

The effect of silicic acid on rice in a P-deficient soil

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Abstract

A pot experiment was conducted to analyze the effect of silicon on the growth of rice grown in a P-deficient soil and on P availability in the soil. Silicic acid was used, rather than a silicate salt, to avoid the complication of changes in soil pH.

Shoot dry weight on silicic acid treated soil ($0.47 \text{ mg Si g}^{-1}$ soil) increased significantly under both nonflooded and flooded conditions. Shoot Si concentration also increased although P concentration did not. Mn concentration decreased with silicic acid, resulting in a higher P/Mn ratio in shoots.

An adsorption and desorption experiment showed that silicic acid did not displace P nor decrease the ability of the soil to adsorb P. In contrast, Si desorption increased with increasing P concentration in the solution, and Si adsorption was reduced when P was applied first.

These results suggest that silicic acid does not increase P availability in soil. Increased dry weight may be attributed to a higher P/Mn ratio in the shoot, which may improve P utilization in the plant.

Introduction

Although silicon has not been recognized as an essential element, its beneficial effects have been reported in many plants. One recognized effect has been the interaction between Si and P.

Fisher (1929) indicated that an increase in barley yield after the application of sodium silicates, resulted from increased P availability in the soil. Bastisse (1947) reported that adsorbed P could be displaced by Si. The displacement of P from certain soils by Si was also demonstrated by adsorption isotherms (Laws, 1951; Obihara and Russell, 1972). Silva (1971) reviewed most of the work conducted in Hawaii and also concluded that Si may replace P at adsorption sites.

Roy *et al.* (1971) reported that silicate applications decreased P adsorption in certain acid soils. Syouji (1981) studied the utilization of adsorbed P by crops from the viewpoint of energy and resource conservation. He found little conversion of P from slightly soluble to soluble forms

after the application of calcium silicate, but P adsorption was prevented. Kundu *et al.* (1988) confirmed these results and reported the time-dependent nature of Si in reducing P adsorption.

The above reports indicate that an increase in soil P availability is attributable to a Si effect. It should be noted, however, that in all abovementioned experiments either sodium or calcium silicate was used as the Si source, or P adsorption and desorption occurred in highly alkaline solutions where pH was above 8. The influence of pH on P availability was ignored in the reports. Furthermore, except in alkaline soils, silicon generally exists as monosilicic acid in soil solutions and is adsorbed as Si(OH)_4 (McKeague and Cline, 1963a;b). It is not known whether the behavior of Si in soil is dependent on its applied form, silicic acid or silicate.

In this paper, the effects of silicic acid on the growth of rice and on P availability in a P-deficient soil are discussed.

Materials and methods

The soil used in the experiment, taken from Yakuno-cho, Kyoto Metropolitan Prefecture of Japan, is a light clay with CEC 22.7 meq 100g⁻¹, 9.02% C and 0.33% N. The soil had a pH of 4.5 and a PAC (phosphate adsorption coefficient) of 980 mg P 100 g⁻¹ soil. The soil was derived from sediments of weathered basalt, but the upper part of the profile received an addition of volcanic ash (Miura, 1986).

Rice experiment

A completely randomized design with 4 replications was prepared using silicic acid times moisture treatments. Fractions of soil that had passed a 2-mm sieve were used for pot culture of rice (*Oryza sativa* L. cv. Akebono). The soil had previously received 0 or 0.47 mg Si g⁻¹ soil (-Si and +Si, respectively) as silicic acid which was prepared by the Okuda and Takahashi method (1961). Rice seeds were soaked in distilled water for one day and then sown 30 per pot in pots each containing 300 g of treated soil.

Pot soil was kept in a water-saturated state until seedling establishment. Seedlings were then thinned to 25 per pot and the soil was irrigated with distilled water to create two moisture conditions; flooded and nonflooded. For the non-flooded condition, pot soil was maintained at field capacity with supplied water daily. The flooded condition was maintained at a standing depth of 2 cm. No fertilizer was applied. Plants were grown for one month after sowing in a greenhouse and then harvested for analysis. The concentrations of P, Si, Fe and Mn in shoots were analyzed by methods reported previously (Ma and Takahashi, 1989).

Adsorption experiment

Three replicates each of two gram samples of soil, previously received 0, 0.23, 0.47, or 0.94 mg Si g⁻¹ soil as silicic acid, were equilibrated in 40-mL plastic centrifuge tubes for 5 days at 20°C with 30 mL of 0.01 M CaCl₂ containing 12 mM P as Ca(H₂PO₄)₂·H₂O. Two drops of toluene per tube were added. Tubes were shaken twice daily. After 5 days samples were centrifuged, filtered

and analyzed for P in the supernatant using the molybdenum blue colorimetric method. Phosphorus which had disappeared from the solution was considered to have been adsorbed.

Desorption experiment

For P desorption experiment, three replicates each of ten gram samples of soil, previously received 0 or 4 mg P g⁻¹ soil as Ca(H₂PO₄)₂·H₂O, were equilibrated for 5 days at 20°C with 25 mL of 0.01 M CaCl₂ containing a range of Si concentrations as indicated in the figures as silicic acid. Phosphorus in the supernatant was determined using the procedures described above, and Si using the colorimetric molybdenum blue method. Phosphorus which appeared in the solution or Si which disappeared from the solution were considered to have been desorbed or adsorbed, respectively.

For Si desorption experiment, three replicates each of ten gram samples of soil, previously received 0 or 0.47 mg Si g⁻¹ soil, were equilibrated with 25 ml of 0.01 M CaCl₂ containing a range of P concentrations as indicated in figure as Ca(H₂PO₄)₂·H₂O under conditions described above. Silicon which increased in the solution was considered to have been desorbed.

Results

Shoot dry weight increased significantly with +Si under both flooded and nonflooded conditions (Table 1). The P concentration of shoots with +Si did not increase compared to -Si under either nonflooded or flooded conditions. Under +Si, shoot Si concentration increased, Mn significantly decreased, and Fe was relatively unchanged. Because of decreased Mn, the P/Mn ratio within shoots increased 12 percent under nonflooded condition and 32 percent under flooded condition, compared to -Si. The shoot P/Fe ratio was not increased by +Si in this experiment.

In the adsorption and desorption experiments, P adsorption was about 175 μmol g⁻¹ soil by samples which had received a range of silicic acid from 0 to 0.94 mg Si g⁻¹ soil (Table 2). P adsorption was not decreased by a previous addi-

Table 1. Dry weight and elemental concentrations in shoots under different moisture conditions and silicic acid treatments

	Nonflooded		Flooded		LSD (0.01)
	-Si	+Si ^a	-Si	+Si	
Dry weight (g)	1.34	1.52	1.40	1.61	0.10
Si (%)	1.44	2.81	2.10	3.58	0.17
P (ppm)	974	880	1041	1030	89.6
Fe (ppm)	96.1	84.6	126	116	21.1
Mn (ppm)	1870	1518	3696	2761	265
B/Fe	10.1	10.4	8.3	8.9	
P/Mn	0.52	0.58	0.28	0.37	

^a Silicic acid was added at 0.47 mg Si g⁻¹ soil. Soil pH with +Si was the same as -Si.

Table 2. Effect of a previous application of silicic acid on P adsorption

Treatment ^a	P adsorbed ($\mu\text{mol g}^{-1}$ soil)
Si0	175.2
Si1	173.9
Si2	175.2
Si3	175.5

^a Si0, Si1, Si2 and Si3 represent soil samples which had previously received 0, 0.23, 0.47 or 0.94 mg Si g⁻¹ soil as silicic acid.

tion of silicic acid. A range of silicic acid concentration did not cause P desorption in soil samples which had received either 0 or 4 mg P g⁻¹ soil (Fig. 1).

Si adsorption responded linearly to Si concentrations, but was significantly reduced in soil samples which has previously received P. Si adsorption ranged from -32 to $567 \times 10^{-2} \mu\text{mol g}^{-1}$ soil in samples which had received no P, and from -153 to $216 \times 10^{-2} \mu\text{mol g}^{-1}$ soil in samples which had previously received P (Fig. 2). Si desorbed by P ranged from 34 to $44 \times 10^{-2} \mu\text{mol}$

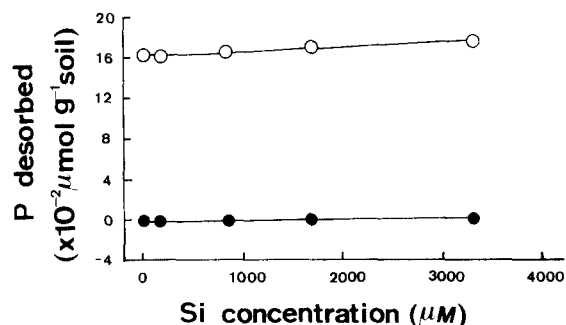


Fig. 1. Effect of Si concentration on P displacement in soil samples which had previously received 0 (●) or 4 mg P g⁻¹ soil (○).

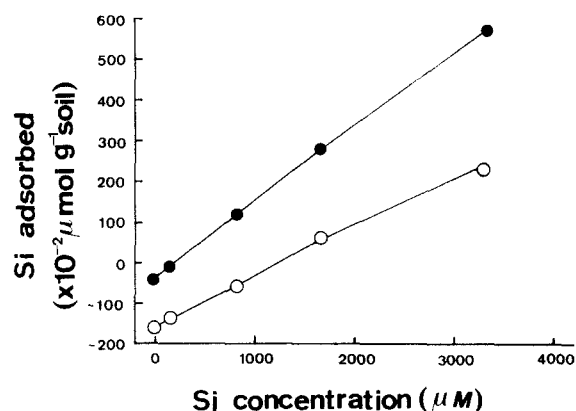


Fig. 2. Si adsorption by soil samples which had previously received 0 (●) or 4 mg P g⁻¹ soil (○).

g⁻¹ soil in samples which had received no Si, and from 82 to $104 \times 10^{-2} \mu\text{mol g}^{-1}$ soil in samples which had received Si (Fig. 3). Si desorption increased with increasing P concentration in the solution.

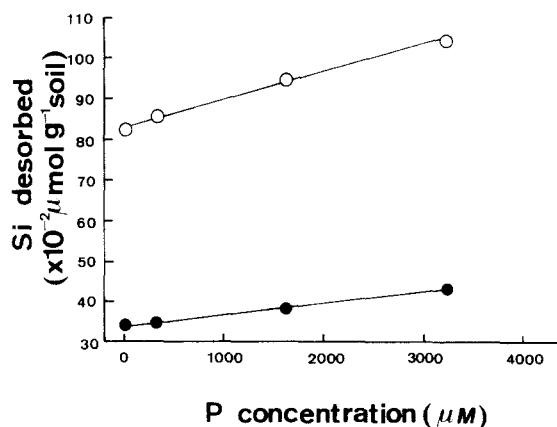


Fig. 3. Effect of P concentration on Si displacement in soil samples which had previously received 0 (●) or 0.47 mg Si g⁻¹ soil (○).

Discussion

Silicic acid was used as the Si source, rather than a silicate salt, to separate the pH effect caused by silicate application from the Si effect. Shoot dry weight significantly increased with +Si, but was not accompanied by increased P concentration in shoots. Likewise in the adsorption and desorption experiments, P adsorption was not decreased by a previous addition of silicic acid (Table 2) nor was P desorption affected by a range of silicic acid concentrations (Fig. 1). These observations suggest that silicic acid did not affect P availability in Yakuno soil.

Both P and Si were adsorbed by the soil (Table 2, Fig. 2). However, much more P was adsorbed than Si. Miura (1986) indicated that Yakuno soil was rich in Al-humus complexes. Wada and Gunjigake (1979), and Shoji and Fujiwara (1984) found that Al-humus complexes have a great affinity for P, and that P adsorption by nonallophanic soils is mainly governed by Al-humus complexes. In addition, Saito and Shoji (1984) reported that Al in Al-humus complexes has a low reactivity with Si. These observations suggest that Yakuno soil has a high affinity for P than for Si.

Results shown in Figures 2 and 3, indicate that some sites of Si adsorption may be the same as those of P. Thus added P may not only decrease Si adsorption, but may also displace adsorbed Si because of its higher site affinity, however the reverse is not true.

The decrease in P adsorption by Si reported by Noda and Komai (1958); Roy *et al.* (1971); and Syouji (1981) might have resulted from a pH effect because these researchers used Ca or Na silicates as a Si source, which is known to increase soil pH. However, the maximum adsorption of Si usually occurs in the pH range of 9–10, and P in the pH range of 2–4 (Higashi and Shinagawa, 1981; Imai, 1981; Obihara and Russell, 1971). Acid soils deficient in P usually have a pH below 5. It can be assumed that P adsorption by these soils is much greater than Si adsorption. On the other hand, Toth (1939) indicated that P was released from the adsorbed state only in slightly alkaline media, meaning that displacement of P was by hydroxyl or silicate ions rather than silicic acid. Thus it seems

impossible that Si affects P availability in these soils, although further study will be necessary to confirm this speculation.

Our results suggest that increased shoot dry weight may result from other reasons. In a previous paper, we reported that P utilization in the plant might be indirectly improved by Si when the P level in solution was low (Ma and Takahashi, 1990). We suggested that plant P/Mn and P/Fe ratios may be more indicative of P nutrition than P concentration. In this report, as shown in Table 1, the concentration of Mn decreased with +Si and thus the P/Mn ratio increased under both flooded and nonflooded conditions, though the P/Fe ratio did not increase. Rice is known to be a Mn-accumulator, and may contain 20 to 30 times more Mn than Fe (Table 1). Thus Mn is thought to be the main factor controlling P availability within the plant.

In summary, Si, as silicic acid, did not increase P availability in our soil. But increased shoot growth may be attributed to an indirect improvement in P utilization by the plant from a decrease in Mn uptake.

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