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Effect of silicon fertilization on wheat productivity and profitability in Southern Rajasthan

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ABSTRACT

Area under organic cultivation of wheat (*Triticum aestivum* L.) is increasing in India. The present two-year study was carried out during 2017–18 and 2018–19 to observe the yield performance of wheat with application of silicon solution (amorphous silica SiO_2) under sub-humid conditions of southern plains and Aravalli Hills of Rajasthan. Factorial RBD with five levels of silicon concentration and three growth stages, viz. CRI, tillering and jointing stages were replicated thrice during *rabi* season of 2017–18 and 2018–19 at Udaipur, Rajasthan, India. Results revealed that application of silicon 8 g/litre water at tillering stage proved significantly superior in enhancing growth characteristics, yield attributes, yield and also gave maximum net returns of 110281/ha and B:C ratio of 2.32.

Keywords: Profitability, Quality, Silicon, Wheat and Yield

Wheat (*Triticum aestivum* L.) is the most widely cultivated crop providing food and nutrition to the two third population of the world. It is the second most important staple food crop of India after rice. It has significantly contributed towards success of the green revolution and has greatly helped to transform our country from a situation of "ship to mouth" to self-sufficiency. World Bank estimates the demand for wheat in developing countries will increase 60% by 2050 (Scott 2018). India ranks second in wheat production next to China, producing 109.24 million tonnes from 30.72 mha of land with the productivity of 3172 kg/ha (Government of India 2020–21). In Rajasthan state, it is grown on 3.10 mha with production 10.4 million tonnes having productivity of 3367 kg/ha (Government of Rajasthan 2017). Organic agriculture is gaining momentum worldwide. There is a growing demand of organic food. Organically grown wheat is a principal cereal crop of the world. Area and production of organic wheat is increasing in India due to high demand in the national and international market (Yadav *et al.* 2020).

Balanced nutrition results in increased production potential for wheat plants, to grow and develop in the presence of essential mineral elements. In addition to these essential elements, there are other elements that benefit plant nutrition, such as silicon (Si). Balanced mineral nutrition is the key to high-yielding and high-quality wheat production. Crop nutrition studies have recently shown that micronutrients are as important as macronutrients for crop growth and development. It is also suggested that the silicon plays a crucial role in preventing or minimizing the lodging incidence in the cereal crops. Silicon plays a significant role in imparting both biotic and abiotic stress resistance and thereby enhances productivity (Jain *et al.* 2020). Singh *et al.* (2006) in their results showed that increasing application rates of Si up to 120 kg Si/ha significantly increased dry matter, flag leaf effectively, yield attributes, and yield of rice, compared to the 60 kg Si/ha rate.

In organic production, natural sources of silicon can be used to increase the growth and yield of organic wheat. The use of this element for foliar nutrition of plants may become an important element of integrated plant protection in the near future, which all farmers in the European Union are obliged to apply. Also important is the fact that foliar application of silicon is safe for the natural environment and can also be used in organic farming, which is becoming more important in Europe. Therefore, use of silicon in wheat can help in enhancing the growth and productivity and it can be used as 100% organic input. Foliar application of silicon has a bio-simulative effect, and the best results are observed in stressful conditions for plants such as salinity, deficiency or excess of water, high and low temperature, and the strong pressure of diseases and pests, etc. Keeping these facts in view, a field experiment to study the effect

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of silicon on growth, yield and quality of organic wheat (*Triticum aestivum* L.) was conducted during *rabi* 2017–18 and 2018–19.

MATERIALS AND METHODS

Experimental site and soil: The experiment was conducted during *Rabi* season 2017–18 and 2018–19 at the Rajasthan College of Agriculture, Udaipur situated at an altitude of 579.5 m amsl and at 24°34' N latitude and 73°42' E longitude. The region falls under agro-climatic zone-IVa (Sub- humid Southern Plain and Aravalli Hills) of Rajasthan, India. The climate of the study area is sub-humid with a mean maximum and minimum temperatures ranged between 23.47–31.71°C and 5.21–13.03°C, respectively, during *rabi* 2017–18 and 2018–19 and the average annual rainfall of 637 mm occurring mostly during the months of July–October. Soil of the experiment was clay loam in texture, alkaline in reaction, medium in organic matter; low in available nitrogen (N), phosphorus (P), high in available potassium (K) and low in available zinc.

Growth and yield attributes: The height of five randomly selected plants in each plot was measured at 60, 75 and 90 DAS and at harvest from the soil surface to fully opened top leaf of the plant before ear emergence and up to the top of upper spikelet of main ear (excluding awns) at harvest and the average height was calculated and expressed in cm. The net plot crop was harvested, threshed and winnowed. The grain harvested from each plot were sun dried for 2–3 days to attain 10% moisture and then the weight of grains per net plot area was recorded and expressed in kg/ha.

Collection of silicon and analysis of silicon in grain: The silicon was collected from the M/s Seema Minerals & Metals Ltd., Udaipur, Rajasthan, India. The powdered sample of grain (0.1 g) was digested in a mixture of 2 ml each of 50% H_2O_2 and then 4.5 ml of 50% NaOH was added at ambient temperature in each polypropylene 100 ml tube. The tubes were individually covered with loose fitting plastic cups. The rack of tubes was placed in an autoclave (15 psi and 138 Kpa) for one hour. The volume of digested contents in the tubes was made up to 50 ml with double distilled water and after filtration; 1 ml aliquot was taken for Si estimation. The Si concentration in the digested solution was determined by 1 ml of digested aliquot and it was transferred to a plastic centrifuge tube and 30 ml of 20% acetic acid, 10 ml of ammonium molybdate (54 g/L *p*H 7), 5 ml of 20% tartaric acid and 1 ml of reducing ANSA solution (1-amino-2- naphthol-4-sulphonic acid) were added and the volume was made up to 50 ml with 20% acetic acid. After 30 minutes, the absorbance was measured at 650 nm with a UV-spectrophotometer (Ma and Tamai 2002). It contained 81% SiO_2.

Spray of silicon: Different doses of silicon were sprayed in experimental plots as per treatment during crop period. Diatomaceous earth was used as source of silicon. Silicon solutions were prepared as per treatment application, for example 2 g silicon/litre of water of silicon solution was prepared by adding 2 g of silicon to one litre of water. After

Table 1 Effect of silicon application time on yield attributes and yield of wheat during 2017–18 and 2018–19 and on pooled

Treatment	No. of tillers/m^2			Ear length (cm)			No. of spikelet/ear			No. of grain/ear			Grain yield (kg/ha)		
	2017–18	2018–19	Pooled	2017–18	2018–19	Pooled	2017–18	2018–19	Pooled	2017–18	2018–19	Pooled	2017–18	2018–19	Pooled
Concentration of Silicon															
Control	212	238	225	11.19	11.38	11.28	17.11	17.18	17.15	40.69	40.88	40.78	4067	4192	4129
2% Silicon	216	242	229	11.63	11.62	11.62	18.78	18.99	18.88	42.59	42.88	42.73	4177	4302	4239
4% Silicon	219	246	233	11.99	12.07	12.03	19.44	19.38	19.41	43.42	42.79	43.11	4222	4347	4285
6% Silicon	225	250	237	12.42	12.52	12.47	20.67	20.89	20.73	45.89	46.07	45.98	4413	4538	4475
8% Silicon	226	251	239	12.78	12.93	12.86	20.78	20.69	20.78	45.92	46.11	46.02	4494	4619	4557
S.Em ±	1.87	1.90	1.89	0.14	0.15	0.13	0.40	0.38	0.39	0.66	0.74	0.67	104	88	63
CD (P=0.05)	5.42	5.47	5.45	0.40	0.43	0.39	1.16	1.11	1.13	1.92	2.14	1.95	302	254	183
Time of application															
CRI stage	212	240	226	11.69	11.79	11.74	18.27	18.28	18.27	42.34	42.64	42.49	4073	4198	4135
Tillering stage	227	252	240	12.34	12.41	12.38	20.40	20.39	20.40	45.61	45.28	45.45	4487	4612	4549
Jointing stage	219	244	232	11.98	12.12	12.05	19.40	19.60	19.50	43.15	43.32	43.23	4264	4389	4327
S.Em ±	1.45	1.47	1.46	0.11	0.11	0.10	0.31	0.30	0.30	0.51	0.57	0.52	81	68	49
CD (P=0.05)	4.20	4.24	4.22	0.31	0.33	0.30	0.90	0.86	0.87	1.49	1.65	1.51	234	197	141

dilution the silicon solution has to be filtered before using it for spraying. The spray solution of silicon was sprayed at the time of CRI, tillering and jointing stages.

Chemical analysis of organic inputs and plant samples: The nutrient composition content in materials was analyzed by following the procedures of association of official agricultural chemists (AOAC 1960). The nitrogen content in the organic inputs/plant sample was determined by Macro-Kjeldahl method (Jackson 1973). Phosphorus, potassium and micronutrients were determined by using 1 g of dry compost/plant sample and digested with tri-acid mixture (HNO_3: $HClO_4$:H_2SO_4 in 9:3:1 ratio) on a hot plate at 180–200°C. Phosphorus extracted solution was estimated by spectrophotometer method (Jackson 1973), potassium was determined by flame photometer method given by Toth *et al.* (1948) and the protein content of seed was estimated by multiplying nitrogen content of seed with conversion factor of 6.25 (AOAC 1960).

Experimental design and treatments: The experiment was laid out in factorial randomized block and replicated thrice in the plot size of 5.0 m × 3.60 m (18 m^2). The treatments comprised of five levels of silicon, viz. control, 2.0, 4.0, 6.0 and 8.0 g/L and three levels of stage, viz. CRI, tillering and jointing. The wheat var. Raj. 4120 was sown in lines 22.5 cm apart. Silicon solutions were prepared as per treatments by adding dose to one litre of water and total of about 550 litre water/ha was used for silicon spray in the experimental field. For silicon, diatomaceous earth (amorphous silica SiO_2) source was used. The general dose of NADEP compost, vermicompost and neem cake were applied about 15 days before sowing and thoroughly incorporated with the help of spade in 15 cm top soil layer. The N @90 kg/ha was applied in two equal splits, the half as basal and the remaining half was top dressed at the time of first irrigation. The basal dose was applied through urea after adjusting the quantity supplied through diammonium phosphate (DAP). The P @30 kg/ha through DAP and K @30 kg/ha through muriate of potash were applied as basal and drilled at the depth of 8–10 cm along basal dose of N prior to sowing. The test crop was sown on 29th November, 2017 and 26th November, 2018, respectively. The seeds obtained from the produce of individual plot were recorded as grain yield kg/plot and later it was converted into kg/ha.

Observations recorded: The grain yield was recorded from net plot area of each treatment. The data obtained from various characters under study were analyzed by the method of analysis of variance as described by Panse and Sukhatme (1985). Net return and B:C ratio were calculated on the basis of prevailing market prices of inputs and produce.

Statistical analysis: The data recorded for different parameters were analyzed with the help of analysis of variance (ANOVA) technique for a factorial randomized block design. The results are presented at 5% level of significance (P=0.05).

RESULTS AND DISCUSSION

Yield attributes: The data (Table 1) revealed that application of 8 g silicon/litre recorded significantly higher number of tillers/m^2 at harvest, ear length, no. of spikelets/ear and number of grains/ear (239, 12.86 cm, 20.78 and 46.02, respectively) as compared to other treatments under study based on pooled data. However, dose of 8 g silicon/litre was found at par with 6 g silicon/litre (237, 12.47 cm, 20.73 and 45.98, respectively). Whereas, silicon application at tillering stage proved significantly superior in recording maximum number of tillers/meter^2 at harvest, ear length, no. of spikelets/ear and number of grains/ear (240, 12.38 cm, 20.40 and 45.45, respectively) compared to CRI (226, 11.74 cm, 18.27 and 42.49, respectively) and jointing stage (232, 12.05 cm, 19.50 and 43.23, respectively). Silicon had many positive effects on the physiology and metabolism of crop plants. Increase in yield attributes of wheat due to silicon application might be due to higher photosynthetic activity of plant, more formation of carbohydrates and more uptakes of other nutrients. Similar results were also noticed by Gholami and Falah (2013). Results also revealed that

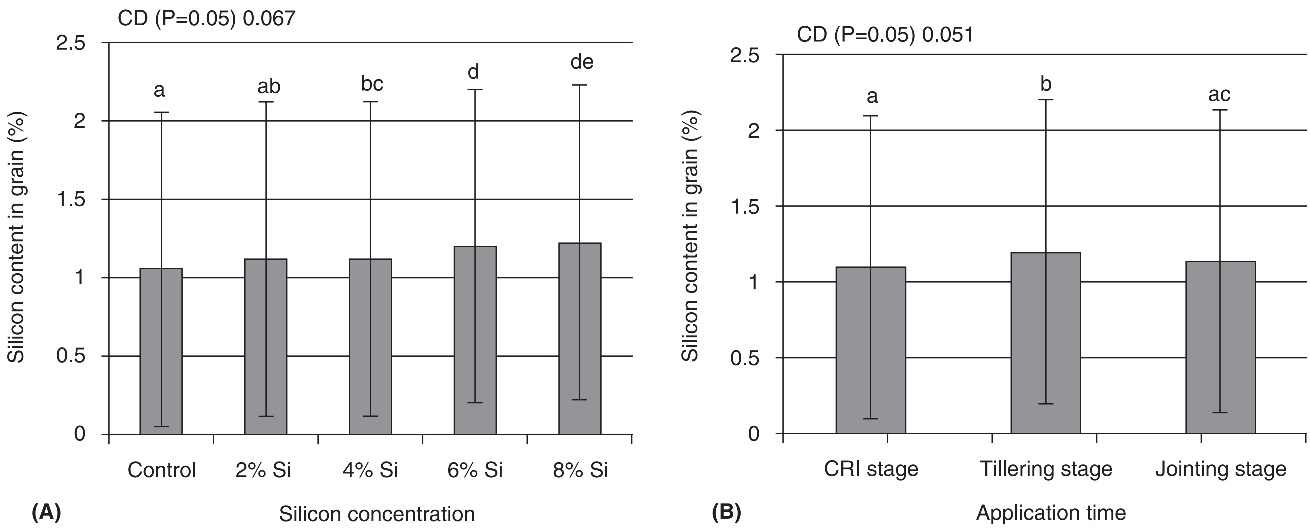

Fig 1 Effect of A) silicon concentration and B) application time on silicon content in grain of wheat (Pooled basis).

Table 2 Effect of silicon application time on profitability of wheat during 2017–18 and 2018–19 and on pooled.

Treatment	Gross return (₹/ha)			Net return (₹/ha)			B:C ratio		
	2017–18	2018–19	Pooled	2017–18	2018–19	Pooled	2017–18	2018–19	Pooled
Silicon Concentration									
Control	144520	150250	147385	97285	103015	100150	2.06	2.18	2.12
2% Silicon	148133	153863	150998	100848	106578	103713	2.13	2.25	2.19
4% Silicon	149476	155206	152341	102141	107871	105006	2.16	2.28	2.22
6% Silicon	157807	163537	160672	110422	116152	113287	2.33	2.45	2.39
8% Silicon	160601	166331	163466	113166	118896	116031	2.39	2.51	2.45
S.Em ±	2906	2578	1799	2906	2578	1799	0.06	0.05	0.04
CD (P=0.05)	8420	7470	5213	8420	7470	5213	0.18	0.16	0.11
Application Time									
CRI stage	144732	150462	147597	97397	103127	100262	2.06	2.18	2.12
Tillering stage	159379	165109	162244	112044	117774	114909	2.37	2.49	2.43
Jointing stage	152212	157942	155077	104877	110607	107742	2.22	2.34	2.28
S.Em ±	2251	1997	1394	2251	1997	1394	0.05	0.04	0.03
CD (P=0.05)	6522	5786	4038	6522	5786	4038	0.14	0.12	0.09

silicon addition helped plant growth, which might be due to the increased photosynthetic efficiency upon silicon addition, and it was exerted through the numbers of productive tillers, number of grains/ear, number of spikelet's, test weight and the reduction of pest and disease infestation.

Grain silicon (GS) and silicon uptake by grain: The data (Fig 1, Supplementary Fig 1) illustrated that application of 8 g silicon/litre recorded significantly higher GS and grain Si uptake (1.223% and 56.69 kg/ha, respectively) as compared to other treatments based on pooled data. However, these were found at par with 6 g silicon/litre (1.201%, and 54.56 kg/ha, respectively). Similarly, silicon application at tillering stage proved significantly superior in recording maximum GS and grain Si uptake (1.194% and 56.20 kg/ha, respectively) compared to CRI (1.095% and 44.35 kg/ha, respectively) and jointing stage (1.136% and 47.55 kg/ha, respectively). Choudhary *et al.* (2017) reported that K uptake was significantly increased in plant shoots when Si was added to soil.

Grain yield (GY): A wide range of GYs from 4129–4557 kg/ha were obtained (Table 1). The data illustrated that application of 8 g silicon/litre recorded significantly higher GY (4557 kg/ha) as compared to other treatments based on pooled data. However, these were found at par with 6 g silicon/litre (4475 kg/ha). Similarly, silicon application at tillering stage proved significantly superior in recording maximum GY (4549 kg/ha) compared to CRI (4135 kg/ha) and jointing stage (4327 kg/ha). Generally, observed variations in GYs were due to differences in inherent soil fertility and Si rate and application time. Silicon application, that may significantly reduce empty spikelet's number in wheat and increase fertility, increased spikelets per ear that ultimately increased crop yield. Similarly, showed that Si fertilization increased oat and wheat grain yield by 34.0% and 26.9%, respectively. Also, foliar fertilization with silicon significantly influenced the increase of wheat yield in studies conducted in India (Pooja *et al.* 2019).

Gross and net return and B:C ratio: Application of 8 g silicon/litre recorded maximum gross return, net return and benefit cost ratio (₹163466/ha, ₹116031/ha and 2.45, respectively) while minimum was recorded with control (₹147385/ha, ₹100150/ha and 2.12, respectively) based on pooled data. Profitability with the Si application time was noted significantly higher at tillering stage (₹162244/ha, ₹114909/ha and 2.43, respectively) as compared CRI (₹147597/ha, ₹100262/ha and 2.12, respectively) and jointing stage (₹15577/ha, ₹107742/ha and 2.28, respectively) (Table 2).

Silicon 8 g/litre water applied at tillering stage proved significantly superior in enhancing all the growth characteristics, yield attributes and profitability of the wheat, thereby Si application resulted in qualitative and quantitative produce under organic farming.

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