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RESEARCH PAPER

Effect of silicon fertilization on growth and yield of soybean [*Glycine max* (L.) Merrill] in Vertisol

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Abstract: A field experiment was conducted at the Main Agricultural Research Station, University of Agricultural Sciences, Dharwad, to study the effect of silicon fertilization on growth and yield of soybean in a Vertisol during *kharif* 2018. Experiment was laid out in RCBD design with nine treatments replicated thrice. The treatments included were two soil (25 and 50 kg ha^{-1}), two foliar (0.25 and 0.50 %) application rates of silicon and their combinations with one control. The results revealed that soil application of silicon @ 25 kg ha^{-1} + foliar application of silicon @ 0.25 per cent improved the growth parameters *viz.,* number of leaves (27.47) and chlorophyll content (49.40) $plant^{-1}$ at 60 DAS (days after sowing) and effective nodules $plant^{-1}$ (19.73) at 50 DAS and yield parameters *viz.*, number of pods (39.87), pod weight (24.21 g) $plant^{-1}$ and 100-seed weight (14.97 g). A significant increase in seed (14.84 q ha^{-1}) and haulm (19.72 q ha^{-1}) yields were recorded with soil (25 kg ha^{-1}) + foliar (0.25 %) application of silicon and the lowest seed (12.86 q ha^{-1}) and haulm (17.68 q ha^{-1}) yields were recorded in the control. It can be concluded that soil application of silicon (25 kg ha^{-1}) at the time of sowing + foliar (0.25 %) at 30 DAS along with RPP (recommended package of practice) recorded highest soybean yield in a Vertisol.

Key words: Growth, Silicon, Soybean, Vertisol, Yield

Introduction

Soybean [*Glycine max* (L.) Merrill] is considered a "Glden bean" and "Miracle crop" of 21st century due to its high yielding potential with high protein (40-42 %) and oil content (18-20 %). Soybean is also rich in minerals (Ca, Mg, P and Fe) and vitamins (A, B and D). Soybean forage and cake are excellent nutritive foods for livestock and poultry birds. Cultivation of soybean improves soil fertility through fixation of atmospheric nitrogen and addition of leaf residues.

The area under soybean is increasing in recent years due to its high nutritive value but its productivity is declining, as most of the farmers are not applying adequate and balanced dose of fertilizers. Therefore, balanced application of macro and micronutrients will help in augmenting the production and productivity of soybean crop. Among the beneficial nutrients, silicon plays an important role in providing beneficial effects on growth and yield of crops. It helps in alleviating various abiotic stresses like metal toxicity, drought, radiation damage due to high temperature and biotic stresses like pest and disease incidence such as blast in rice, powdery mildew in cucumber *etc.*, Silicon also prevents the lodging in cereal crops besides increasing photosynthesis, improving water economy of plants and strengthening the culm wall which are of great importance in terms of achieving higher yield. Under Si-deficit conditions, soybean plants displayed malformations such as curling of newly developed leaves during flowering, necrotic spots on leaves and low pollen fertility particularly in case of severe Si deficiency.

Studies on Si fertilization particularly in soybean are scarce. Moreover, at present there is no recommendation of silicon nutrient to crops. With this background, the present experiment was initiated to come out with optimum dose, method and time of application of silicon for sustainable soybean production in Vertisol.

Material and methods

The experiment was conducted at the Main Agricultural Research Station, University of Agricultural Sciences, Dharwad. This research station comes under Northern Transitional Zone (Zone 8) of Karnataka. The site was located at 15° 29' N latitude and 74° 59' E longitude with an altitude of 678 m above mean sea level. Experiment was laid out in RCBD design with nine treatments *viz.,* T_1: Control; T_2: Soil application of silicon @ 25 kg ha^{-1}; T_3: Soil application of silicon @ 50 kg ha^{-1}; T_4: Foliar application of silicon @ 0.25 %; T_5: Foliar application of silicon @ 0.50 %; T_6: Soil (25 kg ha^{-1}) + Foliar (0.25 %) application of silicon; T_7: Soil (25 kg ha^{-1}) + Foliar (0.50 %) application of silicon; T_8: Soil (50 kg ha^{-1}) + Foliar (0.25 %) application of silicon; T_9: Soil (50 kg ha^{-1}) + Foliar (0.50 %) application of silicon with three replications. Recommended fertilizers as per package (N: P_2O_5: K_2O @ 40: 80: 25: kg + $ZnSO_4.7H_2O$ @ 12.5 kg + Gypsum @ 100 kg ha^{-1}) were applied to all the treatments at the time of sowing. Calcium silicate and monosilicic acid were the sources of silicon used for soil application at the time of sowing and foliar application at 30 DAS, respectively. Initial properties of experimental soil were determined by standard procedure and values are presented in Table 1.

Crop was raised by following recommended cultural practices and was harvested at maturity. Growth parameters *viz*., plant height, number of leaves, number of branches and chlorophyll content per plant were recorded at different growth stages of crop. Total and effective nodules were counted by uprooting the plant at 50 DAS. While yield parameters (Number of pods $plant^{-1}$, pod weight $plant^{-1}$ and 100 seed weight) and yield were recorded at maturity.

The statistical analysis and interpretation of data was done using the Fischer's method of analysis of variance technique as

Table 1. Initial physical and chemical properties of the experimental soil

Sl. No.	Particulars	Value
I	Physical properties	
1.	Partical size analysis	
	Sand (%)	16.00
	Silt (%)	23.84
	Clay (%)	60.16
	Textural class	Clay
2.	Bulk density (Mg m^{-3})	1.32
3.	MWHC (%)	63.19
4.	Aggregate stability (%)	62.80
II.	Chemical properties	
1.	Soil reaction (1:2.5 soil: water suspension)	7.69
2.	Electrical conductivity	
	(1:2.5 soil: water extract) (dS m^{-1})	0.22
3.	Organic carbon (g kg^{-1})	7.40
4.	Available macronutrients (kg ha^{-1})	
	Nitrogen (N)	141.24
	Phosphorous (P_2O_5)	44.80
	Potassium (K_2O)	250.33
5.	Available micronutrients (mg kg^{-1})	
	Zinc (Zn)	0.64
	Iron (Fe)	4.86
	Copper (Cu)	0.89
	Manganese (Mn)	7.99
6.	Available silicon (mg kg^{-1})	318.56

described by Gomez and Gomez (1984). The level of significance used in 'F' and 't' test was P=0.05. Critical differences were calculated wherever 'F' test was significant and treatment means were compared by applying Duncan's multiple range test (DMRT).

Results and discussion

Effect of silicon on growth parameters

Perusal of data presented in Tables 2, 3 and 4 reveals that there was a variation in the growth parameters of soybean due to application of silicon through soil and foliar. Critical examination of the data revealed that, the application of silicon either through soil and/or foliar resulted in favorable effects on growth parameters. Further, the combined application of silicon resulted in greater growth parameters compared to only either soil or foliar application.

There was no significant difference on plant height and number of branches but there was a significant increase in number of leaves (27.47), chlorophyll content (49.40) at 60 DAS, number of effective nodules (19.73) at 50 DAS and dry matter production (37.50 g) per plant at harvest with the soil application of silicon @ 25 kg ha^{-1} + foliar @ 0.25 per cent (T_6). This might be due to supply of silicon both from the soil and also from the foliar. Silicon plays a major role in increasing the photosynthesis. Si gets deposited in the plant tissue causing erectness of leaves and stem which makes efficient utilization of sunlight. Lee *et al.* (2010) reported that application of silicon as sodium silicate to hydroponically grown soybean improved plant height and biomass. Hamayun *et al.* (2010) reported that application of silicic acid enhanced the plant growth under control condition to soybean. Further, the shoot fresh weight and dry weight attributes also significantly improved when Si applied alone under salt stress. Miao *et al.* (2010) also observed enhanced root and shoot growth of soybean seedlings with the application of silicon in K-deficient medium.

Manju *et al.* (2008) recorded maximum relative nodule number, nodule fresh and dry weights with the application of silicon @ 100 µg g^{-1}. Nelwamondo and Dakora (1999) also reported promotary effects of silicon on formation of more number of effective nodules and greater symbiotic N fixation by cowpea. Similarly, increased total biomass, root length and root mass were also observed by Miyake and Takahashi (1985), Paul *et al.* (2018) in soybean and Mali and Aery (2009) in cowpea. In view of these, the results of present study are in conformity with the findings of earlier workers.

Effect of silicon on yield and yield parameters of soybean

There was a significant effect of soil and foliar application of silicon on yield and yield parameters of soybean (Table 5).

Table 2. Effect of soil and foliar application of silicon on plant height and number of branches of soybean at different growth stages

Treatments	Plant height (cm)				Number of branches per plant			
	30 DAS	45 DAS	60 DAS	Harvest	30 DAS	45 DAS	60 DAS	Harvest
Control	16.87[a]	37.33[a]	39.93[a]	40.40[a]	1.53[a]	6.80[a]	7.40[a]	7.40[a]
Soil application of silicon @ 25 kg ha^{-1}	16.80[a]	36.47[a]	39.60[a]	41.40[a]	1.60[a]	7.13[a]	7.67[a]	7.93[a]
Soil application of silicon @ 50 kg ha^{-1}	15.87[a]	34.67[a]	37.47[a]	40.80[a]	1.60[a]	7.13[a]	7.60[a]	7.87[a]
Foliar application of silicon @ 0.25 %	18.60[a]	37.73[a]	40.47[a]	41.80[a]	1.53[a]	7.33[a]	7.87[a]	8.07[a]
Foliar application of silicon @ 0.50 %	17.53[a]	37.47[a]	40.13[a]	41.60[a]	1.47[a]	7.20[a]	7.93[a]	8.07[a]
Soil (25 kg ha^{-1}) + Foliar (0.25 %) application of silicon	17.00[a]	36.47[a]	38.87[a]	42.07[a]	1.53[a]	7.60[a]	7.93[a]	8.20[a]
Soil (25 kg ha^{-1}) + Foliar (0.50 %) application of silicon	17.60[a]	38.40[a]	40.40[a]	41.80[a]	1.47[a]	7.20[a]	7.67[a]	7.87[a]
Soil (50 kg ha^{-1}) + Foliar (0.25 %) application of silicon	17.20[a]	35.53[a]	38.20[a]	41.07[a]	1.40[a]	7.40[a]	7.87[a]	8.07[a]
Soil (50 kg ha^{-1}) + Foliar (0.50 %) application of silicon	15.40[a]	36.73[a]	39.07[a]	41.80[a]	1.47[a]	7.13[a]	7.67[a]	7.87[a]
LSD	NS	NS	NS	NS	NS	NS	NS	NS

Recommended package of practice (RPP) is common to all treatments

Soil and foliar application of silicon at the time of sowing and 30 DAS (Days after sowing), respectively

Calcium silicate and monosilicic acid were used for soil and foliar application, respectively

In a column, mean values followed by the common letter are not significantly different at P = 0.05 level (DMRT at 5 % level).

Table 3. Effect of soil and foliar application of silicon on number of leaves and nodules of soybean at different growth stages

Treatments	Number of leaves			Number of nodules50 DAS	
	30 DAS	45 DAS	60 DAS	Total nodules	Effective nodules
Control	7.33^{b}	22.53^{b}	23.80^{d}	20.27^{d}	9.80^{d}
Soil application of silicon @ 25 kg ha^{-1}	6.80^{a}	23.73^{ab}	25.47^{a-d}	24.60^{bc}	14.27^{c}
Soil application of silicon @ 50 kg ha^{-1}	7.47^{ab}	22.87^{ab}	23.93^{cd}	22.53^{cd}	12.80^{cd}
Foliar application of silicon @ 0.25 %	7.40^{ab}	23.27^{ab}	26.80^{ab}	29.13^{a}	18.47^{a}
Foliar application of silicon @ 0.50 %	7.67^{ab}	24.33^{ab}	26.00^{a-c}	26.40^{ab}	14.73^{bc}
Soil (25 kg ha^{-1}) + Foliar (0.25 %) application of silicon	7.00^{ab}	23.20^{ab}	27.47^{a}	29.27^{a}	19.73^{a}
Soil (25 kg ha^{-1}) + Foliar (0.50 %) application of silicon	8.13^{a}	24.87^{a}	26.07^{a-c}	27.33^{ab}	18.13^{ab}
Soil (50 kg ha^{-1}) + Foliar (0.25 %) application of silicon	7.33^{ab}	23.87^{ab}	25.33^{a-d}	23.33^{cd}	13.13^{cd}
Soil (50 kg ha^{-1}) + Foliar (0.50 %) application of silicon	6.80^{b}	22.73^{ab}	24.93^{b-d}	22.60^{cd}	13.00^{cd}
LSD	1.07	2.03	1.92	2.91	3.51

Table 4. Effect of soil and foliar application of silicon on chlorophyll content and dry matter production of soybean

Treatments	Chlorophyll content (SPAD)			Dry matter production (g plant^{-1})			
	30 DAS	45 DAS	60 DAS	30 DAS	45 DAS	60 DAS	Harvest
Control	18.66^{c}	35.53^{e}	46.19^{d}	1.99^{a}	7.09^{g}	15.99^{d}	33.91^{d}
Soil application of silicon @ 25 kg ha^{-1}	20.69^{a}	38.99^{c}	47.05^{c}	2.10^{a}	9.45^{c-e}	18.94^{b}	35.63^{bc}
Soil application of silicon @ 50 kg ha^{-1}	19.61^{b}	37.04^{d}	46.78^{c}	2.09^{a}	7.67^{fg}	16.99^{c}	34.95^{cd}
Foliar application of silicon @ 0.25 %	18.60^{c}	41.37^{a}	48.27^{b}	2.31^{a}	11.07^{ab}	20.15^{a}	36.74^{ab}
Foliar application of silicon @ 0.50 %	18.59^{c}	39.45^{c}	47.86^{b}	2.00^{a}	9.85^{cd}	18.96^{b}	36.60^{ab}
Soil (25 kg ha^{-1}) + Foliar (0.25 %) application of silicon	20.56^{a}	41.84^{a}	49.40^{a}	2.29^{a}	11.65^{a}	20.67^{a}	37.50^{a}
Soil (25 kg ha^{-1}) + Foliar (0.50 %) application of silicon	20.61^{a}	40.68^{b}	47.97^{b}	2.29^{a}	10.35^{bc}	19.15^{b}	36.65^{ab}
Soil (50 kg ha^{-1}) + Foliar (0.25 %) application of silicon	19.86^{b}	38.86^{c}	47.04^{c}	2.06^{a}	8.78^{de}	17.51^{c}	35.37^{b-d}
Soil (50 kg ha^{-1}) + Foliar (0.50 %) application of silicon	19.97^{b}	37.67^{d}	46.83^{c}	2.13^{a}	8.69^{ef}	17.23^{c}	35.36^{b-d}
LSD	0.33	1.04	0.97	1.49	1.04	0.97	1.49

Table 5. Effect of soil and foliar application of silicon on yield and yield parameters of soybean

Treatments	Number of pods plant^{-1}	Pod weight plant^{-1}(g)	100-seed weight (g)	Seed yield (q ha^{-1})	Haulm yield (q ha^{-1})
Control	31.20^{e}	20.90^{e}	13.80^{b}	12.86^{e}	17.68^{d}
Soil application of silicon @ 25 kg ha^{-1}	36.87^{b-d}	22.49^{b-d}	14.48^{ab}	13.81^{b-d}	18.41^{cd}
Soil application of silicon @ 50 kg ha^{-1}	34.20^{d}	21.77^{de}	13.82^{b}	13.43^{de}	17.98^{d}
Foliar application of silicon @ 0.25 %	39.07^{ab}	23.79^{ab}	14.90^{a}	14.55^{ab}	19.54^{ab}
Foliar application of silicon @ 0.50 %	37.60^{a-c}	23.37^{a-c}	14.58^{ab}	14.21^{a-c}	18.52^{b-d}
Soil (25 kg ha^{-1}) + Foliar (0.25 %) application of silicon	39.87^{a}	24.21^{a}	14.97^{a}	14.84^{a}	19.72^{a}
Soil (25 kg ha^{-1}) + Foliar (0.50 %) application of silicon	38.20^{a-c}	23.62^{ab}	14.79^{a}	14.23^{a-c}	19.11^{a-c}
Soil (50 kg ha^{-1}) + Foliar (0.25 %) application of silicon	36.40^{b-d}	22.17^{c-e}	14.40^{ab}	13.61^{c-e}	18.36^{cd}
Soil (50 kg ha^{-1}) + Foliar (0.50 %) application of silicon	35.93^{cd}	22.05^{c-e}	14.39^{ab}	13.57^{c-e}	18.30^{cd}
LSD	2.53	1.26	0.79	0.69	1.00

Recommended package of practice (RPP) is common to all treatments
Soil and foliar application of silicon at the time of sowing and 30 DAS (Days after sowing), respectively
Calcium silicate and monosilicic acid were used for soil and foliar application, respectively
In a column, mean values followed by the common letter are not significantly different at P = 0.05 level (DMRT at 5 % level)

The number of pods per plant, pod weight per plant, 100-seed weight, haulm yield and seed yield of soybean were greatly influenced by either individual soil and/or foliar application of silicon. The highest number of pods (39.87) and pod weight per plant (24.21g) were recorded with soil application @ 25 kg ha^{-1} + foliar @ 0.25 per cent (T_6) closely followed by T_4 (only foliar 0.25 %), T_5 (only foliar 0.50 %) and T_7 (soil @ 25 kg ha^{-1} + foliar @ 0.50 % Si). The highest 100-seed weight (14.97) was also recorded in the same treatment T_6. However, all other treatments barring T_1 and T_3 were on par with T_6 as seed weight is a genetic character of a crop.

The highest seed (14.84 q ha^{-1}) and haulm (19.72 q ha^{-1}) yields were recorded with soil application of silicon @ 25 kg ha^{-1} + foliar @ 0.25 per cent (T_6). However, treatments T_4, T_5 and T_7 were on par with T_6 with respect to seed yield and treatments T_4 and T_7 were on par with T_6 with respect to haulm yield. The lowest seed (12.86 q ha^{-1}) and haulm yield (17.68 q ha^{-1}) was recorded in the control which did not receive silicon. However, the soil application of silicon (50 kg ha^{-1}) and foliar application (0.25 % and 0.50 %) and their combination did not increase seed and haulm yields.

In the present investigation, application of silicon had promotary effects on soybean growth parameters consequently increased the yield and yield parameters and also dry matter production. This might be due to efficient partitioning of photosynthates and better utilization of absorbed nutrients with the application of silicon. One of the most important role of Si is to stimulate the plants defense abilities against abiotic and biotic stresses. Si deposited on the leaf tissue surface has been found to be responsible for the protective effect of silicon against biotic stresses. Paul *et al.* (2018) recorded increase in yield parameters of soybean with foliar application of Si up to 125 ppm. Shwethakumari (2017) also noticed enhanced seed yield and pod yield over control with the application of silicic acid @ 2 ml L^{-1} for three times. Malav *et al.* (2018), Ali *et al.* (2020), Dhamapurkar *et al.* (2011) and Nagula *et al.* (2016) reported that individual application of silicon produced the highest grain and straw yield in rice. Hongwen *et al.* (2016) and Meena *et al.* (2018) reported that application of silicon enhanced net photosynthetic rate and grain yield in maize. Similar results were also observed by Talashilkar *et al.* (2001) and Jadhav *et al.* (2000) in sugarcane.

Conclusion

Based on the response of soybean in terms of growth and yield, a combination of soil application of silicon @ 25 kg ha^{-1} at the time of sowing and foliar application of silicon @ 0.25 per cent at 30 DAS was found beneficial in a Vertisol.

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