreased significantly with time and was slightly lower in the SS treatments compared to the Control treatments. Porewater pH decreased from initial values of 7.2-7.3 to near neutral values at 14 days. Increased incubation time increased porewater Fe, dissolved reactive P (DRP), and total P (TP). Increases in Fe, DRP and TP were attributed to reducing conditions affecting the solubility of Fe-oxides. Swine slurry addition increased porewater DRP and TP.

Infiltration measured as the ratio of cm runoff:cm rainfall was similar for all runoff events. Under the WET condition, infiltration was greater in the SS treatments compared to the Control treatments, and was attributed to the positive effect of swine slurry on resisting dispersion and surface sealing, which was most likely due to the slurry supplying electrolytes which increased flocculation. Runoff sediment load (SEDL), pH, and total P load (TPL) were consistently greater for soils under the SAT moisture condition compared to soils under the WET condition. The increase in SEDL and TPL under the SAT condition was attributed to decreased soil strength and increased erosion, while increased runoff pH was attributed to release of OH^- during reductive dissolution of Fe-hydroxides. Runoff dissolved reactive P load (DRPL) was significantly greater in SS treatments under the SAT moisture condition compared to the Control treatment under the WET condition (Figure 2).

Comparisons of initial and post incubation soil samples showed that dilute salt extractable P (DSP) values significantly decreased in soils incubated under the SAT condition for 28 d, and was attributed to the greater ammonium oxalate extractable Fe (Fe_{ox}) measured in these soils. The addition of swine slurry increased Bray-P1, ammonium oxalate extractable P (P_{ox}), and P saturation index (PSI) in pre- and post-incubation soil samples. Soil Fe_{ox}, P_{ox}, and PSI generally decreased with depth.

This study indicates that high-moisture conditions have a significant impact on sediment, P losses in runoff and on nutrient dynamics in soil. Decreased infiltration and increased sediment, dissolved and total P losses were observed in soils maintained under a saturated condition compared to a wet, but not saturated, condition. The increased erosion and nutrient losses from saturated soils can be attributed to decreased soil strength under the saturated condition, to changes in nutrient dynamics caused by reducing conditions, and by larger zones of interaction between rainfall and saturated soil. Due to the impact of moisture condition on P losses and on nutrient dynamics, we suggest that further work investigating runoff nutrient losses from soils should control or account for moisture conditions that reflect typical soil moisture conditions when runoff occurs. This study also showed that incorporated swine slurry applied at a rate of 200 kg N ha^{-1} (42 kg P ha^{-1}) increased P losses in runoff and increased the concentration of P in soil and porewater in the Chalmers soil, but results from a previous experiment using a different soil and slightly higher P rates showed little effect on nutrient losses due to incorporated manure or inorganic fertilizer applications.

Based on these results, measures to control sediment and nutrient losses should focus on areas prone to wet or saturated conditions where runoff is generated. Limiting manure and/or fertilizer applications to these areas will further decrease nutrient loss potential. Based on the decrease in soil P solubility observed following reduction and reoxidation, further work is needed to determine the impact of saturation/reduction and subsequent reoxidation on longer-term runoff P losses.

Diet and Manure Application Study

Due to the reductions in P excreted from the low P diet, P application rates were reduced by 50% compared to the high P diet when manures were applied on an equal P basis. This reduction in P application rate resulted in P runoff losses nearly 1.3 times greater from the high P diet than from the low P diet. However, application method had the greatest effect on runoff P. Surface applied manure treatments lost 150 times more DRP (Figure 3), 18 times more FeO-P, and 6.7 times more TP (Figure 4) than the control treatment, while surface treatments lost 31 times more DRP, 8 times more FeO-P and 4.2 times more TP than incorporated manure treatments which lost 5 times more DRP than the control treatment.

Diet manipulation will have a significant long-term impact on P runoff by reducing P application rates and P loading to soils in areas of high animal densities. Furthermore, based on the effects of application method on P runoff, applying manure to soils with the lowest risk of discharging runoff to surface waters and incorporating manures whenever possible can greatly reduce the environmental impacts of animal production agriculture.

Another observation made in this study was that when manure was applied, FeO-P runoff was consistently less than DRP runoff. These differences may be due to the sorption of P onto eroded sediment during the incubation time required for FeO-P analysis and indicates that 1) the DRP measure is highly dependent upon time, and 2) DRP concentrations in runoff may be affected by sediment concentration and the ability of sediment to sorb P. More studies to determine the interactions of field runoff with receiving body sediments are needed.

Phosphorus Sorption Study

The presence of inositol hexaphosphate (IP_6) or adenosine triphosphate (ATP) in solution competitively inhibited inorganic P (P_i) sorption in all three soils used in this experiment. In all three soils, competition between P_i and ATP (Figure 5) reduced P_i sorption more than competition between P_i and IP_6 (Figure 6). Desorption of P_i occurred in the Sleeth soil under conditions of competition with ATP. Sorption of IP_6 was not affected by the presence of P_i in solution; however, high concentrations of P_i in solution did decrease ATP sorption in the competitive (P_i + ATP) isotherm. Inositol hexaphosphate was completely sorbed in the Cecil soil under both noncompetitive and competitive conditions.

These studies clearly show that soil P sorption (and P loss) is dependent on the forms of P added to the soil. The organic P forms used in this study have been identified in manures and may explain the greater vertical movement of inorganic P in manured soils. By improving our understanding of how these, and other P compounds, interact in soils, we may be able to develop management strategies or manure treatment to reduce the risk of soluble P loss from soils.

Take Home Messages

1. Minimizing soil erosion losses from fields to receiving waterbodies is the most effective method of reducing P losses from agricultural soils.

2. Manure applications should be avoided when soil saturation and runoff are likely in the short-term (less than one month).

3. Incorporated manure (and commercial fertilizer) applications have a much lower P loss potential than surface applications.

4. Improved dietary P management will reduce long-term P loading to soils when manures are applied at nitrogen-based rates.

5. Increased P leaching from manured soils may be impacted by the forms of P present in manures, but other compounds (organic materials and salts) also may play a significant role.

Figures

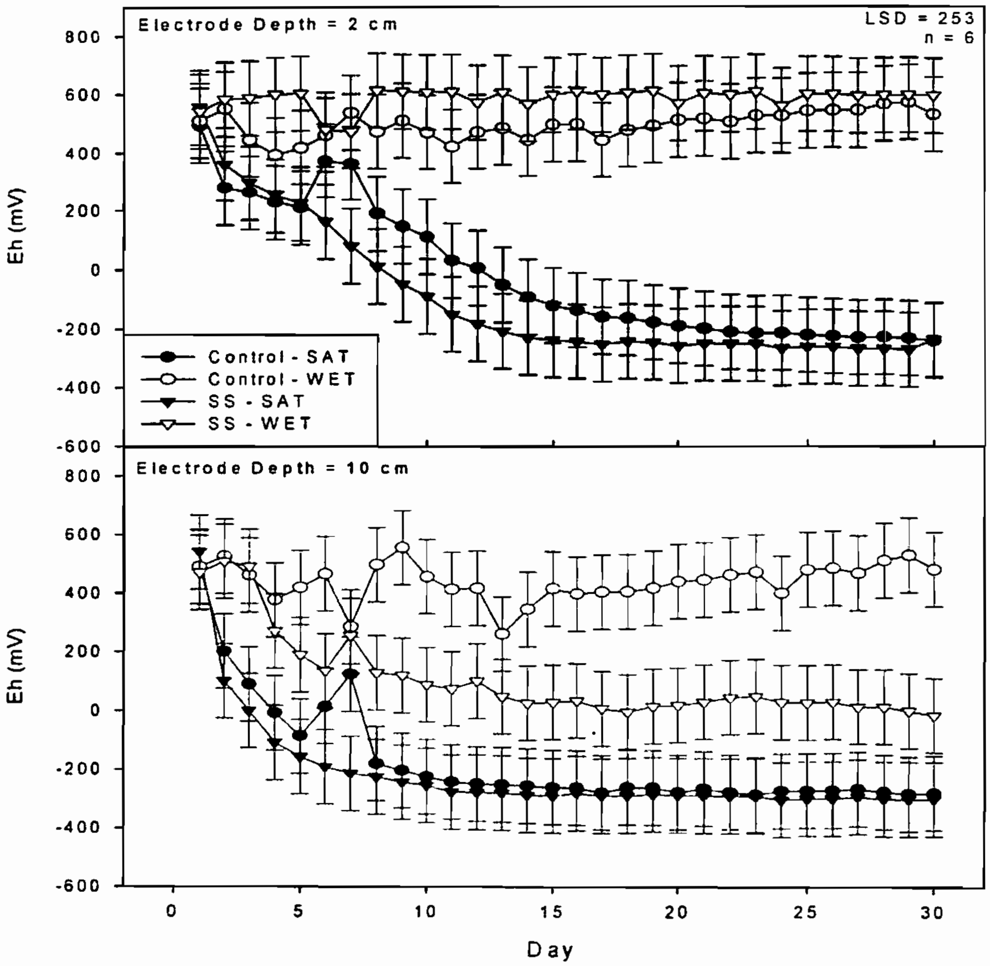

Figure 1. Soil redox potential (Eh) measured at 2 cm and 10 cm depths. Error bars indicate the LSD/2 (α=0.05) shown in the upper right corner; therefore means with overlapping error bars are not significantly different.

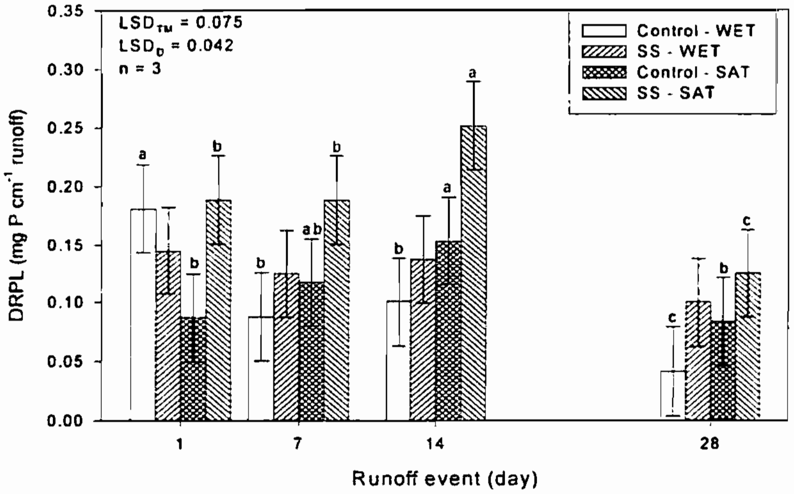

Figure 2. Effect of moisture condition (WET or SAT), swine slurry addition (SS), and incubation time on runoff dissolved reactive P load (DRPL). Error bars represent one-half of the least significant difference for within-day comparisons of treatment and moisture condition means (LSD$_{TM}$). Different letters above error bars within the same moisture condition indicate significant differences between runoff event means according to the least significant difference for between-day comparisons (LSD$_D$).

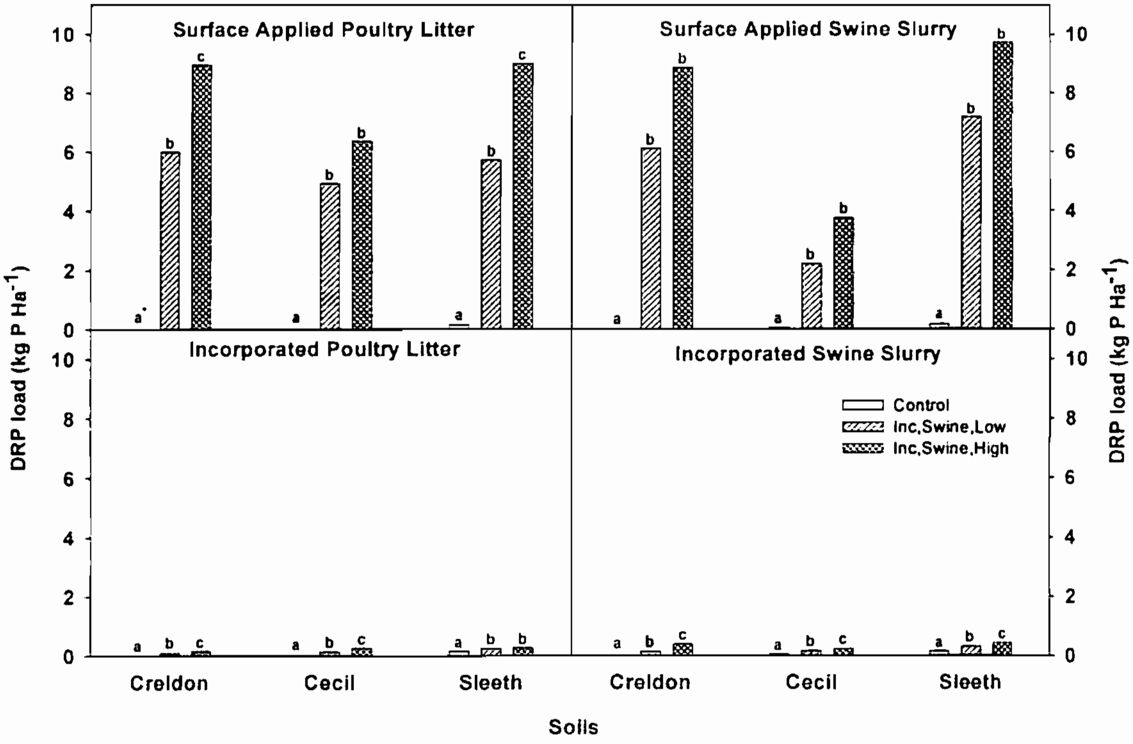

Figure 3. Cumulative Dissolved Reactive Phosphorus (DRP) runoff losses. *Values within an application type, animal species and soil type preceded by a different lower-case letter are significantly different (p<0.05) using the LSD procedure.

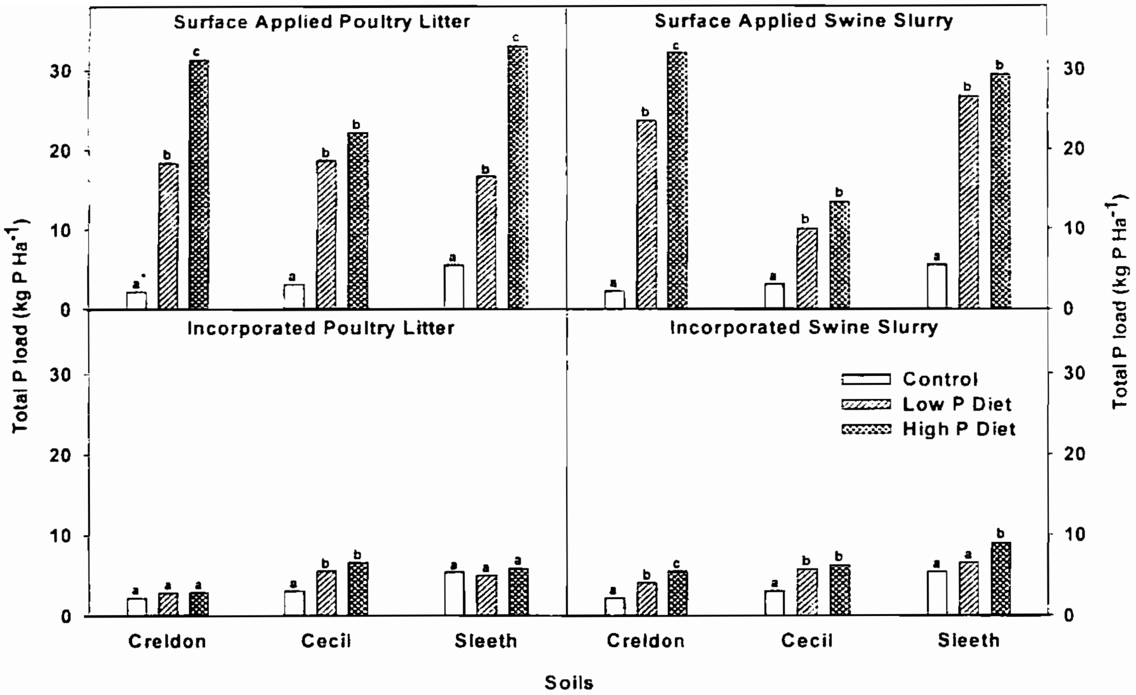

Figure 4. Cumulative Total Phosphorus (Total P) runoff losses. *Values within an application type, animal species and soil type preceded by a different lower-case letter are significantly different (p<0.05) using the LSD procedure.

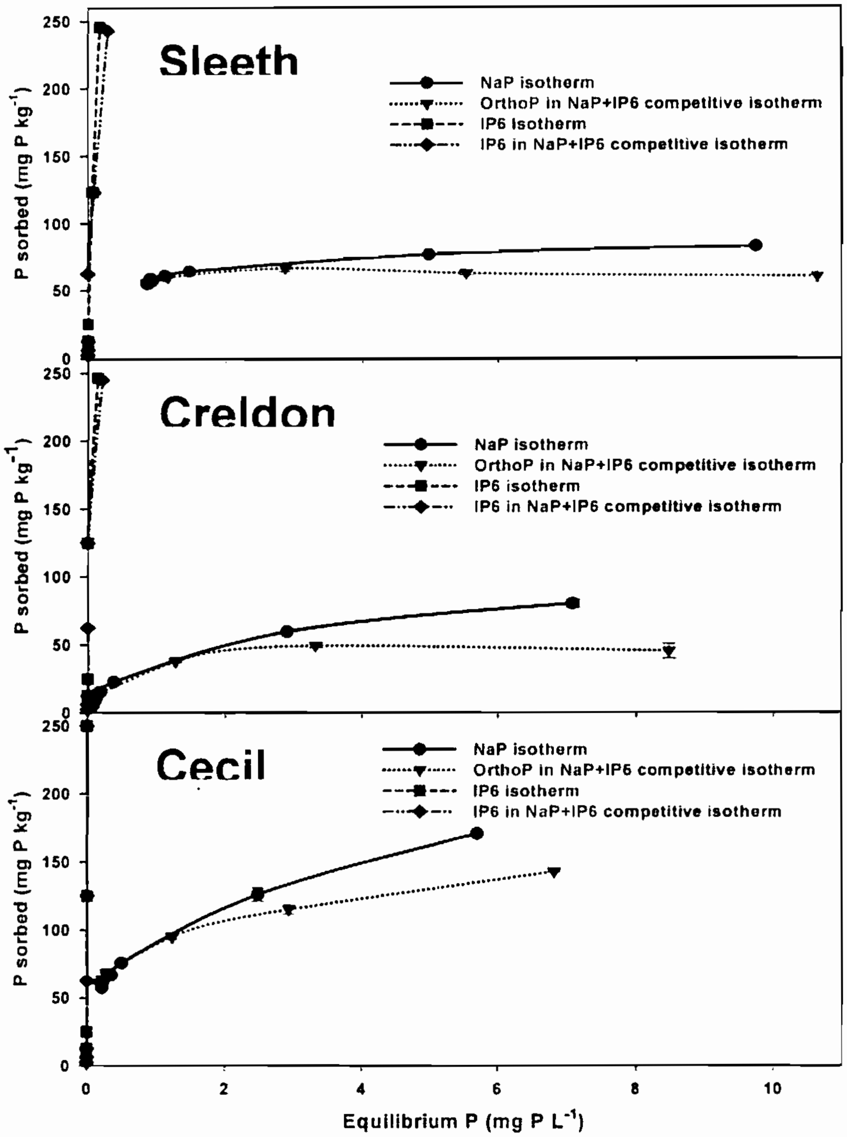

Figure 5. Phosphorus sorption under noncompetitive conditions and under competition between NaP and IP6. Error bars indicate the standard error of the mean.

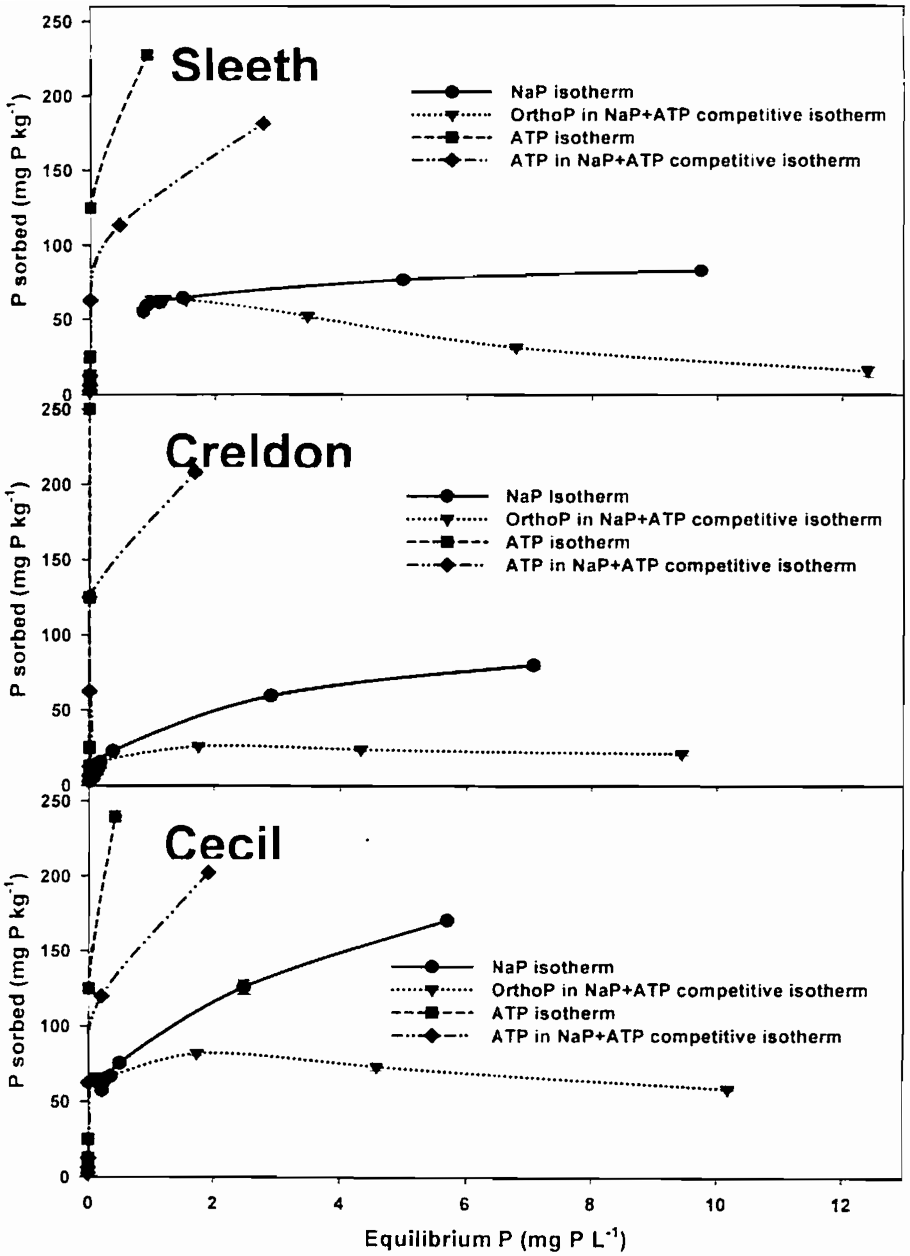

Figure 6. Phosphorus sorption under noncompetitive conditions and under competition between NaP and ATP. Error bars indicate the standard error of the mean.

PROCEEDINGS OF THE

THIRTY-THIRD NORTH CENTRAL EXTENSION-INDUSTRY SOIL FERTILITY CONFERENCE

Volume 19

November 19-20, 2003
Holiday Inn University Park
Des Moines, IA

Program Chair:
John E. Sawyer
Iowa State University
Ames, IA 50011
(515) 294-1923

Published by:
Potash & Phosphate Institute
772 – 22nd Avenue South
Brookings, SD 57006
(605) 692-6280
Web page: www.ppi-ppic.org