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ABSTRACT

The influence of silicate on solubility and availability of soil P was determined for some Hawaiian Latosols. Phosphate requirements (sorbed P at 0.2 ppm P in the supernatant solution) ranged from 240 ppm P for a soil containing kaolin to 1,400 ppm P for a soil rich in non-crystalline hydrated oxides. Applications of silicate decreased P requirements to the extent of 9 to 43 percent. The greatest decrease was for the kaolin system and the lowest was for hydrated oxides Desorption of P increased in the presence of sorbed Si. Residual effects of fertilizing soil (a Gibbsihumox) with 9 tons/ha of calcium silicate slag and 110 kg/ha P was to decrease the phosphate requirement by 500 kg P/ha. Apparently, residual silicate was more efficient than residual phosphate in decreasing P sorption. Extractable P increased with increasing rates of silicate initially applied to the soil. Silicate applied to a P deficient soil significantly increased dry matter yields of sugarcane (Saccharum officinarum). *Check plants were highly deficient in P but apparently not in Si. Increased yields were associated with improved plant P nutrition. Silicon in the plant seems to decrease the internal P requirement of sugarcane as indicated by relatively large effects of Si when P was at low concentration in the sheaths.*

Phosphorus problems in the humid tropics are more acute than in the humid temperate zone (Bradfield 1963). Recently several investigators in the tropics have demonstrated that silicates increase crop yields. Applications of silicate slags are commerically practical for sugar production in Hawaii (Ayres 1966). Some, but by no means all, of the yield response obtained can be related to improved P

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nutrition. This investigation is an attempt to isolate some of the effects of silicate applications on plant growth. It presents information on the influence of silicate on phosphate sorption and availability in some Hawii Latosols and the relationship between plant Si content and P nutrition of sugarcane.

EXPERIMENTAL

Phosphate sorption studies: Phosphate sorption was determined for four Hawaiian Latosols belonging to four great soil groups representing a wide range of mineralogy and weathering. Some of the important characteristics of the soils are presented in table 1.

TABLE 1

Some important soil characteristics of experimented soils

Soil Series	Soil subgroup	Rainfall (mm)	Parent material	Important secondary soil minerals	pH	Si in water extract (ppm)	P[1] extracted (ppm)
Wahiawa	Tropeptic Eutrorthox	1140	Basalt	1:1 clays	6.5	1.0	8
Leilehua	Humoxic Tropohumult	1780	Basalt	1:1 clays Illite	5.0	0.8	8
Paaloa[2]	Humoxic Tropohumulrs	1900	Basalt	1:1 clays Illite	4.9	1.0	14
Kapaa	Typic Gibbsihumox	2300	Basalt	Gibbsite Goethite	5.0	0.8	7
Akaka	Typic Hydranpept	5100+	Volcanic ash	Hydrated oxides	5.0	0.8	36

[1] Modified Truog's method.

[2] Soil used for pot experiment.

Wahiawa, Leilehua (was Kawailoa) and Paaloa soils were collected from the Waialua Sugar Plantation on the island of Oahu. Akaka soil was obtained from the Pepeekeo Sugar Plantation on the island of Hawaii. Kapaa soil was sampled from the Kauai Branch Station of the University of Hawaii. Treatment rates for all soils except Akaka were calculated on an oven-dry soil basis, while Akaka soil was used on a field moist basis (about 40 per cent dry matter). This was considered reasonable since most of the water held by this soil under field conditions is considered to be an integral part of the soil.

Residual effects of field applied silicate on phosphate solubility were investigated in the laboratory using a gibbsitic Kapaa soil from

the island of Kauai. Plots being used to evaluate interactions among silicate, phosphate and soil pH were laid out in August, 1966. The soil samples were taken after 9 months growth of sugarcane. Eight factorial treatment combinations of 110 and 1,100 kg P/ha, zero and 9 tons calcium silicate slag/ha and pH 5.5 and 6.2 were used.

Phosphate sorption and desorption by soils was measured as described by Fox and Kamprath (1970). In the cases where effects of silicate on phosphate sorption were investigated, soil samples were equilibrated for 24 hours simultaneously with serial rates of phosphate and silicate. The rates of silicate were 0, 250 and 500 ppm Si.

Phosphorus was extracted by a modification of Truog's method: 0.02*N* H_2SO_4, $(NH_4)_2SO_4$ solution (0.3%) at soil: solution ratio of 1 : 100.

Influence of silicate on phosphorus nutrition of sugarcane: A pot test with sugarcane was carried out using Paaloa soil in 20 litre pots. A factorial experiment with four replicates was laid out in a randomized complete block design with the following variables: 0, 1400, and 5600 kg P/ha and 0, 1.0 and 2.0 tons Si/ha. On a per plant basis (two plants per pot), this is equivalent to P fertilization at 0, 112 and 560 kg P/ha assuming a population of 7500 stools/ha.

Six months after planting each pot was harvested for dry matter yield, crop-log tissue (Clements 1960), green tops and millable cane. Plant analyses were performed on tissues separately.

RESULTS AND DISCUSSION

Phosphate sorption in Hawaiian Latosols: The extremes of phosphate requirements by the experimental soils are presented in Figure 1. Fox et al. (1968) used 0.2 ppm P in the supernatant solution as a standard value for estimating phosphate requirements of Hawaiian soils. This standard is believed to be adequate for growing several crop species on some Hawaiian Latosols.

Phosphate requirements of the soils were between 240 and 1,400 µg P/g, the lowest value being for the Leilehua soils and the highest for the Akaka soil. Least sorption was associated with crystalline kaolin type clays (Table 1). High sorption by Akaka soil was attributed to its high specific surface and very reactive hydrated Fe and Al oxides. The high content of Al and Fe oxides, especially in the amorphous forms in the Kapaa soil was thought to be responsible for high P sorption.

Influence of silicate on phosphate sorption: Silicate applied to soil at 500 ppm Si decreased P sorption by 47, 41, 24 and 9 per cent for the Leilehua, Wahiawa, Kapaa and Akaka soils, respectively

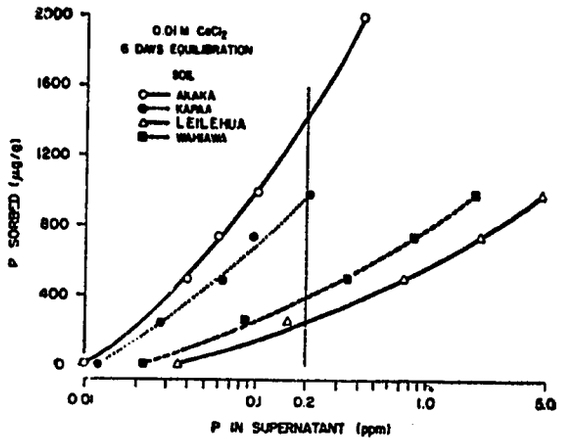

Fig. 1. Phosphorus sorbed by four Hawaiian soils in relation to P remaining in solution. The value 0.2 ppm P in the supernatant has been used as a standard value for comparing P adsorption

(Table 2). This soil sequence is the same as that for concentration of P remaining in solution when P was equilibrated with these soils (Figure 1). Apparently silicates decrease phosphate sorption most in soils which sorb phosphate least. Decreases in P fixation by prior treatment of Hawaiian soils with silicates have been demonstrated (see the review by Silva in these proceedings). Raupach and Piper (1959) found that silicate applications temporarily increased availability of P in lateritic soils. Concentrations of Si in soil solution also seem to be an important factor in decreasing P sorption by soils. The relatively great effect of silicate on P sorption by the Leilehua

TABLE 2

Influence of added silicate on phosphate sorption and desorption from four Hawaiian Latosols

Soil	$CaSiO_3$ Added (ppm Si)					
	0	250	500	0	250	500
	P requirement (µg/g)[1]			P desorbed (ppm in solution)[2]		
Leilehua	187	125	100	5.35	5.90	6.13
Wahiawa	425	325	250	3.36	4.80	4.64
Kapaa	725	625	550	0.46	0.55	0.56
Akaka	1150	1050	1050	0.14	0.15	0.16

1 P sorbed at 0.2 ppm P in supernatant solution.

2 P added initially, 1000 µg/g

soil was associated with high Si solubility in this soil. The small effect of silicate on P sorption by the Akaka soil might be explained by high Si sorption by this soil.

Phosphate desorption from soils was increased to a small amount by the presence of sorbed Si (Table 2). These results suggest that the influence of Si on P desorption is related to the nature of the soil minerals on which P and Si are sorbed. Apparently P sorption is more reversible for soils with kaolinitic clays than for soils rich in gibbsite or amorphous oxides. Although detailed data are not presented here, concentrations of P in soil solutions were maintained at higher levels during continued desorption in the presence of sorbed Si. The results of these investigations suggest that silicate, when applied to soils, not only decreases P sorption capacities of soils but also helps to maintain P concentrations of soil solutions during P depletion.

Residual effects of field applied silicate on phosphate sorption and extraction: The beneficial effects on sugarcane yields and P uptake of silicate applications to Kapaa soil have been demonstrated in a field trial in Kauai. This experimental site was used to evaluate residual effects of silicate on the phosphorus status of soils. Soil samples from zero and high silicate plots were equilibrated with graded amounts of P, and P in the supernatant solution determined. Phosphorus sorption decreased in the presence of field applied silicate (Figure 2). Silicate decreased P sorption more effectively at low

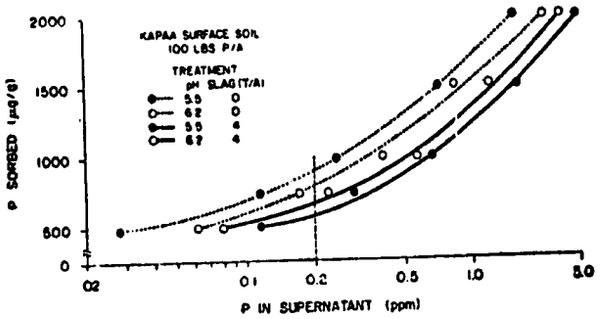

Fig. 2. Phosphorus sorbed by Gibbsihumox in relation to prior field treatments with calcium silicate slag and/or calcium carbonate to give two Si levels and two pH levels (one T/A = 2.24 T/ha)

soil pH than at high soil pH. However, P sorption was greater at pH 5.5 than at 6.2. This agrees with most concepts of phosphorus solubility in soils. The phosphate requirement was decreased by 300 µg P/g soil (about 500 kg P/ha) by the prior field application of 9 tons/ha of TVA slag at pH 5.5. It was only 125 µg P/g

soil at pH 6.2. The effects of phosphate and silicate were not additive. The pronounced effect of Si at low soil pH seems to be related to an inverse relationship between soil pH and Si solubility.

Extractable P was evaluated nine months after silicate applications, during which time plots were cropped with sugarcane (Figure 3). Extractable P increased with increasing rates of silicate

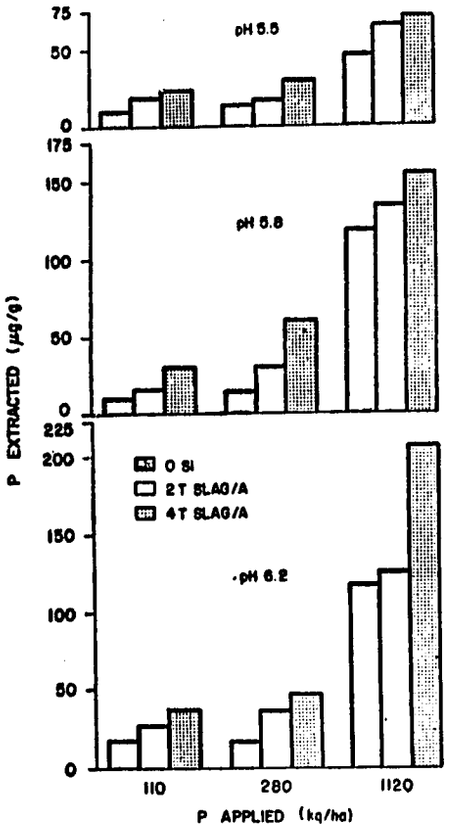

Fig. 3. Phosphorus extracted from a Gibbsihumox (Kappa series) in relation to prior field treatments with calcium silicate slag and/or calcium carbonate to give three levels each of Si and pH (one T/A = 2.24 T/ha)

initially applied and was highest at the highest pH level. These studies indicate that P extractability from soils can be increased by silicate applications without increasing soil pH or applied phosphorus levels.

Influence of silicate on phosphorus nutrition of sugarcane: In the pot experiment, dry matter yield, P percentage, and yield of

plant P increased greatly with increasing rates of applied P (Table 3). The amplified phosphorus index for the check treatments was 1,070, a value far below the critical value of 1,800 set by Clements (1965)—which demonstrated that the experimental soil was extremely deficient in plant available P. Silicate applications tended to increase P content in the green tops and decrease P concentration in the stalk when no P was applied (Table 3). An indication of this trend was also evident at the intermediate level of P fertilization but was absent when the level of P nutrition was high. These data suggest that Si enhances P mobilization from metabolically less active to metabolically more active tissue when the level of P nutrition is low.

TABLE 3

Effect of phosphorus and silicon applications on the phosphorus and silicon status of sugarcane at six months

Treatment						
Si T/ha	P kg/ha	API[1]	Green tops % P	Cane stalks % P	Total P yield g/pot	Sheath Si %
0	0	1,070	0.083	0.036	0.149	0.70
	1400	6,740	0.141	0.086	0.678	0.54
	5600	32,680	0.198	0.159	1.200	0.53
1.0	0	1,027	0.084	0.031	0.208	0.90
	1400	6,530	0.142	0.075	0.741	0.69
	5600	36,580	0.194	0.163	1.320	0.68
2.0	0	1,153	0.094	0.028	0.325	0.89
	1400	6,230	0.148	0.072	0.865	0.76
	5600	36,490	0.196	0.154	1.380	0.73

API—Amplified Phosphorus Index

A close relationship between Si and P in the plant is not difficult to suppose although exact mechanisms are certainly not obvious. Fox *et al.* (1969) have studied the soluble Si component in sugarcane tissues. Although this form is not abundant in these tissues, it is most concentrated in those which are metabolically most active and thus also high in P.

The largest yields were associated with the highest rate of Si applied (Figure 4). Silicon content of the check plants was 0.7 per

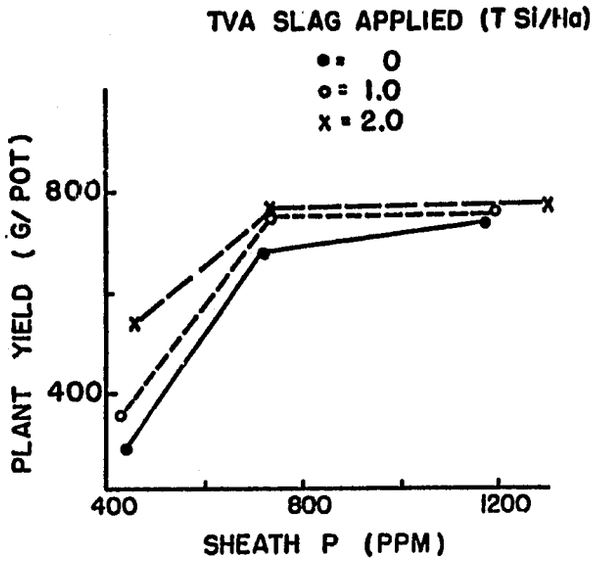

Fig. 4. Relationship between P content of sugarcane leaf sheaths and sugarcane yield at three levels of applied calcium silicate slag. Values are means of 4 levels of applied Zn.

cent which is on the borderline of adequacy for Si in sugarcane (Fox *et al.* 1967). When yields were increased by P fertilization, Si percentage declined (Table 3). These Si levels may seem anomalous since the soil Si level is quite low. However, this may be explained by the fact that irrigation water used for the experiment contained 20 ppm Si and thus supplied some Si to all pots, including the checks. Figure 4 and Table 3 indicate that silicate somehow improved plant P nutrition when no P was applied. Without P added silicate visibly increased tillering which is generally associated with improved P nutrition. It is probable that silicate increased the solubility of native and applied P which, under conditions of P deficiency would be accompanied by increased yields. However, an examination of yields in relation to plant P content indicate that at identical, low P levels the silicate-treated plants grew best (Figure 4). Obviously something more than P availability must have been involved. Silicon seems to have helped meet the internal P requirement of sugarcane through more efficient utilization of a limited supply within the plant. For example, Figure 4 indicates that sugarcane tended to attain *maximum* yield at a lower concentration of plant P when silicate was in abundant supply.

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