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Maize (*Zea Mays L.*) Yield and Nutrient Content as Influenced by Different Levels of Silicon and Phosphorus in *Typic Ustochrepts* Soil

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ABSTRACT

The effort was made for study the maize yield and nutrient content as influenced by different levels of silicon and phosphorus in *Typic Ustochrepts* soil. A pot experiment was conducted in 2012 in the greenhouse of the Anand Agricultural University, Anand. Treatments were arranged in a factorial completely randomized design with silicon factor at five levels (0, 100, 200, 300 and 400 ppm) and two levels of P (0 and 40 mg P kg soil⁻¹) and maize were taken as a test crop with three replicates. Indian improved and high-yielding variety, GM-6, was used. The application of Si @ 300 mg Si kg⁻¹ soil recorded significantly the highest green shoot yield (93.03 g pot⁻¹) in loamy sand soil, whereas, the highest dry shoot yield (52.25 g pot⁻¹ and 64.3 g pot⁻¹) was noted under same treatment in both the soils. On the whole results of study indicate that application of silicon @ 300 mg kg⁻¹ and phosphorus at 40 mg P₂O₅ kg⁻¹ gave highest maize yield under P stress condition and also enhanced silicon, phosphorus content by maize plant but obtainable Fe and Mn contents were significantly decline by maize plant.

Key words Silicon, Phosphorus, Maize, Content

Maize, scientific name *Zea mays*, also known as corn or mielie/mealie, is one of the most extensively cultivated cereal crops on Earth. The exact domestication point for maize is unknown, but it is estimated that the crop is at least 5,000 years old. The plant was originally domesticated in Mesoamerica, and appears to be related to species of wild grass which still exist in Central American today. People in many English speaking nations know maize as corn. Originally, the term “corn” could refer to any type of grain. When maize was brought back to Europe, it was called “Indian corn,” a reference to the source of the plant. The term was shortened to “corn” as maize became ubiquitous in many gardens. In Africa, it is known as mealies. Globally, maize is a staple crop, and many people rely on it as a primary source of nutrition. In addition to playing a major role in the human diet, maize is also used as livestock fodder. Maize is processed to make an assortment of products ranging from high fructose corn syrup to biofuels, all of which play important roles in human society. Oddly enough, maize is at the forefront of the green revolution with byproducts like compostable containers and biofuel, while simultaneously being used as a controversial food additive in the form of corn syrup and other derivatives.

Maize is mainly a rainfed *kharif* crop which is sown just before the onset of monsoon and is harvested after retreat of the monsoon. In Tamil Nadu it is a rabi crop and is

sown a few weeks before the onset of winter rainy season in Sept. and Oct. It requires 50-100 cm of rainfall and it cannot be grown in areas of more than 100 cm rainfall. In areas of lesser rainfall, the crop is irrigated. For example, more than half of the maize area in Punjab and Karnataka is irrigated. Long dry spell during the rainy season is harmful for maize. Sunshine after showers is very useful for maize. Cool and dry weather helps in ripening of the grain. This crop usually grows well under temperatures varying from 21°C to 27°C, although it can tolerate temperatures as high as 35°C. Frost is injurious to maize and this crop is grown only in those areas where there are about four and a half frost free months in a year. Maize is an important cereal of India and is grown over 4 per cent of the net area sown of the country. There have been large variations in the production of maize in India since Independence. It was only 1.7 million tonnes in 1950-51 which rose to 4.1 million tonnes in 1960-61 and 7.5 million tonnes in 1970-71. In Gujarat, Mahsana, Banaskantha, Rajkot and Kheda districts in the valleys of the Sabarmati and Mahi rivers are the main producers and together contribute over 55 per cent of the state's production. At one stage, Bihar was the largest producer of maize but this state has lost much of its importance as a major maize producer in the country.

Silicon is the second most abundant element after oxygen in soil. As a consequence, all plants rooting in soil contain some significant amounts of silicon in their tissues. However, the role of silicon in plant growth and development was overlooked for a long period of time until the beginning of 20th century. Repeated cropping with a constant application of chemical fertilizers such as nitrogen, phosphorus and potassium has depleted plant available silicon in soil. As such, the awareness of silicon deficiency in soil has become recognized as being a limiting factor for crop production, especially in soil that are deemed to be low of limiting in plant available silicon. Although, five international five international conferences on silicon in agriculture were held in different parts of the world, there is lack of awareness on its importance in Indian agriculture. In this regard the student has taken up a study on importance of silicon in P stressed soils to know the benefit in maize crop. Crops such as rice, barley, cucumber, wheat, maize, sorghum and sugarcane absorb silicon in greater amounts than nitrogen, phosphorus and potassium, and yet silicon is not recognized as a major plant nutrient (Epstein, 1994). Application of Si is recognized by scientists working on cereals (Horiguchi, 1988).

Phosphorus (P) is also an essential nutrient required by plants for normal growth and development. Research results show that relatively high P fertilizer rates are required for crops grown in alkaline soil. Concentrated P fertilizer

Table 1. Initial soil properties of the bulk samples used in pot house study

A	PHYSICAL PROPERTY (Mechanical Composition, g 100 ⁻¹ g)	Hadgud Soil (S ₁)	Vaso Soil (S ₂)
	Coarse sand	00.42	00.12
	Fine sand	81.10	65.55
	Silt	12.21	24.25
	Clay	06.04	20.05
	Texture Class	Loamy sand	Silt Loam
B	CHEMICAL PROPERTIES		
1	pH (1:2.5)	8.14	8.09
2	EC (1:2.5) dSm ⁻¹	0.24	0.33
3	Organic carbon (g kg ⁻¹)	2.20	4.60
4	Available P ₂ O ₅ (kg ha ⁻¹)	19.50	21.30
5	Available Si (mg kg ⁻¹)	55.83	46.00
6	Available Fe (mg kg ⁻¹)	9.50	8.50
8	Available Mn (mg kg ⁻¹)	20.0	21.0
7	Available Zn (mg kg ⁻¹)	0.70	0.80

bands improve P solubility with resulting yield increases, even when applied to crops grown in soil with relatively high soil test P concentrations. It is important to maintain a proper balance of P with other nutrients for general plant health and to avoid excess nutrient induced deficiencies of other nutrients (Western Nutrient Management Conference, 2005). Soils containing insufficient amounts of plant-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 currently deficient and where its use is economically feasible.

Ever since the discovery of beneficial effects of silicate on crop production, attempts have been made to find an explanation in improved phosphorus nutrition of plants. In the humid tropics, silicate rocks undergo rapid chemical weathering resulting in the release of Si, Fe, Al, etc., from the soil. The solubility of Si in soils is important both for P and Si availability and Si movement, including leaching, in the soil. Modifying the Si status of sub-soils may influence the solubility of many elements and those which may be toxic to plants. The beneficial effect of silicon on the plant growth and resistant to biotic stress has been proved 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 scientific application of fertilizers in maize in P deficient area (Yang *et al.*, 2008). Application of soluble Si in acid soil could decrease adsorption of phosphorus in soil and soil pH, which improve dry weight and absorption by maize (Owino and Gascho, 2004). To establish the relationship between silicon and phosphorus under P stressed saline soil conditions. Maize is an exhaustive crop. It has very high nutrient requirement and its productivity is mainly depended on nutrient management. Therefore, the paper deals with the maize yield and nutrient content and uptake

as influenced by different levels of silicon and phosphorus in *Typic Ustochrepts* soil.

MATERIALS AND METHOD

Agro-climatic conditions

The climate of this region is arid and semi-arid. The soil type of middle Gujarat varies from loamy sand to medium black with a good drainage capacity. The important soil orders in this region are Inceptisols, Entisols and Vertisols. The total rainfall of region is about 800-1000 mm. Average minimum and maximum temperature of the year of study was 19.6°C and 33.3°C, respectively.

Preliminary survey

To know the deficiency of phosphorus in soils of middle Gujarat, 15 surface soil samples were collected from Anand and Kheda districts. These soil samples were analyzed for available phosphorus by Olsen's method, besides other important physico- chemical properties.

Pot study

Bulk soil sampling

Two representative P deficient bulk soils were collected from Hadgud and Vaso villages. The soil samples were air dried, hand pounded and stored in large size polyethylene bags. The initial soil chemical properties as well as available silicon were estimated as per standard procedures and data are given in Table 1.

Experimental details

The experiment was taken in 6 kg capacity earthen 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) silicon in the form of calcium silicate and P in the form of potassium di-hydrogen phosphate (KH₂PO₄) and mixed properly. After sowing, pots were regularly watered and weed free condition was maintained up to 60

Table 2. Effect of Si and P levels on green shoot yield and dry shoot yield (g pot⁻¹) of maize in different soils

Si levels (ppm)	Green shoot yield (g pot ⁻¹)				Dry shoot yield (g pot ⁻¹)			
	Hadgud Soil (S ₁)		Vaso Soil (S ₂)		Hadgud Soil (S ₁)		Vaso Soil (S ₂)	
	P levels		P levels		P levels		P levels	
	P0	P40	P0	P40	P0	P40	P0	P40
Si0	66.23	77.69	95.12	107.23	39.05	45.12	50.24	54.62
Si100	71.36	83.56	103.45	113.56	39.45	43.30	41.70	60.45
Si200	76.56	88.36	111.85	120.25	45.12	48.10	47.22	55.12
Si300	89.36	96.70	117.12	121.52	47.56	56.44	58.45	70.20
Si400	82.12	96.12	121.45	122.30	41.86	55.86	52.49	54.52
SEm+	0.66	0.66	0.93	1.48	0.74	0.74	1.05	1.67
CD @ 5%	1.89	1.89	NS	NS	2.14	2.14	NS	NS
CV%	3.70				7.80			

DAS condition required for optimum growth and development of maize crop. Top dressing of nitrogen with urea was done at 15 days after sowing. Maize plants were harvested once they attained the age of 60 days. Plant samples (straw) were drawn for the further analysis.

RESULT AND DISCUSSION

Green and dry shoot yield

In Hadgud soil (S₁), significantly the highest green shoot yield (93.03 g pot⁻¹) whereas, highest dry shoot yield (52.25 g pot⁻¹ and 64.3 g pot⁻¹) was observed in Hadgud and Vaso soils, respectively under treatment Si₃₀₀ but it was significantly decreased at the highest (Si₄₀₀) Si level over preceding level (Si₃₀₀) in both the soils (Table 2). The increase in dry shoot yield due to Si₃₀₀ level was to the tune of 24.2 and 22.7 per cent over control in Hadgud and Vaso soils, respectively. The higher maize yield obtained in Vaso soil as compared to Hadgud soil may be attributed to better fertility status of Vaso 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 Hadgud and Vaso soils, the dry matter yield was significantly decreased under S₄₀₀ over S₃₀₀, which could be attributed to decrease in leaf area and stem thickness. Similar results were reported by Nieuwenhuis and Lales (2001).

In both P deficient soils, the application of phosphorus (P₄₀) significantly increased the green and dry shoot yields. The mean dry shoot yield was obtained 49.76 g pot⁻¹ and 58.98 g pot⁻¹ due to P₄₀ level in Hadgud and Vaso 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. It is probable that silicate increased the solubility of native and applied P under P deficiency condition accompanied by increase in yields (Roy *et al.*, 1971). Owino and Gascho (2004) also observed that under limiting condition of phosphorus in the soil, applied P at different rates increased maize dry weight.

Nutrients content in plant

Si content

The data on Si content of maize as influenced by Si application are presented in Table 3. In Hadgud soil (S₁), the mean Si content in maize plant was observed as 2.55, 2.88, 3.02 and 3.95 per cent under different silicon levels like Si100, Si200, Si300 and Si400, respectively. Similar results were also obtained at different levels of silicon in Vaso soil (S₂) but the relative Si content was higher in Vaso soil than Hadgud soil. The plant Si increased with increasing Si levels because the plant available Si increased in soil solution with increasing Si levels. Similar results were also observed by Drees *et al.*, (1989). In both P deficient soils, the application of phosphorus (P₄₀) also significantly increased Si content in maize straw. The mean Si content was 3.12 and 4.03 per cent due to P₄₀ level in Hadgud and Vaso soils, respectively.

The concentration of Si in the plants was increased by Si addition into the nutrient solution. Water stress reduced leaf calcium (Ca) and potassium (K) of maize plants, but addition of Si increased these nutrient levels; Ca levels were similar to WW under the high-Si treatment, but K was lower. Root Ca and K were both increased by WS; root Ca was further increased by high Si (WS + Si₂ treatment). Addition of Si to the WS treatments did not change root K. Results indicate that while application of Si may be one approach to improve growth of this crop and increase its production in arid or semi-arid areas where water is at a premium, this technique would not fully substitute for an

Table 3. Effect of Si and P levels on Nutrient contents (%) of maize straw in different soils

Si levels (mg kg ⁻¹)	Nutrient content (%)															
	Si				P				Fe				Mn			
	Hadgud Soil (S1)		Vaso Soil (S2)		Hadgud Soil (S1)		Vaso Soil (S2)		Hadgud Soil (S1)		Vaso Soil (S2)		Hadgud Soil (S1)		Vaso Soil (S2)	
	P levels		P levels		P levels		P levels		P levels		P levels		P levels		P levels	
	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	1.99	1.95	2.01	3.00	0.17	0.20	0.16	0.18	328.32	303.68	331.52	306.88	28.98	30.52	29.18	30.72
Si ₁₀₀	2.25	2.85	2.75	4.08	0.16	0.35	0.15	0.33	304.16	292.96	307.36	296.16	28.31	29.01	28.51	29.21
Si ₂₀₀	3.01	2.75	2.50	4.25	0.21	0.33	0.20	0.31	287.84	275.68	291.04	278.88	28.12	27.99	28.32	28.19
Si ₃₀₀	2.10	3.95	2.98	4.45	0.23	0.40	0.22	0.38	290.00	289.92	293.12	240.00	27.23	28.91	27.43	25.00
Si ₄₀₀	3.80	4.10	3.42	4.35	0.21	0.38	0.20	0.36	287.52	273.60	276.80	235.00	27.10	27.97	27.30	26.00
S. Em±	0.09	0.09	0.13	0.20	0.004	0.004	0.006	0.009	1.57	1.57	2.22	3.51	0.11	0.11	0.16	0.25
CD@5%	0.26	0.26	NS	NS	0.012	0.012	NS	0.02	4.48	4.48	6.34	10.03	0.33	0.33	0.46	0.74

adequate water supply (Kaya *et al.*, 2006). Drees *et al.*, (1989) also showed that phosphorus increased the Si concentration in plants by affecting its absorption.

P content

The data on P content as affected by Si on P application to maize presented in Table 3 revealed that among different level of Si, Si₃₀₀ recorded maximum P content (0.31 & 0.30 %) in both soil, however at the highest level (Si₄₀₀) of Si, it was significantly decreased over former level. Ma *et al.* (2001) reported that the enhanced P uptake in the presence of Si was due to increased transpiration rate when P status is low in soil. They asserted that this meant that Si improved internal P utilization. It is also probable that silicate increased the solubility of native and applied P, which would be accompanied by increase P content in plant (Roy *et al.*, 1971). The P content increased when Si was applied could be attributed to the increase in the soil pH from the accompanying calcium and Si concentration in the soil solution, which improved the conditions for uptake of P by maize (Owino and Gascho, 2004). The mean P content obtained due to P₄₀ level was 0.33 % and 0.31% in Hadgud and Vaso soils, respectively. Aslam (1986) concluded 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 P content in maize plant.

Data on interaction effect of Si x P in Hadgud soil (S1) indicated that the highest P content (0.40%) was recorded under Si₃₀₀ x P₄₀ and the lowest P content (0.17%) was under control (Si₀xP₀). In Vaso soil (S2), the same treatment combination gave the highest P content (0.38%) and the lowest (0.16%), respectively. The combined application of Si and P improved P content in maize as compared to P application in absence of silicon. Ma *et al.* (2001) also reported that silicon improved internal P utilization. Similar results were also noticed by Schaller *et al.* 2012. The increased available P with Si application could be due to the release of absorbed P by anion exchange. Due to application Si compounds and their large surface area, they increase the soil adsorption capacity. In addition to

increasing of adsorption surface area and the content of monosilicic acids (Matichenkov and Ammosora, 1996). These changes in soil optimize the phosphate fertilizer efficiency and due to this transformation of slightly soluble phosphate turn in to plant available forms and reduce the phosphate leaching from the arable horizon. Si fertilizes can also increase the quantity of mobile phosphate in the soil (Gladcova, 1982) and thermodynamic calculations showed that the reaction of displacing phosphate anion by silicate anion from slightly soluble phosphate of the corresponding silicate is possible (Matichenkov and Snyder, 1996). The model and field experiments have completely confined this suggestion. First, an increase in concentration of monosilicic acids is observed in the soil solution, along with their adsorption on slightly soluble phosphate of calcium, Al, ferric and magnesium, phosphorus was absorbed by applied silicon rich substances. The data demonstrated that adsorbed P remained in a plant available form (Lindsay, 1979).

Fe and Mn content

The results given in Table 3 indicated that the application of Si at different levels (Si₀, Si₁₀₀, Si₂₀₀, Si₃₀₀ and Si₄₀₀) significantly decreased Fe and Mn contents. Ma *et al.* (2001) also asserted that Si reduced Mn and Fe activity in the presence of Si. In case of phosphorus application, Fe and Mn contents were significantly modified by application of phosphorus @ 40 kg P₂O₅ ha⁻¹. However, in Hadgud and Vaso soils, Fe content was significantly decrease due to addition of P over no P, while Mn content was increased in Hadgud soil and reverse trend was observed in Vaso soil. The Zn content was increased due to P application in both the soil. Ma *et al.* (2001) also reported that P increased utilization of micronutrients within the plant. The interaction effect of Si x P on Fe and Mn content in maize plant was found significant in both soils. The results revealed that application of Si and P both decreased Fe over control (Si₀xP₀). However, the trend not consistent with regard to Mn content of leaf. Similar results were also noticed by Brackhage *et al.*, (2013). Silicon substances for reducing Fe toxicities were very effective (Baylis *et al.*, 1994).

It is possible to postulate five different mechanisms of Fe toxicity reduction by Si-rich compounds. Firstly, monosilicic acid can increase soil pH (Lindsay, 1979). Secondly, monosilicic acid can be adsorbed on Fe hydroxides, impairing their mobility (Panov *et al.*, 1982). Thirdly, soluble monosilicic acid can form slightly soluble substances with ions of Al (Horiguchi, 1988). Another possibility for Fe toxicity reduction by Si-rich compounds can be strong adsorption of mobile Fe on silicon surfaces (Shulthess *et al.*, 1996). Fifthly, mobile silicon compounds can increase plant tolerance to Fe (Rahman *et al.*, 1998). All of these mechanisms may work simultaneously, with certain ones prevailing under various soil conditions. Interaction between Si and Mn occurs in solution, probably by the formation of Mn-Si complexes, a non-toxic form. However, monosilicic acid concentration in the soil initiated decomposition of secondary minerals that control numerous soil properties (Karmin, 1986). A second negative effect of reduced monosilicic acid concentration in the soil is decreased Mn concentration; thereafter it leads to plant disease and pest resistance (Epstein, 1999).

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