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Article

Effects of Silicate Fertilizer on Increasing Phosphorus Availability in Salt Accumulated Soil during Chinese Cabbage Cultivation

Yong-Bok Lee[1] and Pil-Joo Kim[2,*]

[1] *School of Environment and Natural Resources, The Ohio State University, 2021 Coffey Road, Columbus, OH 43210, USA*
[2] *Dept. Agricultural Chemistry, Division of Applied Life Science, Graduate school, Gyeongsang National University,*
Chinju, 660-701, South Korea

High phosphate accumulations in greenhouse soils have been considered as a new agricultural problem in Korea. The effects of silicate on changes in phosphate fractions and on the yield of Chinese cabbage without P fertilization were investigated by pot experiment. For this experiment, P-accumulated soil was selected (Total-P; 2140 mg kg^{-1}). Three levels of silicate (0, 2, and 4 Mg ha^{-1}) without P fertilization and P fertilizer without silicate application (Si0+NPK) were applied in 1/2000a pots. The same amount of nitrogen and potassium fertilizers were applied to the all pots. The application of 4 Mg ha-1 of silicate greatly increased the yield of Chinese cabbage by 25% compared to Si0+NPK treatment. Although there is no significant difference in plant P absorption among all the treatments, the uptake of P in the 4 Mg ha^{-1} silicate application was significantly higher than Si0+NPK treatment due to increase in yield. The content of available SiO_2 in soil increased with increasing silicate application rates. The Si concentration of plant showed a positive correlation with available SiO_2 contents in soil and the yield of Chinese cabbage. Total P greatly decreased with increasing rates of silicate application, yet the change in available P content was not significant. The Si0+NPK treatment increased the content of Ca-P by 11%, however, which was decreased by 27% in the 4 Mg ha^{-1} silicate application. Therefore, the effect of silicate on reducing total-P was mainly attributed to the change in concentration of Ca-P. Our results suggest that the application of silicate in P-accumulated soils not only increase the crops yield but also reduces phosphate accumulation.

Key words : Phosphate accumulation, Silicate, Ion competition, Phosphate fractions, Chinese Cabbage

Introduction

For the last three decades, the area of greenhouse cultivation has greatly increased in Korea due to high economic benefits. The rates of fertilizer (N, P, K, and compost) application were very high in the greenhouse cultivation, because vegetables were generally cultivated two or three times within a year. In practice, the major nutrients were supplied as fertilizer at each cropping time and liquid fertilizer was sprayed several times to obtain the maximum yield. Therefore, considerable amounts of nutrients after plant uptake remained in soil. The national soil survey date showed that the content of available phosphate was two or three times higher than the optimum levels for plant growth in greenhouse cultivation (RDA, 1988). The phosphate accumulation has became agricultural problems which reduce crop yields and deteriorate the quality of agricultural products. To prevent phosphate accumulation, phosphate fertilizers application should be reduced.

Research on soil phosphate has been focused on increasing P availability under conditions of P deficiency due to very low P availability by fixation. Soluble phosphate rapidly reacts with soil components to form insoluble phosphate. In acid condition, phosphate ion mainly forms Fe-and Al-bounded insoluble phosphates and calcium bounded insoluble phosphates are stable in alkaline condition (Addiscott and Thomas, 2000). Much research has been conducted on the competitive adsorption between phosphate and silicate on soil and the effect of Si on availability of applied and adsorbed phosphate (Haynes, 1984; Obihara and Russell, 1972; Pardo and Guadalix, 1990; Ryden et al., 1987; Smyth and Sanchez, 1980). Shariatmadari and Mermut (1999) reported that addition of Si sharply reduced the P sorption of calcite. Although Lee et al.(2004) showed, in the laboratory experiments, that silicate application increased P desorption in P-

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*Corresponding author: Phone : +82557515466,
Fax: +82557570178, E-mail : pjkim@nongae.gsnu.ac.kr

accumulated soil, information on which forms of P were affected by silicate application was not be elucidated.

Although Si is not essential element for plant nutrition, the beneficial effect of Si on rice and sugarcane yields have been intensively studied (Ayres, 1966; Fisher, 1929; Lee et al., 2002; Raid et al., 1992), The beneficial effects of Si on crop growth are to alleviate salt stress, water stress and excess N stress through its deposition within leaf tissue (Ma et al., 2001). Silicate application may alleviate not only P-deficiency stress (Ma and Takahashi, 1990; Roy et al., 1971; Silva, 1971; Syouji, 1981) but also P-excess stress (Miyake and Takahashi, 1985). According to Ma et al. (2001), silicate effects are more obvious under biotic and abiotic stress because the functions of Si in plants are probably mechanical rather than physiological. They also suggested that the important role of Si for better and sustainable production of crops would be realized. Some researchers have reported the uptake of Si in several horticultural crops such as cucumber (Miyake and Takahashi, 1983), strawberry (Lanning, 1960), and tomato (Miyake and Takahashi, 1978). Research on silicate fertilization is required to increase the growth and development of horticultural crops.

The objective of this study were to investigate the effects of silicate application on the growth and yield of Chinese cabbage, and on the changes in phosphate fractional forms in a P-accumulated greenhouse soil.

Materials and Methods

Experimental procedure Bulk soil of 30 cm depth was collected from a greenhouse in *Gyeongnam* province of southern Korea. The major greenhouse crops, that were cultivated in this area for more than 20 yr, were watermelon, green pepper and Chinese cabbage. The soil was air-dried and passed through a 0.5 cm diameter sieve. The silicate was thoroughly mixed with 15 kg soil and transferred to pots (1/2000a). Silicate fertilizer was furnace slag; slag contains 0.5 M HCl soluble CaO (30%) and SiO_2 (28%). The pH and content of phosphate and Ex.-cations (Table 1) in soil was very high, which meet general characteristics of greenhouse soil in Korea.

Three levels of Silicate (0, 2.0, and 4.0 Mg ha^{-1}) were treated (Table 2). In all treatments, the same amount of nitrogen and potassium were applied. 50, 100, 55, and 100% of based nitrogen, phosphorus, potassium, and silicate were applied, respectively, on Sep. 15, 2001. Twenty five percent of nitrogen was top-dressed at Oct. 5, and 25% and 45% of nitrogen and potassium were applied at Oct. 24. The pots were allocated by completely randomized design in greenhouse and each treatment has five replications. To maintain the same lighting conditions, the position of pots were changed in the greenhouse once a week. Chinese cabbage (*Norangbombeachu*), was transplanted one plant per pot

Table 1. Selected properties of the soils used in the pot test before the experiments.

Contents	Mean	SD
pH	7.1	0.1
EC (dS m^{-1})	2.5	0.2
OM (g kg^{-1})	24.3	1.1
Available SiO_2 (mg kg^{-1})	265	26
Ex. Cations (cmol(+) kg^{-1})		
Ca	15.9	0.5
Mg	6.0	0.23
K	2.3	0.32
CEC (cmol(+) kg^{-1})	14.2	1.2
Phosphate (P) (mg kg^{-1})		
Total	2,140	54
Olsen	152	5
Organic	174	12
Inorganic	1,586	46
Residual	380	14
Extractable		
Water soluble	13	3
Ca bounded	490	18
Al bounded	628	17
Fe bounded	132	23

M: organic matter, EC: electrical conductivity, Ex. Cations: exchangeable cations, CEC: cation exchange capacity, SD: standard deviation.

Table 2. Treatments used in this study and field practices.

Treatments	Chemical fertilization (Mg ha^{-1})				Field practices	
	N	P_2O_5	K_2O	Silicate	Events	Dates
Si0+NK	0.32	0	0.2	0	Fertilization	
Si2+NK	0.32	0	0.2	2.0	- Basal	15 Sep.
Si4+NK	0.32	0	0.2	4.0	- 1st	5 Oct.
Si0+NPK	0.32	0.08	0.2	6.0	- 2ed	24 Oct.
					Transplanting	19 Sep.
					Harvest	25 Nom.

on Sep. 19, 2001 and harvested on Nom. 25, 2001.

Soil and plant analysis and soil-P frationation. Soil samples were air-dried and ground to passed through a 2-mm sieve. Soil pH and electrical conductivity (EC) were measured in 1:5 suspensions (deionized water). Organic matter content was determined by wet digestion (Allison, 1965). Available P was determined by extracting 2g of soil with 40 mL of 0.5 M $NaHCO_3$ for 30 min (Olsen et al., 1954). Exchangeable cations (Ca, Mg, and K) were extracted with 1 M NH_4OAc (pH 7.0) before analysis by atomic absorption spectroscopy. Available Si was determined by ICP-AES (Inductively Coupled Plasma Absorption Emission Spectrophotometer) after extracted with 1 M NaOAc (pH 4.0). Cation exchange capacity (CEC) was measured by ammonium acetate (pH 7.0) method (Sumner and Miller, 1996).

Sequential inorganic P fractionation of the soil was performed as follows: extraction with H_2O (water-soluble-P, W-P), 25 g L^{-1} acetic acid and 1 *M* NH_4Cl (calcium-bound-P, Ca-P), 1 *M* NH_4F (aluminum-bound-P, Al-P), and 1 *M* NaOH (iron-bound-P, Fe-P) in term (Watanabe and Kato, 1983). The amount of soil organic P (org-P) was estimated as being the difference in the P content after extraction with 0.5 *M* H_2SO_4 and what remained after igniting the soil sample at 350℃ for 1 h (O'Halloran, 1993). The amount of total P was determined after digested with conc. $HClO_4$.

The plant parts were ground after oven-drying at 70℃ for 72 h and then digested using H_2SO_4 for total nitrogen. A subsample of the oven-dried plant material was digested using a ternary solution (HNO_3:H_2SO_4:$HClO_4$, 10:1:4 v/v) for the determination of Ca, Mg, P, and K. The Si in the plant was weighed after H_2SO_4-$HClO_4$ digestion (RDA, 1988).

Results and Discussion

Yield response In P-accumulated greenhouse soil, the yields of Chinese cabbage showed no significant difference between P fertilization (Si0+NPK) and without P and silicate fertilization (Si0+NK). However, application of silicate increased the yield of Chinese cabbage greatly from 2200 g $plant^{-1}$ in Si0+NK to 2522 g $plant^{-1}$ for Si4+NK(Fig. 1). It is difficult to explain that the effect of silicate on the horticultural crop yield and growth because the modes of action of Si in the horticultural crops were still ambiguous (Savant et al., 1999). Applied silicate in the rice improved the photosynthetic efficiency (Elawad et al., 1982) and the imbalances of nutrients, especially P (Ma et al., 2001), and alleviated the various biotic and abiotic stresses. Most of these effects are caused by deposition of Si on the tissue. Therefore, the enhancement of Chinese cabbage yield with silicate application may be related to a significant increase in Si in the plant (Table 3).

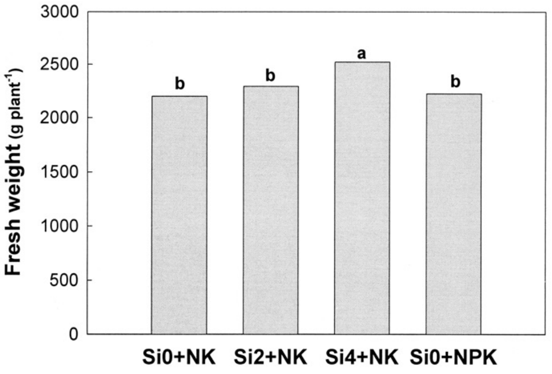

Fig. 1. The effect of silicate on the yield of Chinese cabbage. (The same letter is not significantly difference among the treatments at P<0.05)

Nutrition concentration and uptake The role of Si in the nutrition of horticultural crops has not been extensively studied compared with agricultural corps like rice (Voogt and Sonneveld, 2001). As shown in Table 3, silicate was effective on increasing the nutrient uptakes of

Table 3. Average nutrient content and uptake by Chinese cabbage plants at the harvesting stage.

Treatments	Nutrient content (g kg^{-1})			Nutrient uptake (g $plant^{-1}$)		
	N	P	Si		P	Si
Si0+NK	24.4	5.5	13.1	3.3	0.73	1.8
Si2+NK	25.6	5.6	14.9	3.5	0.78	2.2
Si4+NK	26.5	5.8	19.3	3.6	0.82	2.7
Si0+NPK	25.6	5.4	13.3	3.3	0.70	1.9
$LSD_{0.05}$	ns	ns	0.8	ns	0.07	0.3

ns, no significant difference among the treatments at P<0.05.

Chinese cabbage. The difference in P content in plants among all treatments was not observed. This means the soil had an excess of available phosphate for Chinese cabbage growth. Although silicate application had no effect on the P content in plant, the silicate application (4 Mg ha^{-1}) significantly increased P uptake compared to Si0+NK and Si0+NPK treatments due to yield increase. The Chinese cabbage is not Si-accumulated plant, but the highest Si content in the plant was observed in the highest available SiO_2 in soil. The Si content in the plant was significantly increased with increasing rates of silicate application and was significantly correlated with the contents of available Si in the soil (Fig. 2A). The yield of Chinese cabbage also was significantly and positively correlated with Si concentration in the plant (Fig. 2B), which indicated that deposition of Si in plant could positively affect the yield of cabbage. Generally, silicate has no excess toxicity in plants because silicic acid polymerizes and deposits outside the cell and does not affect metabolic process inside the cell (Takahashi, 2002). Many beneficial effects on rice growth and yield were observed in higher Si content (Takahashi et al., 1990) and deposition of silicate on leaves could enhance photosynthesis (Kaufman et al., 1979).

Soil properties After harvesting, the soil pH in the Si4+NK treatment increased by 0.3 units compared to Si0+NPK treatment due to the liming effect of silicate (Table 4). The EC in the all treatments decreased from 3.5 dS m^{-1} to around 2.0 dS m^{-1} after experiment due to decreases in exchangeable cations. According to Ha et al. (1997) the content of exchangeable K, Ca, and Mg in greenhouse soil were positively correlated with EC due to over 100 % of base saturation. In this study, the soil base saturation was reduced from 139 % before the experiment to around 117 % in all treatments after the experiment, but it was still high for plant growth. It is required to evaluate the effect of excess exchangeable cations on crop growth and agricultural environment.

The content of available Si in soil significantly

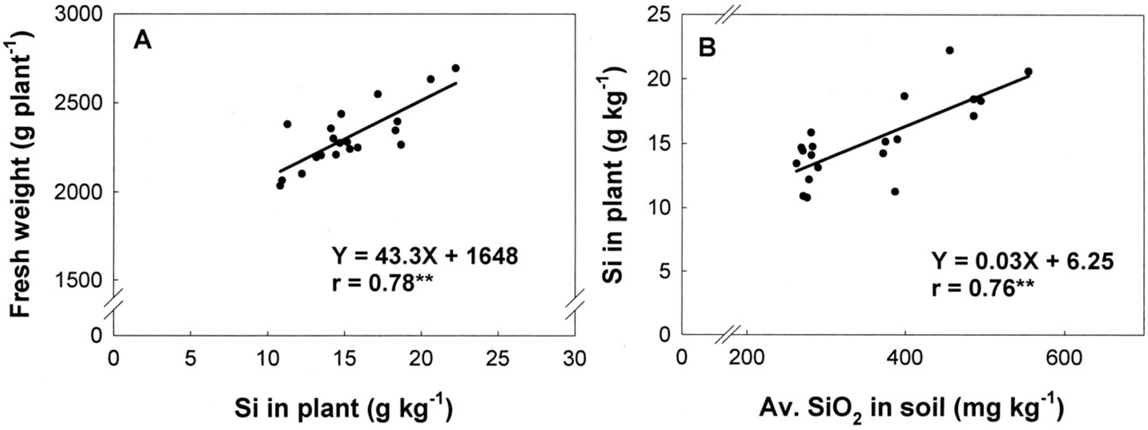

Fig. 2. Relationship between content of Si in the plant and yield (A) and available SiO_2 in the soil (B).

Table 4. Chemical and physical properties of soil after Chinese cabbage harvest.

	Si0+NK	Si2+NK	Si4+NK	Si0+NPK	LSD 0.05
pH	7.1	7.3	7.4	7.0	0.2
EC (dS m^{-1})	1.6	1.8	1.7	2.1	ns
OM (g kg^{-1})	19.7	17.1	18.2	19.5	ns
Available SiO_2 (mg kg^{-1})	272	385	496	280	31
Ex. Cations (cmol(+) kg^{-1})					
Ca	12.3	12.4	12.5	12.4	ns
Mg	3.5	3.7	3.7	3.6	ns
K	0.62	0.49	0.47	0.43	ns
Phosphate (P) (mg kg^{-1})					
Total	1966	1860	1737	2171	42
Olsen	147	151	155	150	ns
Organic	112	101	98	112	ns

ns, no significant difference among the treatments at $P<0.05$.

increased with increasing the rates of silicate application, which affected the absorbed Si in plant (Fig 2B).

As expected, the contents of total P in the Si0+NPK treatment increased from 2140 mg kg^{-1} before the experiment to 2171 mg kg^{-1} after the experiment. which, in the silicate treatments, total-P significantly decreased with increasing the rates of silicate application. For example, the content of total P decreased from 1966 mg kg^{-1} in Si0+NK to 1860 mg kg^{-1} in Si2+NK and 1737 mg kg^{-1} in Si4+NK. The content of available P (Olsen-P) in soil was similar between silicate treatments without P fertilization and Si0+NPK treatment, while total P was significantly reduced. Many researchers showed that various Si sources could increase the quantity of mobile phosphate in the soil (Alvarez et al., 1980; Lee et al., 2004; Pardo and Guadalix, 1990; Raupach and Piper, 1959). This result indicates that application of silicate without P fertilization in P-accumulated soil could reduce total P along with maintaining the similar levels of available P to P fertilization.

Although we did not separate precipitation and specific adsorption, the concentration of Ca-P in the Si0+NPK treatment was 543 mg kg^{-1} after experiment, which is higher than that before experiment. In the same treatment, the changes in Al-P and Fe-P were not significant between before and after the experiment. It is well known that Ca-P is a favorable form of P in alkaline soils. The effect of silicate on reducing total-P was mainly attributed to the change in concentration of Ca-P. As seen Fig. 3, the concentration of Ca-P markedly decreased from 482 mg kg^{-1} for Si0+NK to 359 mg kg^{-1} for Si4+NK. Comparing between before and after the experiment, the content of Ca-P was reduced by 16% in Si2+NK and 27% in Si4+NK treatment, but the changes in Al-P and Fe-P were not significant, indicating that silicate may enhance the solubility of Ca-P. This result was supported by Shariatmadari and Mermut (1999) who reported that the addition of Si increased P desorption mainly through dissolution of calcite and Ca-phosphates in a calcareous system.

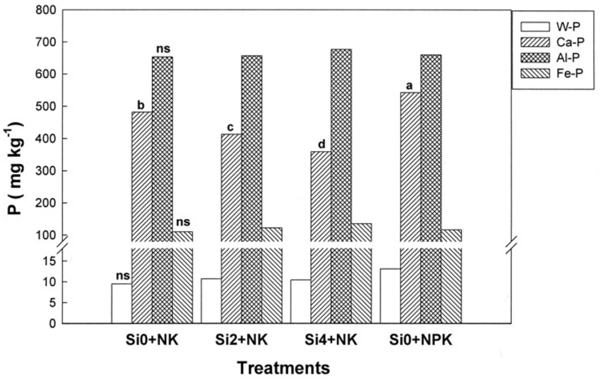

Fig. 3. Effect of application of silicate on the concentration of inorganic P fractions in the soil. (Within same P fraction, the same letter are not significantly different at $P<0.05$, ns indicated no significant difference among the treatment at $P<0.05$)

Conclusion

In salt accumulated soil, silicate fertilizer increased significantly phosphorus availability by ion competition and then inclined markedly the yield of Chinese cabbage and phosphorus uptake, even though phosphorus fertilizer was not applied. The content of available Si in soil and Si in plant increased with increasing rates of silicate application. The increased yield of Chinese cabbage positively correlated to increased Si concentration in the plant. Therefore, the beneficial effect of silicate application in P-accumulated soil may be related to deposition of Si in the plant. After the experiment, the content of total-P was significantly decreased with increasing the rate of silicate applied, but available P in the silicate treatment without P fertilization maintained the same levels with P fertilization. Among the inorganic P fractions, Ca-P levels strongly reduced in all silicate treatment compared to the no-silicate treatment, but Al-P and Fe- P was not greatly affected by silicate. This result indicates that the reduction in total-P by silicate may be mainly attributed to the changes in the concentration of Ca-P.

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염류집적토양에서 규산질 비료가 인산의 유효도 증진에 미치는 영향

이용복[1] · 김필주[2,*]

한글소속 작성요망

시설재배지내 염류와 인산이 집적된 토양(Total-P: 2140 mg kg^{-1})에서 이온간 경쟁에 의한 인산의 유효도를 증진효과 조사하기 위해 현장 작물재배시험을 실시하였다. 규산의 인산유효도 증진효과를 알아보기 위해 규산을 처리하지 않은 삼요소구(NPK)를 대비구로 하여, 인산무시용 조건에서 규산질비료를 세수준(0, 2, 4 Mg ha^{-1}) 처리하여 비교하였다. 인산을 시용한 삼요소구에 비해 인산을 무처리하고 규산을 처리시 배추의 생육과 수량은 크게 증대되었다. 특히 인산을 무처리하고 규산을 4 Mg ha^{-1} 처리시 삼요구에 비해 약 25%의 수량증대가 확인되었다. 식물체내 인산함량은 처리간 유의적인 차이는 없었으나 규산 처리량 증가에 따른 수량증대로 인산 흡수량이 유의적으로 증가하였다. 규산질비료 시용량 증가에 따라 토양 중 유효인산함량의 유의적 증가가 하였으며, 토양의 유효규산과 식물체의 규산함량간(r=0.76**), 그리고 식물체 규산함량과 배추 수량간(r=0.78**)에는 고도의 정의 상관관계가 확인되어 시용규산이 토양 내 인산의 유효도 증진과 작물의 인산흡수량 증가에 직접적 효과가 있는 것으로 조사되었다. 규산질비료 처리량이 증가함에 따라 식물체의 인산 흡수량 증가로 인해 시험 후 토양 중 Total-P 함량은 다소 감소하였으나, 유효인산 함량에는 큰 차이를 발견할 수 없었다. 시험 전 토양과 비교할 때 배추수확 후 토양 내 전 인산 함량 감소는 주로 Ca-P 함량 감소로부터 기인된 것으로 조사되었다. 결과적으로 인산 집적지 토양에 규산질비료의 적절한 시용은 인산의 유효도를 증진시켜 작물의 수량을 증대시키고, 인산시비량 감축에 따른 인산집적을 크게 감소시킬 수 있을 것으로 평가되었다.