

Subject Area 8.1: Environmental Sustainability

Research Article

Use of Amendments to Reduce Leaching Loss of Phosphorus and Other Nutrients from a Sandy Soil in Florida

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Abstract

Goal, Scope and Background. Transport of P from agricultural land contributes to the eutrophication of surface waters. Soil amendment is considered one of the best management practices (BMPs) to reduce P loss from sandy soils. Laboratory column leaching experiments were conducted to evaluate the effectiveness of different soil amendments in reducing P leaching from a typical sandy soil in Florida.

Methods. The tested amendments were CaCl_2 , CaCO_3 , $\text{Al}(\text{OH})_3$, cellulose, and mill mud, and applied at the rate of 15 g/kg for a single amendment and each 7.5 g/kg if two amendments were combined. Leaching was conducted every four days for 32 days, 250 mL of deionized water being leached for each column per leaching event. Leachates were collected from each leaching event and analyzed for reactive P, $\text{PO}_4\text{-P}$, and macro and micro-elements.

Results and Discussion. Except for the soils amended with CaCl_2 , or $\text{CaCl}_2+\text{CaCO}_3$, reactive P and $\text{PO}_4\text{-P}$ leaching losses mainly occurred in the first three leaching events. Phosphorus leaching from the soils amended with CaCl_2 or $\text{CaCl}_2+\text{CaCO}_3$ was less but more persistent than that of other amendments. Reactive P leaching loss was reduced by 36.0% and 40.4% for the amendments of CaCl_2 , and $\text{CaCl}_2+\text{CaCO}_3$, respectively, as compared with chemical fertilizer alone, and the corresponding values for $\text{PO}_4\text{-P}$ were 70.8% and 71.9%. The concentrations of K, Mg, Cu, and Fe in leachate were also decreased by CaCl_2 or $\text{CaCl}_2+\text{CaCO}_3$ amendment. Among the seven amendments, CaCl_2 , CaCO_3 , or their combination were most effective in reducing P leaching from the sandy soil, followed by cellulose and $\text{Al}(\text{OH})_3$, the effects of mill mud and mill mud + $\text{Al}(\text{OH})_3$ were marginal.

Conclusions. These results indicate that the use of CaCl_2 , CaCO_3 , or their combination can significantly reduce P leaching from sandy soil, and should be considered in the development of BMPs for the sandy soil regions.

Recommendations and Outlook. Most agricultural soils in south Florida are very sandy with minimal holding capacities for moisture and nutrients. Repeated application of fertilizer is necessary to sustain desired yield of crops on these soils. However, eutrophication of fresh water systems in this area has been increasingly concerned by the public. Losses of P from agricultural fields by means of leaching and surface runoff are suspected as one of the important non-point contamination sources. The benefits and effectiveness of soil amendment in reducing P losses from cropping production systems while sustaining desired crop yield need to be demonstrated. Calcium chloride, CaCO_3 , or their combination significantly reduce P leaching from sandy soil, and should be considered in the development of BMPs for the sandy soil regions.

Keywords: Florida; leaching loss; nutrients; phosphorus leaching; sandy soil; soil amendments

Introduction

Humans now strongly influence almost every major aquatic ecosystem, and their activities have dramatically altered the fluxes of growth-limiting nutrients from the landscape to receiving waters (Smith 2003). Phosphorus loss from agricultural soils has been reported to be one of the major non-point sources for pollution of surface waters and contribute to the eutrophication of fresh waters (Daniel et al. 1998, Parry 1998), and it has increased over the last few decades as a result of increased fertilizer input and the development of a more industry-based type of agriculture (Eghball et al. 1996).

Water quality throughout south Florida has been a major concern for many years (Chamberlain and Hayward 1996). Most of the citrus acreage in Florida is on extremely sandy soils characterized by sand content often in excess of 90% (Hoogeweg and Hornsby 1997). Sandy soils, characterized by their low content of P-retaining soil constituents (clay, organic matter, and oxides of Fe and Al), are readily subjected to P leaching loss, especially when applied with water-soluble P fertilizers (Ellittott et al. 2002). The P recommendation rate for citrus was over 59 kg/ha (Tucker et al. 1995). However, phosphorus removal via harvested produce usually accounted for less than 29 kg/ha, i.e. < 50% of the

applied amount in South Florida (He et al. 2000). A recent column leaching study indicated that a typical sandy soil of Florida applied with water-soluble P fertilizer resulted in leaching loss of added P by 96.6% (Chen et al. 2006).

In recent years, many amendments (CaCl_2 , $\text{Al}(\text{OH})_3$, etc.) and industry byproducts (such as mill mud) have been suggested to reduce P and metal leaching in sandy soils (O'Connor et al. 2005). And liming acid soils improves crop yield and quality due to improved soil environment for root development. Liming also decreases losses of nutrients and metals in surface runoff by increasing soil holding capacity for these elements. These soil amendments could be useful in reducing P loadings in surface runoff from citrus groves. However, no systematic studies have been conducted in the Indian River area to demonstrate the effectiveness of these materials in reducing nutrient losses into surface waters. The objective of this study was to evaluate the effectiveness of some commonly used organic and inorganic amendments in reducing leaching potential of P and other nutrients in typical sandy soils in the Indian River area of Florida.

1 Material and Methods

The soil was collected at 0- to 30-cm depth from a representative citrus grove in the Indian River area. The soil samples were air dried, and ground to < 2 mm prior to physical and chemical analysis. Some properties of the soil are presented in Table 1. Electrical conductivity and pH of the soil samples were measured in slurry with deionized water at a soil: water ratio of 1:2 and 1:1, respectively, using a pH/ion/conductivity meter (Model 220, Denver Instrument, Denver, CO). Available N ($\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$) was determined by shaking a 2.5 gram air-dried sample in 25 ml of 2 M KCl for 1 h and the concentrations of $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ in the filtrate were analyzed using a N/P Discrete Autoanalyzer (EasyChem, Systea Scientific LLC, Oak Brook, IL). Soil labile P (Olsen-P) was extracted using 0.5 M NaHCO_3 and P concentration in the extract was determined by the molybdenum-blue method (Kuo 1996).

1.0 kg air-dried soil was thoroughly mixed with chemical fertilizer and one or two of the amendments, depending on treatment. There were two levels of P: 0 and 100 mg/kg P as KH_2PO_4 . The fertilizer levels were equivalent to 112.5 kg/ha, which is close to the field conditions of the south Florida. Soils receiving neither amendment nor chemical fertilizer were used as control. There were seven amendment treatments: (1) CaCl_2 , (2) lime (CaCO_3), (3) $\text{CaCl}_2 + \text{CaCO}_3$, (4) cellulose (organic carbon; C), (5) $\text{Al}(\text{OH})_3$, (6) mill mud, and (7) mill mud + $\text{Al}(\text{OH})_3$, with three replications for each treatment. Mill mud (pH 6.88) is an organic waste from

sugar industry, containing approximately 24% organic C, 1% N, 0.9% P, and 0.2% K. The application rate was 15 g/kg for a single amendment and 7.5 g/kg each if two amendments were applied together. Deionized water was added to maintain soil moisture at 70% field-holding capacity. The mixtures were then incubated in an incubator at 25°C for 10 days prior to column leaching study to ensure adequate equilibrium of chemical reactions between soil and the amendment.

Plexiglas leaching columns (30.5-cm long, 6.6-cm inner diameter), with several 5-mm diameter holes at the bottom were used. After incubation, the soil was packed into each column. Prior to leaching, the soil columns were saturated with deionized water at room temperature for three days to allow soil compact naturally and equilibrium of chemical and biological reactions prior to leaching. Leaching was conducted every four days for 32 days, 250 mL of deionized water being leached for each column per leaching event, which is 1.25 pore volume. The total amount of water leached for the eight successive leaching events was 2,000 mL, which was equivalent to a half year's rainfall in the Indian River area. The deionized water was applied using a peristaltic pump. Leachates were collected in 500-mL polyethylene bottles below the soil columns from each leaching event, filtered through a Whatman # 42 filter paper, and analyzed for reactive P. Filtration of leachates with 0.45- μm membrane was performed on the same day. Portions of the filtrate (through 0.45- μm) were used to analyze orthophosphate ($\text{PO}_4\text{-P}$) and metals. Reactive P was determined by the molybdenum-blue method (Kuo 1996). Orthophosphate was measured using an Ion Chromatograph (IC, DX 500; Dionex Corporation Sunnyvale, CA) following EPA method 300.0. Dissolved total concentration of metals was determined using an inductively coupled plasma atomic emission spectrometry (ICP-AES, Ultima, JY Horiba, Edison, NJ) following EPA method 200.7.

2 Results and Discussion

Application of chemical fertilizer alone markedly increased the concentrations of all the measured P forms in leachate, especially in the first and second leaching events, by 10 to 20 times, as compared with the control (Figs. 1 and 2). The amounts of reactive P, the potentially bio-available P pool, released during the whole leaching period ranged from 62.9 to 122.4 mg/kg, depending on the treatments. For different amendments, the changes of reactive P in leachate as a function of leaching events were similar (see Fig. 1). The concentration of reactive P in leachate increased in the second leaching, decreased markedly in the third leaching event, and remained largely unchanged afterwards. In the third leach-

Table 1: Relevant properties of the tested soils

Soil Depth (cm)	pH (H_2O)	EC ($\mu\text{S}/\text{cm}$)	Mehlich 3- P (mg/kg)	Olsen P (mg/kg)	KCl extractable N (mg/kg)	
					$\text{NO}_3^-\text{-N}$	$\text{NH}_4^+\text{-N}$
0–15	6.26	326.35	95.65	62.88	26.47	23.72
15–30	6.50	405.35	98.47	47.16	25.80	28.00

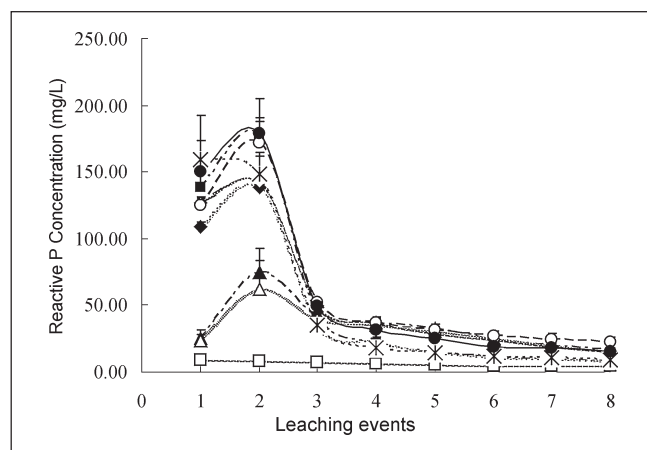


Fig. 1: Effect of soil amendments on reactive-P in the leachate from the eight successive leaching events. Error bars indicate standard deviation

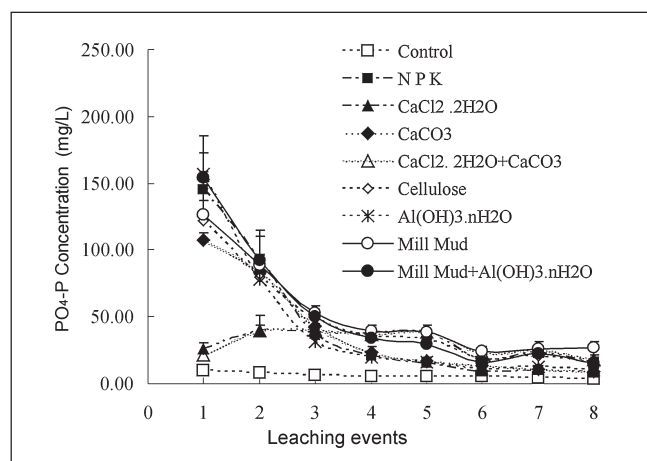


Fig. 2: Effect of soil amendments on $\text{PO}_4\text{-P}$ concentrations in leachate of the eight successive leaching events. Error bars indicate standard deviation

ing event, the concentration of reactive P in leachate decreased to a similar level, which was about 21.9% to 41.5% of those in leachate from the first leaching for all the treatments except for those amended with CaCl_2 or $\text{CaCl}_2 + \text{CaCO}_3$, which was 162% and 173%, respectively, as compared to the first leaching event. Reactive P concentrations in leachate were not significantly different from the third to the eighth leaching events. The highest reactive P concentration in leachates occurred in the first and second leaching event, suggesting that some of the leachable P was released from the soil rapidly. Reactive P in leachate of the control remained low for the whole leaching period. The amounts of leachate reactive P was significantly reduced only by addition of CaCl_2 , CaCO_3 , or $\text{CaCl}_2 + \text{CaCO}_3$, which was 36.0%, 17.5%, and 40.4%, respectively, as compared to chemical fertilizer alone. However mill mud and mill mud+ $\text{Al}(\text{OH})_3$ increased reactive P leached. The amounts of leachate reactive P lost from the eight leaching events decreased among the different treatments in the order of mill mud = mill mud+ $\text{Al}(\text{OH})_3$ > cellulose > chemical fertilizer alone = $\text{Al}(\text{OH})_3$ > CaCO_3 > CaCl_2 > $\text{CaCl}_2 + \text{CaCO}_3$.

The concentration of $\text{PO}_4\text{-P}$ in leachate was time-dependent and the highest $\text{PO}_4\text{-P}$ concentrations in leachates generally occurred in the first or second leaching event except for those treated with CaCl_2 or $\text{CaCl}_2 + \text{CaCO}_3$ (see Fig. 2). After the third leaching event, the $\text{PO}_4\text{-P}$ concentration in leachates tended to decrease gradually with leaching progress for all the treatments, except for CaCl_2 or $\text{CaCl}_2 + \text{CaCO}_3$ amendment, for which there was no significant decrease in leachate $\text{PO}_4\text{-P}$ concentration during the whole leaching process. These results indicate that P leaching in the soils amended with CaCl_2 or $\text{CaCl}_2 + \text{CaCO}_3$ was less but more steadily than other treatments. The amounts of $\text{PO}_4\text{-P}$ released in the first leaching event ranged from 5.3 to 39.1 mg/kg and the corresponding values for the second, third, fourth, and 8th (last) leaching events were 9.8 to 23.1 mg/kg, 7.8 to 13.2 mg/kg, 4.9 to 10.0 mg/kg, and 2.2 to 6.7 mg/kg, respectively. The total amount of $\text{PO}_4\text{-P}$, representing readily bioavailable P pool, released during the eight leaching events ranged from 59.5 to 106.0 mg/kg (excluding the control column). For the soils having received different amendments (except CaCl_2 and $\text{CaCl}_2 + \text{CaCO}_3$), the amounts of $\text{PO}_4\text{-P}$ released were generally greater during the first three leaching events than those released in the subsequent leaching events, which accounted for 63.2–81.5% of total $\text{PO}_4\text{-P}$ leached during the whole leaching process. These results also indicate that the release of loosely adsorbed or water soluble P was a fast reaction, whereas less soluble P fractions were more slowly but steadily released. The continued loss of $\text{PO}_4\text{-P}$ was likely related to the dissolution of various calcium phosphates in the soil. Additionally, relatively low $\text{PO}_4\text{-P}$ concentrations occurred in the leachate of columns with CaCl_2 or $\text{CaCl}_2 + \text{CaCO}_3$ application, which was 70.8% and 71.9%, respectively, of the columns receiving chemical fertilizer alone. Leachate $\text{PO}_4\text{-P}$ from the eight leaching events decreased in the same order as reactive P among the different treatments. In this study, $\text{PO}_4\text{-P}$ concentrations of most leachate water samples were lower than or equal to the corresponding reactive P, which is expected, because in addition to $\text{PO}_4\text{-P}$, the latter also includes particulate P that passed through Whatman #42 filter paper and a variable portion of hydrolysable organic P. The peak reactive P concentration occurring in the second leaching event is likely due to increased particulate P leaching as most water-soluble salts were leached in the first leaching event. The major mechanisms of reduced P leaching by CaCl_2 or $\text{CaCl}_2 + \text{CaCO}_3$ include the formation of less water soluble calcium phosphates, increased P sorption by Ca-bridging between the negatively charged soil surface and phosphate (He et al. 1992) and reduced leaching of particulate P in the soil.

The concentrations of macro-elements and micro-elements in the leachate generally decreased with leaching events, and most leaching loss occurred in the first two leaching events. There were minimal effects of soil amendments on the leaching of Cd, Co, Cr, Na, Ni, and Pb. However, application of CaCl_2 and $\text{CaCl}_2 + \text{CaCO}_3$ significantly decreased the concentration of K, Mg, Cu, and Fe in leachate, probably due to the co-precipitation with calcium phosphates, which were likely formed because of increased Ca concentration in soil solution. The extent of decrease in the con-

centrations varied with elements. The decreases ranged from 23.5% and 26.9% for K, 29.2% and 19.1% for Mg, 31.6% and 41.9% for Cu, and 71.4% and 75.8% for Fe, respectively, by CaCl_2 and $\text{CaCl}_2+\text{CaCO}_3$ application.

3 Conclusions

Soil amendments vary greatly in their effectiveness in reducing P leaching in sandy soils. Reduction in leachate P concentration was most significant when the soil was amended with CaCl_2 , CaCO_3 , or both. The effects of cellulose and $\text{Al}(\text{OH})_3$ on reduced P leaching were modest, and those of mill mud and mill mud + $\text{Al}(\text{OH})_3$ were marginal. Reactive P leaching loss was reduced by 36.0%, 17.5%, and 40.4%, respectively, by amendment of CaCl_2 , CaCO_3 , or $\text{CaCl}_2+\text{CaCO}_3$, as compared to chemical fertilizer application alone. Low $\text{PO}_4\text{-P}$ concentrations occurred in the leachates of soils that received CaCl_2 or $\text{CaCl}_2+\text{CaCO}_3$ amendment, and $\text{PO}_4\text{-P}$ concentrations were reduced by 70.8% and 71.9%, respectively, as compared with chemical fertilizer alone. In addition, application of CaCl_2 and $\text{CaCl}_2+\text{CaCO}_3$ significantly decreased the concentration of K, Mg, Cu, and Fe in leachate.

In general, CaCl_2 appeared to be the most promising soil amendment for reducing P leaching in sandy soil in the Indian River area, followed by $\text{CaCl}_2+\text{CaCO}_3$ and CaCO_3 . The losses of P were significantly reduced, and the applied P was more maintained in the soil with a slow pace of release. The effectiveness of CaCl_2 and CaCO_3 in reducing P leaching is likely related to their strong reactions with P in the soils, and they should be considered in the development of BMPs for the sandy soil in Florida.

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