

EFFECT OF Si-RICH SLAG AND LIME ON P LEACHING IN SANDY SOILS

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ABSTRACT

Phosphorus (P) contamination of natural surface and subsurface waters draining from agricultural soils is a persistent environmental and economic problem in Florida. A silicon (Si) soil amendment (Si-rich slag) and lime (CaCO_3) were compared to determine their effects on P leaching from cultivated Spodosols, Entisols and Alfisols in soil columns and in greenhouse experiments with Bahiagrass (*Paspalum notatum* Fluigge) grown under various levels of P fertilization. The Si slag reduced P leaching considerably more than lime in all soils investigated. Lime transformed plant-available P into plant-unavailable forms, while Si slag maintained P in a plant-available form. In greenhouse experiments, plant growth responses were greater from Si slag-treated soil than from P fertilization. The Si slag improved P availability and had a positive effect on the development of the Bahiagrass root system. Application of Si slag to sandy soils could help reduce P leaching and the potential pollution of natural waters.

INTRODUCTION

The lack of soil nitrogen (N), phosphorus (P) and potassium (K) is a major factor limiting plant growth on native sandy soils in Florida. Commercial fertilizers containing these elements plus other macro- and microelements are used to overcome this limitation.

Sandy soils often have low P retention due to: (1) the essential lack of aluminosilicates and metal-oxide clays in the albic E horizon (Harris et al., 1996), and (2) the presence of a seasonal shallow water table promoting lateral P transport within the E horizon (Mansell et al., 1991). Frequent, heavy rainfall, and widespread use of irrigation and drainage may lead to leaching of 20 to 80% of added P (Campbell et al., 1985; Sims et al., 1998). This problem has ecological, economic and animal health consequences. Leached P promotes eutrophication of natural waters and P deficiency in plants (Richardson and Vaithyanathan, 1995). Nutrient leaching can cause soil nutrient deficiencies, giving rise to the need for additional fertilization. The present method for reducing P leaching from sandy soils is through the use of limestone (Sims, et al., 1998). Unfortunately, lime transforms plant-available P into plant-unavailable forms (Lindsay, 1979), which increases the need for P fertilization.

Silicon-rich biogeochemically active substances (Si soil amendments) usually exhibit a high adsorption capacity for anions (Rochev et al., 1980). They can adsorb mobile P and render it in a plant-available form (Matichenkov et al., 1997). Preliminary column experiments showed that the application of various Si-rich materials reduced P leaching by 30 to 90% (Matichenkov et al., 2000).

The objective of this study was to compare the effect of Si slag, (a finely processed calcium magnesium silica slag, PRO-CHEM Chemical Company, FL) with lime on P leaching from soils classified as cultivated Spodosols, Entisols and Alfisols in column and greenhouse experiments.

MATERIALS AND METHODS

Soil samples representing two soil orders were collected at the University of Florida, Indian River Research and Education Center in Fort Pierce. Soil samples were selected at the depth of 0-20 cm from a cultivated Alfisol (Winder series, fine-loamy, siliceous, hyperthermic Typic Grossaqualfs) and a cultivated Spodosol (Ankona series, sandy, siliceous, hyperthermic, orstein Arenic Haplaquods). Sampling sites for the Alfisol and the Spodosol were under citrus groves. Soil samples representing a third soil order - a cultivated Entisol (Margate series, sandy, siliceous, hyperthermic Mollic Psammaquents) were collected in Hendry county in a commercial sugar cane field at the depth of 0-20 cm.

The study had both column and greenhouse experiments. The column experiment was used to model P leaching using Si slag and lime (CaCO_3) at 10 t ha^{-1} mixed with the different soils. The plastic column had a volume of 60 cm^3 and a diameter of 2.5 cm. Distilled water or a P-bearing solution (prepared from dissolving KH_2PO_4 , 10 mg P L^{-1}) was added to the column at $6-8 \text{ mL h}^{-1}$ using a peristaltic pump. The percolate was collected in 20 mL intervals. Collected solutions were placed in a refrigerator at 4°C after adding a drop of chloroform for reduction of microbial activity. A total of 300 mL of solution was applied to each column. Each column was replicated three times and triplicate analyses were made on each liquid sample. After the leaching experiment was completed, the soils were dried at 65°C and passed through a 1-mm sieve. Triplicate soil and sand samples were analyzed for water-extractable and acid extractable (0.1 M HCl) P. Phosphorus concentration was determined according to the method of Walsh and Beaton (1973).

The greenhouse experiment was conducted with a cultivated Entisol. The soil was mixed with Si-rich slag or lime at the rates of 0 and 10 t ha^{-1} . The P fertilizer (ground superphosphate) was applied at the rates of 0, 50 and 100 kg P ha^{-1} . One kg of treated soil was then placed into plastic pots. Bahiagrass was used as a test plant (120 seeds per pot). Each variant had 2 replications. Irrigation was conducted with distilled water. After seedling and once a week percolate samples were collected from the bottom of each plot and filtered. After 3 months, the plants were harvested. The weight of fresh and dried (65°C) shoots and roots were separately measured. After that, dried shoots and roots were ground and analyzed. The percolates, water and acid extracts were analyzed colorimetrically for P using a spectrophotometer at a wave length of 880 nm (Eaton et. al., 1995).

All data were subjected to a statistical analysis based on comparative methods using the $P < 0.05$ value obtained from a multiple comparison test of variance and Duncan's coefficients (Parl, 1967).

RESULTS AND DISCUSSION

Irrigation with distilled water in the column experiment was intended to represent the percolation of heavy rainfall (150-mm cm^{-2}). In the Entisol, the concentration of P in the percolate gradually decreased from 5.2 to 1.6 mg P L^{-1} in the control, from 4.8 to 1.2 mg P L^{-1} in the lime-treated soil, and from 1.5 to 0.5 mg P L^{-1} in the Si-slag-treated soil (Figure 1). Irrigation with the P-bearing solution represented both heavy rainfall and P fertilization. The Entisol soil was gradually saturated with P (Figure 2). The concentration of P in the percolate solution increased from 4.5 to 8.7 mg P L^{-1} in the control, from 2.0 to 6.6 mg P L^{-1} in the lime-treated soil and from 0.4 to 0.7 mg P L^{-1} in the Si-slag-treated soil (Figure 2).

In the Spodosol treated with Si slag or lime, the P concentration in the percolate was relatively stable under irrigation with distilled water (Figure 3), while that for the control sharply increased and then decreased. In the Spodosol irrigated with the P-bearing solution, the P in the percolate sharply increased both in the control and in the lime-treated soil, while the soil treated with Si slag showed only a small amount of P leaching (Figure 4).

Phosphorus concentration in the percolate from the Alfisol under distilled water irrigation sharply increased from 0.5 to 0.9 mg P L^{-1} in the control and from 0.3 to 0.6 mg P L^{-1} in the lime-treated soil, but stayed relatively stable (from 0.3 to 0.4 mg P L^{-1}) in the Si-slag-treated soil (Figure 5). Under irrigation with the P-bearing solution, P in the percolate gradually increased from 0.8 to 9.7 mg P L^{-1} in the control and from 0.7 to 4.5 mg P L^{-1} in the lime-treated soil, but remained stable (from 0.6 to 0.7 mg P L^{-1}) for the Si-slag-treated soil (Figure 6).

The column experiment demonstrated that Si slag adsorbed mobile P considerably better than lime and had appreciably less P leaching than the lime treatment in all soils investigated (Figures 1-6). This effect may have been caused by the action of several mechanisms. For example, Si slag contains Si, Al and Fe compounds and it is possible that both chemical and physical P adsorption mechanisms by Si slag were involved.

Application of lime or Si slag along with P fertilizer (Figure 7, 8 and 9) influenced P leaching from the Entisol soil in the greenhouse experiment. Lime by itself slightly increased P leaching from the Entisol without P fertilization (Figure 7). Lime had its greatest effect in reducing P leaching from the Entisol treated with 50 kg P ha^{-1} (Figure 8). However, Si slag showed a greater reduction in P leaching than lime at all treatment levels of P fertilization (Figure 7, 8 and 9). These data support the results of the column experiment (Figures 1-6) in that Si slag adsorbs considerably greater concentrations of mobile P than limestone.

Addition of either P or Si slag to the soil increased the mass of shoots and roots of Bahiagrass (Table 1), whereas the lime treatment either had a negative or neutral effect on grass growth. A reduction of P concentration was shown in plants receiving the Si slag treatment (Table 2). For example, in shoots Si concentration decreased from 404 to $309\text{ mg P }100\text{g}^{-1}$, from 422 to $239\text{ mg P }100\text{g}^{-1}$, and from 481 to $339\text{ mg P }100\text{g}^{-1}$ in the treatments with 0 , 50 and 100 kg P ha^{-1} , respectively. Considering the significant effects of Si slag on the Bahiagrass mass (Table 1), the decreased plant P concentration may have been a dilution effect. The content of P in the shoots and the roots after 3 months of growth were examined to see if Si slag had increased P availability to the plants. Data on total P content per 100 plants confirmed this hypothesis (Table 3). The Si slag treatment increased the total amount of P in the shoots (except at 50 kg P ha^{-1}) and roots of Bahiagrass. Conversely, lime had the opposite effect on the shoots, but not roots of Bahiagrass.

The concentration of P in Bahiagrass was higher with the control and lime treatments than with the Si slag treatment (Table 2). However, the content of P in both the shoots and roots was greater with the Si slag treatment than with the control and/or the lime treatment (Table 3). These data can be explained by considering the magnitude of increase in the biomass of Bahiagrass (Table 1). When compared with the control and lime treatments, Si slag application essentially doubled the biomass of shoots and increased the biomass of roots approximately 7 times. Although Si slag application resulted in a P dilution effect in the shoots and roots the Bahiagrass absorbed more P with the Si slag treatment.

Data on water-extractable and acid-extractable P in the soil after the greenhouse experiment showed that the application of Si slag allowed P to remain in a plant-available form (Table 4). Liming resulted in a reduction in P leaching (Figure 8 and 9), but mobile P apparently was transformed into plant-unavailable P. Si slag also reduced mobile P leaching, probably by adsorption on the surface, but kept P in a plant-available form. Therefore, there appears to be a strong possibility that the application of Si slag to sandy soils could preserve natural waters from P contamination and improve P plant nutrition more efficiently than lime applications.

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Table 1. The weight of fresh shoots and roots of Bahiagrass after growing 3 months in a greenhouse.

Variant	Without P fertilizers		50 kg P ha ⁻¹ as superphosphate		100 kg P ha ⁻¹ as superphosphate	
	Shoots	Roots	Shoots	Roots	Shoots	Roots
-----average weight (g) for 10 plants-----						
Control	0.57b	0.17b	0.84b	0.29b	0.89b	0.37b
Lime	0.47c	0.14b	0.59c	0.31b	0.92b	0.38b
Si slag	1.12a	0.97a	1.14a	1.14a	1.48a	1.37a

Using Duncan's multiple range test, values within a column followed by the same letter are not statistically different ($P < 0.05$).

Table 2. The concentration of P in shoots and roots of Bahiagrass after growing 3 months in a greenhouse.

Variant	Without P fertilizers		50 kg P ha ⁻¹ as superphosphate		100 kg P ha ⁻¹ as superphosphate	
	Shoots	Roots	Shoots	Roots	Shoots	Roots
-----mg P 100 g ⁻¹ ----- ---						
Control	404a	346b	422a	306b	481a	388a
Lime	418a	450a	360b	362a	432b	378a
Si slag	309b	246c	239c	211c	339c	239b

Using Duncan's multiple range test, values within a column followed by the same letter are not statistically different ($P < 0.05$).

Table 3. Total content of P in shoots and roots of Bahiagrass after growing 3 months in a greenhouse.

Variant	Without P fertilizers		50 kg P ha ⁻¹ as superphosphate		100 kg P ha ⁻¹ as superphosphate	
	Shoots	Roots	Shoots	Roots	Shoots	Roots
-----mg P 100 plants ⁻¹ -----						
Control	2.30b	0.59b	3.57a	0.91b	4.28b	1.43b
Lime	1.97c	0.63b	2.12c	1.15b	3.98c	1.43b
Si slag	3.48a	2.40a	2.73b	2.41a	5.03a	3.27a

Using Duncan's multiple range test, values within a column followed by the same letter are not statistically different ($P < 0.05$).

Table 4. The concentration of water- and acid-extractable P in Entisol after growing Bahiagrass in greenhouse study.

Variant	Without P fertilizers		50 kg P ha ⁻¹ as superphosphate		100 kg P ha ⁻¹ as superphosphate	
	Water-extractable	Acid-extractable	Water-extractable	Acid-extractable	Water-extractable	Acid-extractable
-----mg P kg ⁻¹ of soil-----						
Original soil	6.9a	106a	-	-	-	-
Control	2.8b	63b	7.1b	95b	14.8a	123a
Lime	3.6b	51c	7.8b	85b	13.5b	114a
Si slag	6.8a	64b	12.9a	115a	14.8a	128a

Using Duncan's multiple range test, values within a column followed by the same letter are not statistically different ($P < 0.05$).