https://doi.org/10.56093/ijas.v90i3.101469

Indian Journal of Agricultural Sciences **90** (3): 533–6, March 2020/Article

Effect of silicon fertilization and crop establishment methods on yield, soil quality and silicon uptake of rice (*Oryza sativa*)

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Received: 26 December 2018; Accepted: 19 July 2019

ABSTRACT

A field experiment was carried out at ICAR-Indian Agricultural Research Institute, New Delhi during *kharif* 2015 and 2016 to determine the effects of rice establishment method, silicon application levels and silicon solubilizing bacteria on silicon concentrations and uptake by rice (*Oryza sativa*) and soil microbial parameters in rice-wheat cropping system. The experiment was laid out in split-split plot design and replicated thrice. The experiment was conducted with 24 treatment combinations including rice establishment methods in main plot, silicon level in sub plot and silicon solubilizing microbes in sub-sub plot. Silicon concentration in grain and straw was highest in crop establishment of aerobic rice and lowest in TPR methods during both the years. Tested aerobic rice establishment methods significantly influenced the microbial biomass carbon (278.2 and 289.3 µg/g soil), soil dehydrogenase activity (202.3 and 198.3 µg TPF/g soil/day) and total count of silicon solubilizing bacteria (222.5 and 255.9 × 10^2 cfu/g soil) compared to SRI and TPR and the highest silicon concentration and uptake, microbial biomass carbon (285.9 µg/g soil), dehydrogenase activity (189.7 µg TPF/g soil/day) and total count of silicon solubilizing bacteria (239.6 10^2 cfu/g soil) was recorded with silicon application 120 kg/ha which at par with 80 kg/ha but statistically superior over to control and 40 kg/ha in terms of nutrient uptake in grain and straw and soil quality parameters during both years of study.

Key words: Dehydrogenase activity, MBC, Rice establishment methods, Silicon concentration and uptake, Silicon level, Yield attributes

Silicon (Si) is the second most abundant element in soil. In soil solution, Si occurs mainly in the form of uncharged monosilicic acid $Si(OH)_4$ (Ma and Yamaji 2006) at concentrations ranging from 0.1 to 0.6 mM (Ma and Takahashi 2002). Most of the Si in soil occur as insoluble silicates or oxides and is not available for plant uptake (Ma and Yamaji 2006). Si has not been recognized as an essential element for plant growth owing to not involved directly in the metabolism of plant, For this reason, Si has been recognized as an "agronomically essential element" in Japan and silicate fertilizers have been applied to paddy soils. (Ma and Takahashi 2002). Si limits causes various abnormalities in the plant, including increased photosynthetic activity, increased insect and disease resistance, reduced mineral toxicity, improvement of nutrient imbalance, and enhanced drought and frost tolerance (Narayanaswamy and Prakash 2009).

Rice (*Oryza sativa* L.) is considered to be a Si accumulator plant and tends to actively accumulate Si into tissue up to concentrations of 5% or higher (Epstein 1994). Silicon content in rice is higher than the “essential elements” like nitrogen, phosphorus, and potassium (Savant *et al.* 1997). However, information on the importance of Si in Indian rice farming system is limited (Prakash 2002). Silicon plays a significant role in imparting biotic, abiotic stress resistance and enhancing crop productivity (Jawahar and Vaiyapuri 2010). It is also crucial in preventing or minimizing lodging in cereal crops, a matter of great importance in agricultural productivity. Silicon addition increased the erectness of the leaves of rice; it strengthens the air canal, leading to more efficient oxygen supply to roots and to the limited loss of water by evapotranspiration (Gao *et al.* 2006). Silicon is the only element known that does not damage plants with excess accumulation which improves light interception drought resistance, water use efficiency (Gao *et al.* 2005) and photosynthetic efficiency (Epstein 1999, Savant *et al.* 1997).

The largest amount of Si is absorbed by sugarcane (300–700 kg of Si/ha), followed by rice (150–300 kg of Si/ha) and wheat (50–150 kg of Si/ha). The reduced values for Si in the soil can be justified due to: (i) Severe and frequent soil erosion and sediment transportation, (ii) Usually plants absorb Si almost equal to the concentration of most of macronutrients and (iii) Due to the desilication process, Si in the soil is continuously lost as the result of leaching process. Subtropical and tropical soils are generally low in

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available Si and would benefit from Si fertilization. The Si content in some regions might be limited to sustainable crop production. Hence, improved Si management increased yield and sustained crop productivity and thus appeared to be necessary in temperate as well in tropical countries (Yogendra *et al.* 2014). Soil contains a variety of microorganisms but a few are capable of solubilizing the silicates. Several microbes like *Bacillus caldolytyicus*, *Bacillus mucilaginosus* var *siliceous*, *Proteus mirabilis, Pseudomonas* and *Penicillium* have been reported to release silica from natural silicates (Lauwers *et al.* 1974). Hence, the present experiment was carried out to determine the effects of rice establishment method, silicon application levels and silicon solubilizing bacteria on silicon concentrations and uptake by rice and soil microbial parameters in rice-wheat cropping system.

MATERIALS AND METHODS

A field experiment was carried out for two consecutive years during *kharif* seasons of 2015 and 2016 at the research farm of ICAR-Indian Agricultural Research Institute, New Delhi, India. Farm is situated at a latitude of 28° 38' N and longitude of 77° 10' E and at an altitude of 228.6 m amsl. The soil of the experimental field was sandy clay loam and had 8.32 *p*H, 0.55% OC, 166.0 kg/ha available N, 16.54 kg/ha available P, 254.2 kg/ha available K and 266 kg/ha available silicon (Si). The experiment was laid out in split-split plot design and replicated thrice times. The experiment was conducted with 24 treatment combinations including three rice establishment methods in main plot, four silicon application levels in sub plot and silicon solubilizing microbes in sub-sub plot. Main plot treatments in rice crop included transplanted rice (TPR), aerobic rice (AR) and system of rice intensification (SRI). Sub plot treatments in rice crop had four level of silicon application (0, 40, 80 and 120 kg/ha) and sub-sub plot included two silicon solubilizing microbes, viz. *Bacillus* sp. and *Pseudomonas* sp. The rice variety Pusa Basmati 1509 was taken and recommended seed rate used under TPR and AR. The recommended nitrogen fertilizer was applied @120 N kg/ha through urea in three equal splits, i.e. one-third nitrogen applied at the time of puddling and the remaining nitrogen in two equal splits, one three weeks after transplanting and rest at panicle initiation stage of crop. Phosphorus @60 P_2O_5 kg/ha as di-ammonium phosphate and potassium @60 K_2O kg/ha as muriate of potash were applied at the time of final puddling. The Si was applied as per the treatment details before transplanting of rice by broadcasting method as basal dose except in control (no Si treatment). Inoculation of silicon solubilizing microbes was done through seed/seedling treatment. Grain and straw samples of individual treatment were dried in an oven at 60 to 70°C till constant weight was obtained and ground to fine powder in Willey mill with stainless steel blades. Silicon concentration in grain and straw was determined by spectrophotometric method (Ma and Tamai 2002). The powdered plant samples were used for nutrient analysis. Soil samples from 0–15 cm and near to plant roots were taken in small polythene bags from each plot by core sampler. The soil samples were air-dried, ground and passed through 2 mm mesh-sieve and analysis for microbial parameters, viz. microbial biomass carbon (MBC) and microbial community composition (bacteria, fungi and actinomycetes) at initial and at the end of cropping system and soil enzyme activities, viz. dehydrogenase and total count of silicon solubilizing bacteria using Aaleksandrov medium both crops of the system.

RESULTS AND DISCUSSION

Yield and soil biological quality: Among the tested rice establishment methods, TPR recorded better number of panicles per meter square (280.5/m^2) and grain yield (4.92 t/ha) followed by SRI and lowest with aerobic rice yields) during two year of experimentation (Table 1). The differences in grain yield due to TPR and SRI were statistically at par however both of these methods showed significantly higher grain yield than aerobic rice. Hossain *et al.* (2001) found through testing several types of Si fertilizers, including calcium silicate and rice straw, on rice crops in pot culture that rice straw offers better results in terms of Si concentration in plant. Yields are also larger when rice straw is added in ground or combined with an organic matter

Table 1 Effect of rice establishment methods, silicon fertilization and microbes on number of panicles, grain yield and soil biological rice (Mean data of two years)

Treatment	No. of panic-les/ m^2	Grain yield (t/ha)	Microbial biomass carbon (µg/g soil)	Dehydro-genase activity (µg TPF/g soil/day)	Total count of silicon solubilizing bacteria (× 10^2cfu/g soil)
Rice establishment method					
TPR	280.5	4.92	252.0	161.3	210.0
AR	240.5	4.31	283.8	200.3	239.2
SRI	284.0	4.84	278.0	179.4	232.9
SEm±	4	0.08	4.6	3.0	3.8
LSD (P= 0.05)	16.5	0.31	18.0	11.7	15.0
Silicon application level (kg/ha)					
Control	254.0	4.36	251.7	166.8	211.2
40	263.5	4.61	266.9	178.0	223.5
80	276.5	4.85	280.5	186.8	235.2
120	279.0	4.94	285.9	189.7	239.6
SEm±	4.0	0.07	4.1	2.6	3.5
LSD (P= 0.05)	11.0	0.21	12.1	7.6	10.1
Silicon solubilizing microbes					
Bacillus	271.5	4.75	275.0	182.8	232.5
Psudomonas	265.0	4.62	267.5	177.9	222.2
SEm±	2.5	0.05	2.8	1.9	2.4
LSD (P= 0.05)	NS	NS	NS	NS	6.8
Interaction	NS	NS	NS	NS	NS

decomposer. Experiments conducted in Japan showed that Si from rice straw used as a fertilizer is usually not fully available in the short term, but is available at more than 70% in the long (40 years) term. Inorganic silicates affect the yields faster as they are used by plants in the crop following directly the fertilization. This has led to their wide use (Ma and Takahashi 2002). Among silicon application treatments, the highest number of panicles (280.5/m^2) per meter square and grain yield (4.92 t/ha) was recorded with the application of 120 kg silicon/ha followed by SRI and lowest with aerobic rice followed by 80 kg silicon/ha and both of these treatments were statistically at par. However application of 80 and 120 kg silicon/ha gave significantly higher yield over control and 40 kg silicon/ha during both the years. Gholami and Falah (2013) also reported an increase in Si content of stem and leaves, number of tillers, dry leaves weight, 1000-grain weight, and yield upon Si fertilization. Higher Si supply increased the dry weight of both shoots and roots of rice. Inoculation of seed/ seedlings with silicon solubilizing microbes showed no significant influence on grain yield during both the years. However, influence of inoculation on grain yield was superior with *Bacillus* than *Pseudomonas* since grain yield with *Bacillus* was higher.

The levels of microbial biomass carbon (MBC), dehydrogenase activity and total count of silicon solubilizing bacteria in soil were significantly influenced by the establishment methods of rice and application rates of silicon however, inoculation with silicon solubilizing bacteria did not influence MBC levels (Table 1). Among the methods of rice establishment, the highest and lowest MBC, dehydrogenase activity and total count of silicon solubilizing bacteria levels were recorded with aerobic rice and TPR, respectively during both years of experimentation. Significant difference in MBC levels, dehydrogenase activity and total count of silicon solubilizing bacteria were recorded due to varied rates of silicon application, the highest MBC (285.9 µg/g soil), dehydrogenase activity (189.7 µg TPF/g soil/day) and total count of silicon solubilizing bacteria (239.6 µg TPF/g soil/day) were recorded with application at 120 kg/ha but this was statistically at par with 80 kg/ha. Application of 80 and 120 kg/ha had significantly higher MBC, dehydrogenase activity and total count of silicon solubilizing bacteria over control and 40 kg silicon/ha during both the years. Hopkins and Shiel (1996) also observed that soil MBC was positively influenced due to various management practices such as crop rotation, organic amendments, crop residue management and green manuring. Seed/seedlings inoculation with silicon solubilizing microbes did not show significant influence on MBC levels and dehydrogenase activity during any year of experiment. The influence of inoculation on MBC levels and dehydrogenase activity were more prominent with *Bacillus* than *Pseudomonas*. Total count of silicon solubilizing bacteria, viz. *Bacillus* (232.5 x10^{2}cfu/g soil) in soil was significantly higher than *Pseudomonas* (222.2 × 10^{2}cfu/g soil). This could be due to transformation of polymerized silica to monomeric form by bacteria which is important in the biogeochemical cycles of silicates in nature. Bacterial dissolution of silicates in soil gained importance not only because of its involvement in the silica cycle but also because of its role in the release of the plant nutrients like potassium, calcium and magnesium from the silicates. (Lauwers *et al.* 1974).

Silicon concentration in grain and straw: The concentration of Si in grain and straw was significantly influenced due to the rice establishment methods (Table 2). The highest Si concentration in grain and straw was registered with aerobic rice and lowest with TPR during the both years of study. The silicon application rates significantly influenced the concentration of Si in grain and straw during both years of studies. Among different levels, the maximum Si-concentration was recorded due to the application of 120 kg silicon/ha in grain (1.58%) and straw (3.99%) followed by application at 80 kg silicon/ha in grain (1.54%) and straw (3.97%) and both of these treatments were statistically at par. However, application of 80 and 120 kg silicon/ha gave significantly higher Si concentration in grain and straw over control and 40 kg silicon/ha during both the years (Kim *et al.* 2012). Several studies have suggested the positive effects of Si on yield (Kim *et al.* 2012, Gholami and Falah 2013,

Table 2 Effect of rice establishment methods, silicon fertilization and microbes on Si concentration and uptake by rice (Mean data of two years)

Treatment	Si concentration in grain (%)	Si concentration in straw (%)	Si uptake by grain (kg/ha)	Si uptake by straw (kg/ha)	Total Si uptake (kg/ha)
Rice establishment method					
TPR	1.43	3.71	70.9	239.7	72.5
AR	1.58	4.03	68.6	239.7	68.1
SRI	1.32	3.84	65.9	244.9	62.7
SEm±	0.03	0.06	2.1	7.7	2.1
LSD (P= 0.05)	0.10	0.24	NS	NS	8.4
Silicon application level (kg/ha)					
Control	1.30	3.69	56.8	214.6	52.4
40	1.36	3.79	62.7	232.8	57.8
80	1.54	3.97	74.1	255.9	75.8
120	1.58	3.99	78.2	262.3	80.8
SEm±	0.02	0.06	1.9	6.9	1.8
LSD (P= 0.05)	0.06	0.16	5.7	20.4	5.2
Silicon solubilizing microbes					
Bacillus	1.46	3.89	69.7	246.6	68.6
Psudomonas	1.42	3.83	66.3	236.2	64.9
SEm±	0.02	0.04	1.4	4.7	1.4
LSD (*P*= 0.05)	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS

TPR, Transplanted rice; AR, Aerobic rice; SRI, System of rice intensification.

Emam *et al.* 2014). Si also increases the translocation of nutrients within the plant as well as water use efficiency by reducing transpiration. Silicon solubilizing microbes had no significant effect on Si concentration in grain and straw during both years of studies. But, effect of *Bacillus* was more superior over the *Pseudomonas* during both year of experimentation. Lauwers *et al.* (1974) also reported superiority of *Bacillus* sp.

Silicon uptake by grain and straw: The Silicon uptake by grain, straw and their total by rice crop were not significantly influenced due to different crop establishment methods. However, silicon application level/rates showed significant effects on silicon uptake in grain and straw of rice (Table 1). Among the silicon application levels, the highest uptake of Si was recorded with the application of 120 silicon kg/ha in grain (78.2 kg/ha) and straw (262.3 kg/ha) and it was followed by 80 Si kg/ha in grain (74.1 kg/ha) and straw (255.9 kg/ha) and both of these treatments were statistically *at par* in case of grain as well as straw. However, application of 80 and 120 silicon kg/ha gave significantly higher Si-uptake by grain, straw and its total uptake over control and 40 kg silicon/ha during both the years. *Bacillus* and *Pseudomonas* silicon solubilizing microbes had no significant effect on Si uptake by grain and straw during both years of study. This might be due to variation in grain and straw yield during both the years (Singh *et al.* 2005). This finding is in agreement with the reports of Singh *et al.* (2006). Silicon solubilizing bacteria did not show significant effect on N, P, K and silicon concentration in grain and straw during both the years of studies.

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