Communications in Soil Science and Plant Analysis

ISSN: 0010-3624 (Print) 1532-2416 (Online) Journal homepage: http://www.tandfonline.com/loi/lcss20

Effect of Silicon on Low pH Soil Phosphorus Sorption and on Uptake and Growth of Maize

C. Owino-Gerroh & G. J. Gascho

To cite this article: C. Owino-Gerroh & G. J. Gascho (2005) Effect of Silicon on Low pH Soil Phosphorus Sorption and on Uptake and Growth of Maize, Communications in Soil Science and Plant Analysis, 35:15-16, 2369-2378

To link to this article: http://dx.doi.org/10.1081/LCSS-200030686

COMMUNICATIONS IN SOIL SCIENCE AND PLANT ANALYSIS
Vol. 35, Nos. 15 & 16, pp. 2369–2378, 2004

Effect of Silicon on Low pH Soil Phosphorus Sorption and on Uptake and Growth of Maize

C. Owino-Gerroh[1] and G. J. Gascho[2,*]

[1]Department of Horticulture, Maseno University Maseno, Kenya
[2]Crop and Soil Sciences Department, Coastal Plain Experiment Station, University of Georgia, Tifton, Georgia, USA

ABSTRACT

High soil sorption of phosphorus (P) in some P deficient low pH soils reduces the efficiency of P fertilizer use and crop yields. Silicon (Si) application has been reported to decrease P sorption and increase yields in such soils. The effect of silicate on P sorption and availability and on growth of maize (*Zea mays* L. cv. Golden Acres 7885) grown in a low pH Greenville soil from the Coastal Plain of Georgia was investigated in laboratory and pot experiments. Applied sodium (Na) silicate markedly reduced the soil's high P sorption. In a pot study in a greenhouse, both maize shoot and root dry weights were increased by applications of silicate, phosphate, and by applications of silicate together with phosphate. Dry weights of

*Correspondence: G. J. Gascho, Crop and Soil Sciences Department, Coastal Plain Experiment Station, University of Georgia, Tifton, Georgia 31793, USA; E-mail: gascho@tifton.uga.edu.

DOI: 10.1081/LCSS-200030686
0010-3624 (Print); 1532-2416 (Online)

both shoot and root were increased by 3.92 mg Si/pot when Si was applied together with P. Silicon and P contents in the shoot and the root were increased by Si, but not by P application. The reduced P sorption when silicate was applied was adduced to the increase in the soil pH from the accompanying Na cation. The applied silicate ion converted to amorphous silicic acid (H_3SiO_4) in the soil. Amorphous H_3SiO_4 has less negative surface charge than the phosphate ion. Therefore, it should not replace P on soil binding sites or be preferentially absorbed when both are in the soil solution. Phosphorus was limiting in the soil and all applied P rates increased maize dry weight. The weight increase when Si was applied was attributed to the increase in the soil pH from the accompanying calcium (Ca^{++}) and Si concentration in the soil solution, which improved the conditions for the growth of maize resulting in increased transpiration and therefore greater P uptake and utilization. The same reason is given for the increase in dry weight when both Si and P were applied. This is because greater dry weight was found at lower P rate (0.1 g P/pot) than the recommended rate (0.2 g P/pot). Greater P uptake and utilization was supported by increased P and Si contents in the shoot and root when Si was applied.

Key Words: Phosphorus availability; Phosphorus sorption; Silicate; Soil acidity.

INTRODUCTION

Phosphorus sorption results in low P use efficiency in acid soils.[1,2] The sorption is mainly associated with the abundance of kaolinitic clays and free hydrous oxides of iron (Fe) and aluminum (Al) in the soils.[2–4]

Silicon has been reported to have many beneficial effects on plant growth that include availing P when the soil has high P sorption stress.[3,5] Explanations for these beneficial effects are varied and even contradictory and include; partial substitution of Si for P,[6] an improvement of available P in the soil,[7] inhibition of Fe, Al, and manganese (Mn) toxicities in such soils and better P utilization.[6] Partial substitution of Si for P in physiological processes is doubtful but an interaction between Si and P in plants may or may not have any effect.[5] Varying experimental materials and methods could be an important reason for the varied explanations in the literature.

Beneficial effects of Si at low soil pH stress have been recorded on many crop plants, and particularly the gramineae.[5,8–11] Soil acidity is strongly related to high P sorption.[7] Recently, it has been reported that

Marcel Dekker, Inc.
270 Madison Avenue, New York, New York 10016

P uptake was markedly increased and plant growth promoted when Si was added to such soil.[5,6,9,11,12] This paper presents the results of P sorption with three rates of added Si and a pot experiment on the effect of Si, applied as a silicate, on P availability and growth of maize (*Zea mays* L.) in a low pH soil.

MATERIALS AND METHODS

Greenville sandy clay (Rhodic Paleudult), a well-drained Coastal Plain soil, was used in the study. It was found on a slope of <4%, has dark reddish brown surface profile which is about 180 mm thick, with low permeability and medium available water content. The sample used was from a location that had never been under cultivation. Its main characteristics are presented in Table 1. The soil was acidic, low in organic matter, available phosphorus and effective cation exchange capacity while Si content was medium according to unpublished ratings of Korndorfer and Snyder.[13]

Phosphorus sorption characteristics of the soil and how they were affected by the addition of the inorganic silicate anion were determined by equilibrating 5.0 g aliquotes of ungrounded sieved soil with P in 250 mL polythene bottles. Concentrations of 0, 77.5, 155, 232.50, 310, and 387.50 mg P/L (P as KH_2PO_4 in 0.1 M KCl, KCl being used to maintain a constant ionic environment) and 0, 28, and 58 mg Si/L (Si as Na_2SiO_3) were used. The bottles were shook for 1 h on a reciprocal shaker, left standing for 24 h, and then shook for an additional 30 min. Thereafter, P in the equilibrium solution was determined colorimetrically using a spectrophotometer after developing the color using ammonium molybdate solution.[14] The P in equilibrium solution and P sorbed data

Table 1. Some physiochemical characteristics of Greenville soil.

Particle size distribution							Exchangeable cations				
Sand	Silt	Clay		pH	Org.C.	Avail.P	Ca	Mg	K	Na	Si
(%)			Texture	(1:2.5 w/v)	(g/kg)	(mg/kg)	(Cmol(+)/kg)				(mg/kg)
60	3	37	Sandy clay	5.3	1.71	20.5	0.5	0.17	0.12	0.09	19

NB: Org.C = Organic carbon.
Avail.P = Available phosphorus.

were then fitted into the Langmuir equation in its linear form $C/\mathrm{Pd} = 1/kb + C/b$; where C is the equilibrium concentration, Pd is the adsorbed P, k is the P sorption energy, and b is the maximum P sorption[17] to determine the P sorption of the amended soil.

The effect of the silicate anion on P availability and growth of maize was carried out in a greenhouse. Air-dried soil was sieved through a 1-mm screen and 1.50 kg was added to 1.5 L capacity round-plastic pots. A 4-by-4 factorial arrangement in a completely randomized design with four replications was used. The factors were four rates of Si: 0, 1.96, 3.92, and 5.88 mg/pot and P: 0, 0.1, 0.2, and 0.3 g/pot (equivalent to 0, 39, 78, and 117 kg P/ha), respectively. Calcium silicate ($CaSiO_3$) and KH_2PO_4 were used as sources for Si and P, respectively. $CaSiO_3$ was thoroughly mixed with the soils in the pot as per treatment before the soil was wetted with dionized water to field capacity. Phosphorus was applied as a solution in the dionized water as per the treatment combination. Thereafter, five certified seeds of maize (*Zea mays* L. cv. Golden Acres 7885) were sown per pot and later thinned to one after seedling emergence. Ammonium nitrate (NH_4NO_3) at 42 mg N/pot was then added as a top-dressing in all the pots. The plants were then allowed to grow for 4 weeks before the shoots were excised from the roots at the soil surface, the soil was washed-off the roots, both the shoot and root dried in the oven at 70°C to constant dry weights, and their dry weights were recorded. Thereafter, the shoots and roots were ground, dry ashed and dissolved in Mehlich 1 reagent before their Si and P contents were determined colorimetrically using silico-molybdic blue and phospho-molybdic blue complex procedures.[14]

RESULTS AND DISCUSSION

The phosphorus sorption of Greenville soil is high; but reduced by increasing rates of the applied silicate (Fig. 1). Applied silicate and phosphate increased shoot and root dry weights but greater increases were found when silicate was applied together with phosphate (Figs. 2 and 3). Dry weight increases were found at the 3.92 mg Si/pot rate for both shoot and root and 0.1 and 0.3 g P/pot rates for shoots and roots, respectively. There was a significant interaction between Si and P rates. The greatest dry weights for both shoots and roots were found at 3.92 mg Si/pot and 0.1 g P/pot. Silicon and P contents in the shoot and root were only increased by Si application. Greatest contents were found when 3.92 mg Si/pot was applied (Table 2).

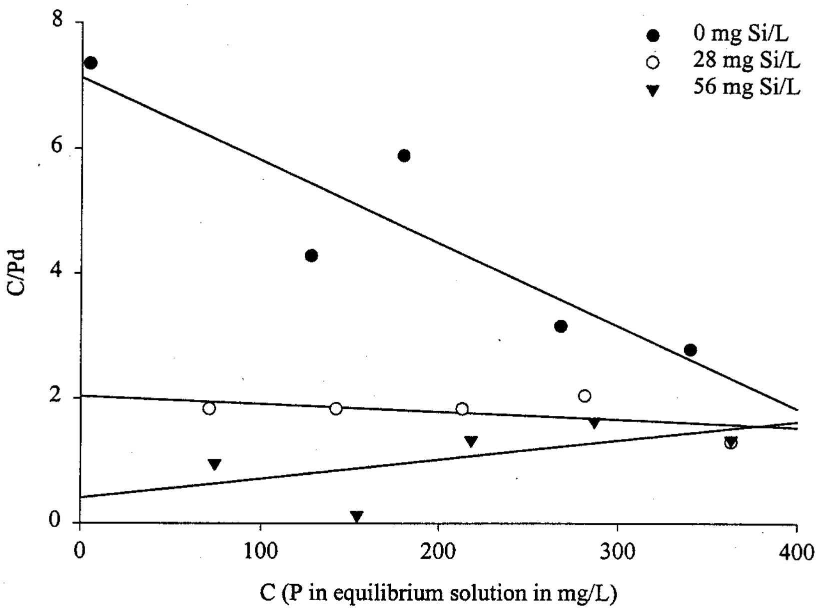

Figure 1. Effect of Si on P sorption of Greenville soil.

The decrease in P sorption could be adduced to the increase in soil pH from the accompanying Na^+ cation. Higher pH was found when sodium silicate was added to the soil and the increase was almost proportional to the amount of silicate added (Fig. 4). Applied silicate ion converts to the amorphous silicic acid (H_3SiO_4) immediately when added to a soil with a pH range 4 to 9.[11,16] This form of Si has some negative surface charges and more reactive than crystalline H_3SiO_4,[17] but the charges are lower than that of the P anion. Therefore, P likely is still absorbed preferentially; not being replaced by the silicate cation at the adsorption site. Koski-Vahala et al.[3] made many observations and asserted that the effects of Si on P dynamics in the soil are negligible. Reduced P sorption when silicate ion is added to the soil has been reported. Ma and Takahashi[6] attributed the reduction of P sorption to the increase in the soil pH due to the accompanying Ca and Na cations when either calcium or sodium silicate are used as sources of Si. Increased shoot and root dry weights upon application of Si can be attributed to the increase in concentration of Si in the soil solution and soil pH. Although the amount of Si in the soil was classified as medium, this is a stressed soil

Marcel Dekker, Inc.
270 Madison Avenue, New York, New York 10016

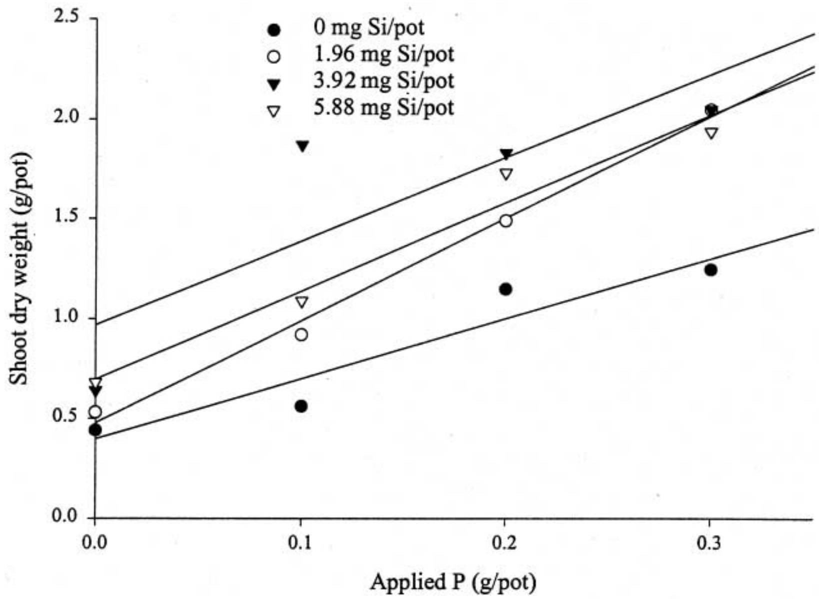

Figure 2. Regressions of maize shoot dry weight on P rate for 4 Si rates.

and under such conditions, Si application has been reported to enhanced the growth of many crops including maize.[5,9] The improved growth has been attributed to many factors. These include better P utilization, enhanced root elongation and reduced concentrations of Mn and Fe and therefore reduction in their uptake.[5] Application of Si also increased the soil pH. This enhanced the availability of P in soil solution. Phosphorus was limiting in this soil and this was ascertained by the increase in dry weight when P was added to the soil. The weight increase as a result of Si and P interaction, could be adduced to several factors. These include an increase in soil pH that made P more available and better plant growth because of improved P uptake and utilization when Si concentration was high in a low pH soil with high P sorption. These conditions also reduce Mn an Fe activity thereby reducing their toxic effects on the growth of maize plant.[5,11] An increase in Si concentration in the soil solution also alters the plant cation-anion balance and increase tissue concentrations of organic acids in plants. This ameliorates negative effects of heavy metals such as Al that are associated with acid soil conditions.[10] The increase in Si and P content in the plant tissue due to addition of Si could also be adduce to the decrease in soil acidity that made P more available hence

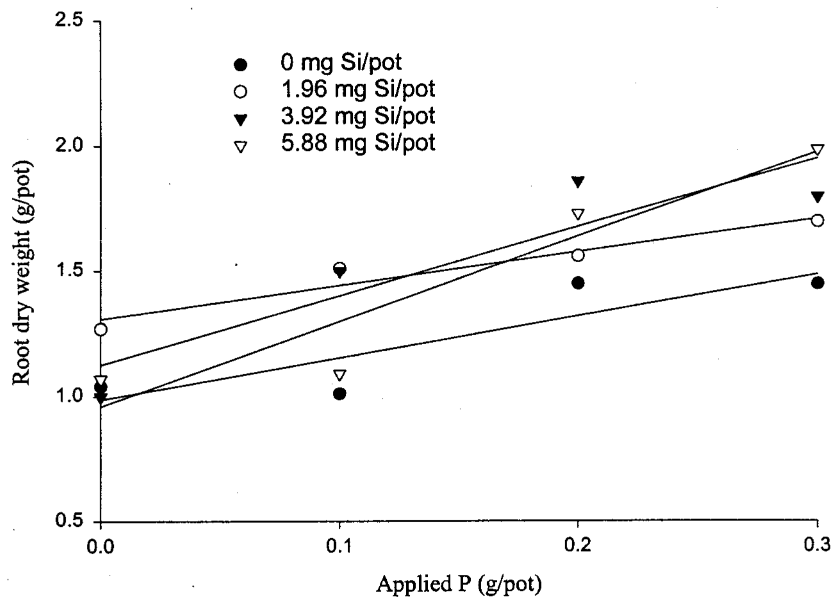

Figure 3. Regressions of maize root dry weight on P rate for 4 Si rates.

Table 2. Effect of silicon on maize (*Zea mays* L.) shoot and root Si and P content.

Si rate (g/kg)	Shoot P (mg/g)	Shoot Si (mg/g)	Root P (mg/g)	Root Si (mg/g)
0	0.55 b	0.24 b	0.34 c	0.54 c
1.96	0.62 b	0.33 a	0.45 b	0.57 bc
3.92	0.91 a	0.36 a	0.67 a	0.72 a
5.88	0.82 a	0.34 a	0.73 a	0.67 ab
F-test	***	*	***	**
$LSD_{(0.05)}$	0.019	0.007	0.008	0.012

(a) *, **, ***, significantly different at $P < 0.05$, 0.01, and 0.001, respectively.
(b) Means followed by the same letter are not different by $LSD_{(0.05)}$.

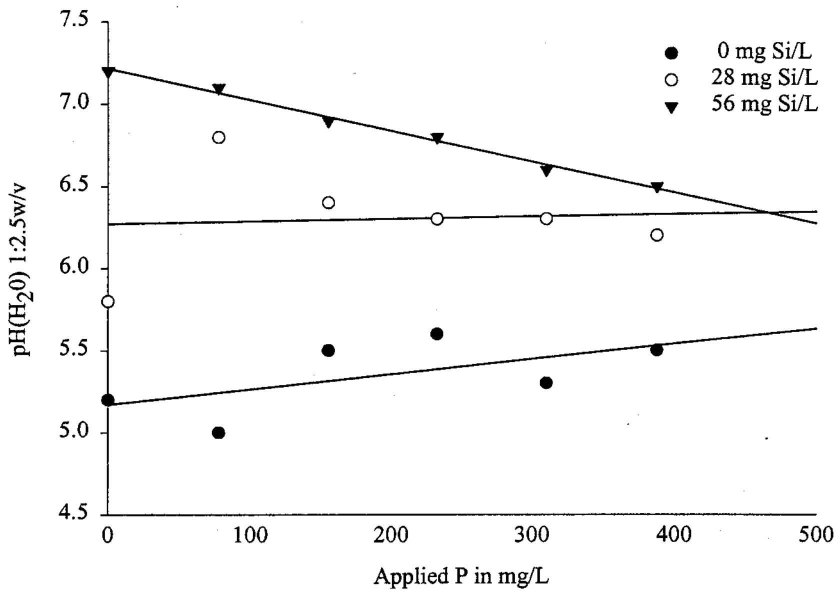

Figure 4. Effect of Si and P on the pH of Greenville soil.

improved growth and nutrient uptake including P and Si. Ma and Takahashi[6] reported that the enhanced P uptake in the presence of Si was due to increased transpiration rate when P levels are low. They asserted that this meant that Si improved internal P utilization and reduction of Mn and Fe activity in the presence of Si; thus the improvement of P:Mn and P:Fe ratios. Many observations were also made by Jen et al.,[18] who reported that Si application promoted nutrient absorption, transpiration and moisture use, and P uptake and utilization by maize plants.

CONCLUSIONS

Phosphorus sorption in the soil was decreased by application of soluble Si. That result is attributed to the increase in soil pH. Applied silicate was converted to amorphous silicic acid (H_4SiO_3). At low soil pH the surface negative charge of H_4SiO_3 is lower than the surface negative charge of phosphate anion. Therefore, P is preferentially adsorbed at the soil binding sites. The applied silicate likely increased the weight of maize by increasing soil pH thereby making P more available, therefore

increasing P uptake and utilization. Greater maize weight and P content were found when silicate was added to the soil.

ACKNOWLEDGMENTS

The authors acknowledge the support from Center for International Exchange of Scholars (CIES), Department of State, USA Government for C. Gerroh under Fulbright Senior Scholar's Award and the University of Georgia. The technical assistance provided by B. H. Baldree and Cindy Roesel is also appreciated.

REFERENCES

1. Quyang, D.S.; Mackenzie, A.F.; Fan, M.N. Avalability of banded triple superphosphate with urea and phosphorus use efficiency by corn. Nutrient Cycl. Agroecosyst. **1999**, *53* (3), 237–247.
2. Zoysa, A.K.N.; Loganathan, P.; Hedley, M.J. Phosphorus utilization efficiency and depletion of phosphate fractions in the Rhizosphere of three tea (*Camellia sinensis* L.) clones. Nutrient Cycl. Agroecosyst. **1999**, *53* (2), 189–201.
3. Koski-Vahala, J.; Hartikainen, H.; Tallberg, P. Phosphorus mobilization from various sediment pool in response to increase pH and silicate concentration. J. Environ. Qual. **2001**, *30*, 546–552.
4. Agbenin, J.O. Extraction of iron and aluminium effects on phosphate sorption in a Savanna Alfisol. Soil Sci. Am. J. **2003**, *67*, 589–595.
5. Ma, J.F.; Miyake, Y.; Takahashi, E. Silicon as a beneficial element for crop plants. In *Silicon in Agriculture*; Datnoff, L.E., Snyder, G.H., Korndorfer, G.H., Eds.; Elsevier: Netherlands, 2001; Studies in Plant Sciences *8*, 17–39.
6. Ma, J.F.; Takahashi, E. Effect of silicate phosphate availability for rice in a P-deficient soil. Plant Soil **1991**, *133*, 151–155.
7. Smyth, T.J.; Sanchez, P. Effect of lime, silicate, and phosphate application to an Oxisol on phosphorus sorption and ion retention. Soil Sci. Soc. Am. J. **1980**, *44*, 500–505.
8. D'Hoore, J.; Coultier, J.K. Soil silicon and plant nutrition. *Soils of the Humid Tropics*; National Research Council Committee on Tropical Soils; National Academy of Sciences: Washington, DC, 1972; 163–173.

9. Ma, J.F.; Sasaki, M.; Matsumoto, H. Al-induced inhibition of root elongation in corn (*Zea mays* L.), is overcome by Si addition. Plant Soil **1997**, *188*, 171–176.
10. Corrales, S.; Poschenrieder, C.; Barcelo, J. Influence of silicon pretreatment on aluminium toxicities in maize roots. Plant Soil **1997**, *190*, 203–209.
11. Epstein, E. Silicon in plants: facts vs. concepts. In *Silicon in Agriculture*; Datnoff, L.E., Snyder, G.H., Korndorfer, G.H., Eds.; Elsevier: Netherlands, 2001; Studies in Plant Sciences *8*, 1–15.
12. Nieuwenhuis, P.; Lales, J.S. Response of maize (*Zea may* L.) to various modes and levels of silicon. Philippine Agric. Scientist. **2001**, *84* (4), 397–400.
13. Snyder, G.H. Methods for silicon analyses in plants, soils and fertilizers. In *Silicon in Agriculture*; Datnoff, L.E., Snyder, G.H., Korndorfer, G.H., Eds.; Elservier: Netherlands, 2001; Studies in Plant Sciences *8*, 185–198.
14. Page, A.L.; Miller, R.L.; Keeney, D.R. *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties*, 2nd Ed.; Soil Science Society of America: Madison, WI, 1982; Agron. No. 9, 1188 pp.
15. Quintero, C.E.; Boschetti, N.G.; Benavidez, R.A. Phosphorus retention in some soils of the Argentinean Mesopotamia. Commun. Soil Sci. Plant Anal. **1999**, *30* (9&10), 1449–1461.
16. William, R.J. Introduction to silicon chemistry and biochemistry. In *Ciba Foundation Symposium: Silicon Biochemistry*; Evered, D., O'Connor, M., Eds.; John Wiley and Sons: Chichester, England, 1986; Vol. 121, 24–29.
17. Langmuir, D. *Aqueous Environmental Chemistry*; Prentice Hall: Upper Saddle River, NJ, 1997; 600 pp.
18. Jen, R.; Jinrui, G.; XinQin, X.; Guang, Q.; ZhenLin, Y. Preliminary study on yield increase effects and yield increase mechanism of silicate fertilizer on maize. J. Maize Sci. **2002**, *10* (2), 86–87.