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Influence of Silicon and Phosphorus on Growth, Yield and Nutrient Uptake by Maize (*Zea Mays L.*) in *Typic Ustochrepts* Soils

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Abstract: Aapplication of Si @ 300 mg Si kg^{-1} soil along with P @ 40 mg P kg $soil^{-1}$ recorded significantly highest green and dry shoot yield (93.03 g pot^{-1}, 52.25 g pot^{-1}, respectively) of maize in loamy sandy and silty loam soils, whereas, the highest root yield (13.39 g pot^{-1}) was also recoded under the same treatment in silty loam soil. The highest chlorophyll content in maize leaf (22.05 cci) was noted with the application of Si @ 400 mg Si kg^{-1} soil along with P @ 40 mg P kg $soil^{-1}$ in both the soils. Results of investigation indicated that application of silicon @ 300 mg kg^{-1} and phosphorus at 40 mg P_2O_5 kg^{-1} gave maximum maize yield under P stress condition and also improved silicon, phosphorus and micronutrients utilization by maize plants.

Key Words: Growth, Maize, Nutrient uptake, Phosphorus, Silicon, Yield

The efficiency of phosphorus fertilizer and crop yields mostly reduces due to high soil sorption of phosphorus in some P deficient soils. Silicon is the second most abundant element after oxygen in soil and its application has been reported to decrease P sorption and increase yields in such soils. It is one of beneficial element for maize growth, which is very important for its morphological and physiological characters. Intensive cropping with a constant application of NPK fertilizers has depleted plant available silicon from the soil. Crops like rice, barley, cucumber, wheat, maize, sorghum and sugarcane absorb silicon in greater amounts than N, P and K (Epstein, 1994). Phosphorus is also an essential nutrient required by plants for normal growth and development of maize. Soils deficient in available P not only produce economically unacceptable yields, but other inputs, particularly N, are also used less effectively. Thus, there is an urgent need to seek strategies by which P fertilizers can be used more effectively in those farming systems where P is deficient and its use is economically feasible.

The solubility of Si in soils is important both for P and Si availability and Si movement, including leaching, in the soil. The beneficial effect of silicon on the plant growth and resistance to biotic stress has been proven in higher plant. Alleviation of Si on P-stressed maize and accumulation of Si and P in maize were well documented by various researchers which provide a theoretical foundation for the scientific application of fertilizers in maize in P deficient area (Yang *et al*., 2008). Application of soluble Si in acid soil could decrease absorption of phosphorus in soil and soil pH, which improve dry weight and absorption by maize (Owino and Gascho, 2004). Hence, pot study was conducted to study the relationship between silicon and phosphorus under P stressed soils keeping maize as a test crop.

MATERIAL AND METHODS

The experiment was conducted at Anand Agricultural University, Anand, during summer 2011, which is located at 22º-35' north latitude and 72º-55' east longitude with an elevation of 45 m above MSL. The area is characterized by low and erratic rainfall with mean annual rainfall of 864 to 870 mm with peaks in July to August. The nature of soil was neutral to alkaline, pH ranged from 7.25 to 8.94. The soluble salts (EC) content was low to high and an overall range was 0.17 to 1.06 dS m^{-1} with a mean value of 0.38 dS m^{-1}. The cation exchangeable capacity (CEC) ranged from 15.0 to 23.0 cmol (p+) kg^{-1}. The available phosphorus, potassium, sulphur and sodium ranged from low to medium.

Earthen pots was taken for the conducting experiment and six kg soil was taken in each pots and calculated quantities of graded levels of Si viz. 0, 100, 200, 300 and 400 mg kg^{-1} soil and two levels of P (0 and 40 mg P kg $soil^{-1}$) applied and mixed properly in soils. The source of silicon was calcium silicate and P as potassium di-hydrogen phosphate (KH_2PO_4). After sowing of maize seeds, pots were regularly watered and maintained optimum moisture up to 60 days required for optimum growth and development. A top dressing of nitrogen with urea was done in 15 days after sowing. Maize plants were harvested once they attained the age of 60 days. Soil and plant samples (shoot) were drawn for the further analysis of soil.

RESULTS AND DISCUSSION

Chlorophyll content: Chlorophyll content in the leaf was significantly improved due to different levels of silicon up to

Si_{300} in both the soils (Table 1). The mean chlorophyll content was 15.32 cci and 20.44 cci in S_1 and S_2 soils, respectively. The interaction effect of Si x P on chlorophyll content in maize was non-significant. The appropriate Si could not only alleviate chlorophyll decomposition at a certain extent, but also enhance absorption of light in leaf (Yang *et al*., 2008). Similar result was also repotted by Rashid and Iqbal (2012).

Table 1. Effect of Si and P levels on chlorophyll content (cci) in maize

Si levels	Chlorophyll content (cci)			
	Soil (S_1)		Soil (S_2)	
	P0	P40	P0	P40
Si0	9.98	11.50	15.10	16.62
Si100	9.95	15.40	15.07	20.52
Si200	11.63	15.95	16.75	21.07
Si300	15.50	16.93	20.62	22.05
Si400	15.50	16.83	20.62	21.95
CD (p=0.05)	0.71	0.71	NS	NS

Plant height: Application of Si @ 300 mg kg^{-1} soil at different levels significantly increased the plant height of maize at all three growth stages (30 and 60 DAS) in both P deficient S_1 and S_2 soils except at 60 DAS in S_1soil, where in maximum plant height was noted under Si_{300} level. The plant height was increased significantly under S_{300} over control and Si_{100} and Si_{200} levels in S_2 soil at all growth stages, however, it was at par with S_{400} at 30 DAS, While at 60 DAS it was significantly the higher under Si_{300}. In case of S_1 soil, initial two growth stages, Si_{300} registered maximum plant height, while in S_2 soil, later two growth stages, Si_{400} recorded maximum plant height, but it was on par with Si_{300} level. Thus the results indicated that under both the soil condition varying in texture class, application of 300 mg Si kg^{-1} was good enough to get beneficial effect on growth of maize crop. In both P deficient soils, the application of phosphorus P_{40} also significantly increased the plant height at 30 and 60 DAS. The increase in plant height at 60 DAS was 5.8 per cent under S_1 soil and 2.9 per cent under S_2 soil due to P_{400} over P_0 level. The difference in P response is mainly due to differences in the initial fertility of soil and also difference in texture of soil. The increase in plant height due to P application @ 40 mg kg^{-1} might be due to the increase in P availability to maize plants. The interaction effect indicate that in absence of P, Si application partly meet the requirement of the crop.

Green and dry shoot yield: The application of Si @ 300 mg kg^{-1} soil significantly increased green shoot yield and dry shoot yield in S_1 and S_2 soils (Table 3). The increase in dry shoot yield due to Si_{300} level was 24.2 and 22.7 per cent over control in S_1 and S_2 soils, respectively. The higher maize yield obtained in S_2 soil as compared to S_1 soil may be attributed to better fertility status of S_2 soil. The results are in accordance with those of Yang *et al*. (2008), who reported that Si with appropriate concentration could promote the growth of maize seedlings, dry matter accumulation of different organs, which significantly alleviated the ill effects caused by low-P stress. Therefore, Si application under low-P stress could improve not only the weight of different organs in maize seedlings, but also the dry matter distribution in different organs, On the other hand Si improved chlorophyll content and net photosynthesis rate of leaves, which promoted dry matter accumulation of maize seedlings. In both P deficient soils, the application of phosphorus (P_{40}) significantly increased the green and dry shoot yields. The mean dry shoot yield was 49.76 and 58.98 g pot^{-1} due to P_{40} level in S_1 and S_2 soils, respectively. The shoot yield was also significantly increased by P supplementation under P stress condition of both soils. This is mainly due to deficiency of available P in both the soils. Ma *et al*. (2001) also noted that higher P dose increased its availability allowing less adsorption of P in soil and so improved plant growth. Owino and Gascho (2004) also observed that under limiting condition of phosphorus in the soil, applied P at different rates increased maize dry

Table 2. Effect of Si and P levels on plant height (cm) at different growth stages of maize

Si levels	Plant height (cm)							
	30 DAS				60 DAS			
	Soil (S_1)		Soil (S_2)		Soil (S_1)		Soil (S_2)	
	P_0	P_{40}	P_0	P_{40}	P_0	P_{40}	P_0	P_{40}
Si_0	26.62	30.72	33.25	35.84	105.95	110.50	120.40	121.26
Si_{100}	29.56	28.97	31.23	38.09	110.89	112.30	117.65	121.45
Si_{200}	35.92	37.62	37.04	42.74	117.25	122.95	125.58	128.16
Si_{300}	30.42	44.82	38.54	46.94	115.85	129.15	123.96	135.45
Si_{400}	35.62	37.52	42.12	42.64	120.95	128.85	128.65	128.06
CD (p=0.05)	NS	NS	NS	NS	2.05	2.05	NS	NS

weight.The interactions effect of Si x P for green and dry shoot yields of maize was found to be non-significant.

Dry root yield: Dry root yield in S_1 Soils was significantly higher under Si_{400} than rest of the treatment barring Si_{300} level. However, in case of S_2 soil, Si_{300} registered significantly the highest dry root (11.70 g pot^{-1}) yield, thereafter it was significantly decreased at Si_{400} to 10.22 g pot^{-1} over preceding level (Table 3). The result showed that application of Si increased the root mass. Yang *et al*. (2008) also noted that Si enhanced permeability of the root cell membrane, allowing nutrients to enter more efficiently, as a result the root mass was increased.The dry root yield was also significantly increased by the application of P_{40} phosphorus in both soils as in case of shoot yields.

Nutrients Uptake

Silicon: Silicon uptake by maize straw (Table 4) was significantly increased by Si application at different levels. In S_1 soil, the highest Si uptake (19.40 g pot^{-1}) was observed under Si_{400} level but in (S_2) soil it was under Si_{300} level 24.32 g pot^{-1}. The Si uptake in both P deficient soils was significantly increased by the application of phosphorus (P: 40). The mean Si uptake was 15.91 and 23.89 g pot^{-1} due to P: 40 level in (S_1) and (S_2) soils, respectively. Barman *et al*. (1998) showed that in soil addition of Si up to 5 mM/g soil would not increase the P availability, but there is every likelihood of increasing Si availability due to P fertilization. The interaction effect of Si x P on Si uptake by maize was found significant, it means that P increased Si uptake by increasing the available Si in soil solution. Owino and Gascho (2004) observed that the applied silicate ion was converted to silicic acid (H_3Si0_4). In soils having low pH the negative charge of soluble silicon (H_3Si0_4) was less than negatively charged phosphate anion, therefore, the phosphorus was preferably adsorbed on the soil particle and it replaced the Si into soil solution.

Phosphorus: Uptake was increased significantly by the silicon application in both soils (Table 4). In (S_1) soil, significantly the highest P uptake (1.67g pot^{-1}) was observed under treatment Si_{300} and similar results were found in case of (S_2) soil (S_2). Owino and Gascho (2004) showed that Si concentration in the soil solution improved growth of maize resulting greater P uptake and utilization. The mean P uptake obtained was 1.68 g pot^{-1} and 1.86 g pot^{-1} due to P40 level in (S_1) and (S_2) soils, respectively. The application of phosphorus (P: 40) also significantly increased the P uptake in both P deficient soils. Sahoo and Panda (2001) indicated that soils low in P will adsorb large amounts of P leaving little for plants and higher P dose increased its availability allowing less adsorption and so improved uptake of P. Data on interaction effect of Si x P in (S_1) soil indicated that significantly the highest P uptake (2.26 g pot^{-1}) was under Si_{300}

Table 3. Effect of Si and P levels on green, dry shoot yield and dry root yield (g pot^{-1}) of maize

Si levels	Green shoot yield (g pot^{-1})				Dry shoot yield (g pot^{-1})				Dry root yield (g pot^{-1})			
	Soil (S_1)		Soil (S_2)		Soil (S_1)		Soil (S_2)		Soil (S_1)		Soil (S_2)	
	P_0	P_{40}	P_0	P_{40}	P_0	P_{40}	P_0	P_{40}	P_0	P_{40}	P_0	P_{40}
Si_0	66.23	77.69	95.12	107.23	39.05	45.12	50.24	54.62	2.69	4.31	6.53	9.59
Si_{100}	71.36	83.56	103.45	113.56	39.45	43.30	41.70	60.45	2.91	4.33	6.42	10.89
Si_{200}	76.56	88.36	111.85	120.25	45.12	48.10	47.22	55.12	4.08	5.08	8.04	10.24
Si_{300}	89.36	96.70	117.12	121.52	47.56	56.44	58.45	70.20	4.35	6.25	10.02	13.39
Si_{400}	82.12	96.12	121.45	122.30	41.86	55.86	52.49	54.52	3.85	7.25	9.02	11.43
CD (p=0.05)	1.89	1.89	NS	NS	2.14	2.14	NS	NS	0.60	0.60	NS	NS

Table 4. Effect of Si and P levels on nutrient uptake by maize plant in different soils

Si levels	Nutrient uptake (g pot^{-1})								Nutrient uptake (mg pot^{-1})							
	Si				P				Fe				Mn			
	Soil (S_1)		Soil (S_2)		Soil (S_1)		Soil (S_2)		Soil (S_1)		Soil (S_2)		Soil (S_1)		Soil (S_2)	
	P_0	P_{40}	P_0	P_{40}	P_0	P_{40}	P_0	P_{40}	P_0	P_{40}	P_0	P_{40}	P_0	P_{40}	P_0	P_{40}
Si_0	7.77	8.80	10.10	16.39	0.66	0.90	0.80	0.98	13.74	16.53	17.40	20.79	1.30	1.63	1.60	1.76
Si_{100}	8.88	12.34	11.47	24.66	0.63	1.52	0.63	1.99	14.47	16.96	17.97	16.73	1.27	1.56	1.47	1.68
Si_{200}	13.58	13.23	11.81	23.43	0.95	1.59	0.94	1.71	12.99	13.95	13.74	16.16	1.15	1.38	1.19	1.77
Si_{300}	9.99	22.29	17.42	31.24	1.09	2.26	1.29	2.67	11.94	11.94	10.01	16.86	1.12	1.26	1.43	1.42
Si_{400}	15.91	22.90	17.95	23.72	0.88	2.12	1.05	1.96	11.23	12.34	11.81	15.12	1.13	1.35	1.34	1.55
CD (p=0.05)	1.61	1.61	NS	3.61	0.09	0.09	NS	0.21	0.58	0.58	0.83	NS	0.06	0.06	NS	NS

x P_{40} and the lowest (0.90 g pot^{-1}) was in Si_0xP_{40} combination, whereas in (S_2) soil the same treatment combinations gave the highest (2.67 g pot^{-1}) and the lowest (0.98 g pot^{-1}) P uptake, respectively. Owino and Gascho (2004) showed that uptake of P was increased as a result of Si and P interaction, which could be due to increase in soil pH that made P more available and better plant growth because of improved P uptake and utilization. Similar results were also recorded by Ma *et al*. (2001).

Uptake of Fe and Mn: Application of Si at different levels decreased Fe and Mn uptake by maize (Table 4). The phosphorus (P: 40) application significantly increased Fe and Mn uptake by maize. The increase in uptake of Fe and Mn could be attributed to increase in shoot and root yield of maize due to P addition over P_0 level. Owino and Gascho (2004) also showed that better P utilization, enhance the root elongation and increased concentrations of Fe, Mn and Zn therefore increasing in their uptake.

CONCLUSION

From the forgoing results, it could be concluded that the application of Si @ 300 mg Si kg^{-1} soil along with P @ 40 mg P kg $soil^{-1}$ significantly increased the plant height, chlorophyll content, green shoot yield, dry shoot yield, dry root yield and nutrient uptake of maize in loamy sand and silt loam soils.

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