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Effect of Different Silicon Sources on Yield, Nutrient Uptake and Silicon Use Efficiency of Rice under Different Establishment Methods

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ABSTRACT

Field experiment was conducted during Rabi season at the farmer field, Orathur Village, Keerapalayam block,Cuddalore District,Tamilnadu, India to study the effect of different silicon sources onyield, nutrient uptake and silicon use efficiency of rice under different establishment methods. The experiment was laid out in split plot design with two replications. The main plots comprised of M_1- Dry Seeded Rice (DSR), M_2- Wet Seeded Rice (WSR) and M_3- Transplanted Rice (TR) and sub plots are S_1- RDF, S_2- S_1 + 100 kg Si ha^{-1} through Calcium Silicate + Silicate solubilising bacteria (SSB), S_3 -S_1 + 200 kg Si ha^{-1} through Calcium Silicate + SSB, S_4 -S_1 + 100 kg Si ha^{-1} through Diatomaceous Earth, S_5 -S_1 + 200 kg Si ha^{-1} through Diatomaceous Earth, S_6 –S_1 + 100 kg Si ha^{-1} through Fly ash + SSB and S_7 – S_1 + 200 kg Si ha^{-1} through Fly ash + SSB. Among the methods of establishments, transplanted rice recorded significantly higher yield (grain and straw), nutrient uptake (N, P, K and Si) and Silicon use efficiency (Agronomic efficiency(AE)and Apparent Si recovery (ASiE)of rice, which was followed by wet seeded rice, With regards to silicon sources, application of 200 kg Si ha^{-1} through Diatomaceous Earth along with RDF recorded higher values for yields (grain and straw),nutrient uptake (N,P,K and Si). However, 100kg Si ha^{-1} through Diatomaceous Earth along with RDF recorded higher values for Silicon use efficiencyof rice. The Diatomaceous earth performed better than Fly ash + SSB (Silicate solubilising bacteria) and Calcium silicate + SSB. This was closely followed by S_4 for yield(grain and straw), nutrient uptake (N, P, K and Si) and S_5 for Silicon use efficiency (AE and ASiE). The interaction effect between establishment methods and sources of silicon was significant. The treatment combination of diatomaceous @ 200 kg Si ha^{-1} earth along with RDF and transplanting method registered its superiority over others and recorded higher yields (grain and straw), nutrient uptake (N, P, K and Si) and thetreatment combination of diatomaceous @ 100 kg Si ha^{-1} earth along with RDF and transplanting method registered its superiority over others and recorded higher silicon use efficiency (AE and ASiE) of rice. Therefore it can be concluded that rice planted at 15x10 cm and fertilized with Diatomaceous Earth @200 kg Si ha^{-1} + RDF is a viable practice to enhance the yield (grain and straw) and nutrient uptake (N, P, K and Si) of rice and Diatomaceous Earth @100 kg Si ha^{-1} + RDF is found to enhance silicon use efficiency of rice.

Key words: silicon sources, establishment methods, Rice, yield, nutrient uptake and silicon use efficiency.

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INTRODUCTION

Rice is the staple food of about 3 billion people and demand is expected to continue to grow as population increases (Carriger and Vallee, 2007). Globally rice is grown over an area of about 149 million ha with an annual production of 600 million tonnes (Bernier *et al.*, 2008). In India, rice is grown about 44.16 million hectares having the annual production of 116.48 million tonnes with the productivity of 3.96 tonnes ha^{-1}(USDA, 2020). In India, Rice cultivation is practiced predominantly under transplanting method that involves raising the seedlings in nursery, uprooting it and transplanting in the main field. Transplanting is a labour intensive, expensive operation and it consumes a large quantity of standing water for puddling (Bouman and Tuong, 2001). The scarcity of water for agriculture production is becoming a major problem in many countries, particularly in wolrd’s leading rice-producing countries like China and India. Direct wet seeding is an alternative method of growing rice instead of conventional transplanting. In this method, sprouted (pre-germinated) seeds are sown on well prepared puddle land. Many Asian countries are now increasingly shifting to direct wet-seeded method of growing rice. However, the practice of direct wet seeding rice is very negligible in India. Direct seeding can be done either by hand broadcasting or by line sowing. Improved short duration and high yielding varieties, nutrient and weed management techniques encouraged the farmers to shift from traditional system of transplanting to direct seeded rice culture. It could reduce labour need by more than 20% in terms of working hour and 20% less water as compared to transplanted rice (Satter and Khan, 1994). Silicon (Si) is ranked as the second-most abundant element (after oxygen) in the earth’s crust with nearly 29% mean content (Sommer*et al.*, 2006).Si content (mostly 1%–45%) in soil ranges depending on soil types (Sommer*et al.*, 2006). In soil, Si mainly presents in various categories of alumino silicate and quartz (SiO_2), which consist of up to 75%–95% of soil inorganic constituents (Liang *et al*., 2015; Meharg and Meharg, 2015).Mono silicic acid or ortho silicic acid ($Si(OH)_4$, or H_4SiO_4) is the soluble, plant available form of silicon in soils. Rice plant absorbs Si by the roots in the form of ortho silicic acid (H_4SiO_4) along with water and translocated to the shoots. The potential of Si in improving crop yield has been demonstrated in many studies, especially under abiotic and biotic stress conditions (drought, heavy metals, salinity and pathogens) (Epstein, 2009). Si has been recognized as a functional nutrient for a number of crops, particularly rice and sugarcane and plays an important role in the growth and development of crops, especially gramineae crops (Epstein 1999).Silicon is considered as a nutrient of agronomic essentiality in that its absence causes imbalances of other nutrients resulting in poor growth. Rice crop uptake Si in the range of 230-470 kg ha^{-1} (Malav and Ramani. 2017). Reports also show that Si uptake for rice and sugarcane is sometimes greater than that of N and K uptake (Savant *et al*., 1997). Reduced amount of silicon in plant produces necrosis, disturbance in leaf photosynthetic efficiency, growth retardation and reduces grain yield in cereals especially rice (Shashidhar*et al.*, 2008).Ahmad *et al.*, (2013) reported that application of Si fertilizers enhanced the growth parameters, increased yield attributes and quality of rice crop.Keeping the above facts in consideration, the present investigation was carried out to study the effect of different silicon sources on yield,nutrient uptake and silicon use efficiency of rice under different establishment methods.

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MATERIALS AND METHODS

Field experiment was conducted in the Orathurvillage ,Keerapalayam block , Cuddalore district during Rabi season to study the effect of different silicon sources on yield, nutrient uptake and silicon use efficiency of rice under different establishment methods. The soil of the experimental field is sandy clay loam in texture with moderate fertility. The experiment was laid out in split plot design with two replications. The main plots comprised of M_1- Dry Seeded Rice (DSR), M_2- Wet Seeded Rice (WSR) and M_3- Transplanted Rice (TR) and sub plots are S_1- RDF, S_2- S_1 + 100 kg Si ha^{-1} through Calcium Silicate + SSB, S_3 -S_1 + 200 kg Si ha^{-1} through Calcium Silicate + SSB, S_4 -S_1 + 100 kg Si ha^{-1} through Diatomaceous Earth, S_5 -S_1 + 200 kg Si ha^{-1} through Diatomaceous Earth, S_6 –S_1 + 100 kg Si ha^{-1} through Fly ash + SSB and S_7 – S_1 + 200 kg Si ha^{-1} through Fly ash + SSB. Rice variety Co-51 was used for this study and was fertilized with 120:40:40 kg NPK ha^{-1}. Entire dose of P_2O_5 was applied as basal. N and K were applied in four equal splits at basal, tillering, panicle initiation and heading stages. Silicon sources and SSB were applied as basal as per the treatments. Biometric observations were recorded at critical stages. The data's were statistically analyzed as suggested by Gomez (1979).

RESULTS AND DISCUSSION

Yield

Yield(grain and straw) of rice was significantly increased with establishment methods and Silicon sources (Table 1). Among the establishment methods transplanted rice registered the highest yield (grain- 5925and straw-9914 kg ha^{-1}) of rice over other establishment methods (wet and dry seeding). Higher yield (grain and straw) in transplanted rice might be due to the Optimal plant spacing, ensure air circulation, adequate availability of water and nutrients and also better light interception and higher photosynthetic efficiency of rice. (Baloch *et al.*, 2002). This was followed by wet seeded rice and recorded the grain yield of 5502 kg ha^{-1} and straw yield of 9694 kg ha^{-1}. Direct seeded rice recorded lesser yield (grain-4776 and straw-9036kg ha^{-1}) of rice.

Among the silicon sources, Diatomaceous Earth recorded higher yield of rice, followed by Fly Ash and Calcium Silicate. Application of Diatomaceous earth @ 200 kg Si ha^{-1} along with recommended dose of fertilizers recorded higher grain (6108 kg ha^{-1}) and straw yield (10517 kg ha^{-1}) of rice. This may be attributed to the increased rate of photosynthesis, increased percentage of filled grains, increase in test weight and reduction in per cent spikelet sterility and disease infestation (Prakash *et al.,* 2011). This treatment was followed by 100 kg Si ha^{-1} through Diatomaceous Earth along with recommended dose of fertilizers. Application of 200 kg Si ha^{-1} through Fly ash + SSB along with recommended dose of fertilizers was next in order. This was on par with 200 kg Si ha^{-1} through Calcium Silicate + SSB plus recommended dose of fertilizers. The lesser yields (grain- 4609 and straw- 8822 kg ha^{-1})of rice was recorded with recommended dose of fertilizers alone.

Among the interaction effect between establishment methods and sources of silicon, diatomaceous @ 200 kg Si ha^{-1} earth along with RDF and transplanting method recorded higher values for yields (6662 kg ha^{-1}– grain and 10920 kg ha^{-1} – straw) of rice. It could be due to higher availability of nutrients and water in the soil and increased growth components

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resulted in higher yield of rice. This was followed by diatomaceous earth @100 kg Si ha^{-1} and recorded the yields 6501 and 10940 kg ha^{-1} for grain and straw yield, respectively.

Nutrient uptake

Data on uptake of nitrogen**,** phosphorus, potassium and siliconsignificantly increased by rice establishment method and application of different levels and sources of silicon (Figure 1 and 2). Among the establishment method, transplanted rice registered it superiority over wet and dry seeded rice. Transplanted rice recorded theN,P,Kuptake at 135.86,23.44 and 118.68 kg ha$^{-1,}$ respectively and total Si uptake during tillering, flowering and harvest stages were 76.4, 192.23 and 231.28 kg ha^{-1} respectively.This could be due to transplanting in puddle soil ensures optimal spacing for proper plant growth and good spacing can enhance the root growth and uptake of applied nutrients resulted N,P,K and Si uptake. This was followed by wet seeded rice and total N,P,K recorded 131.53, 21.64, 114.52 kg ha^{-1} andtotal Si uptake during tillering, flowering and harvest stagewere72.46, 187.69 and 227.48 kg ha^{-1} respectively. The lesser N,P,K and Si was observed under dry seeded rice.

Regarding to silicon sources, Diatomaceous Earth showed better results over Fly Ash and Calcium Silicate.Among the levels of silicon, application of 200 kg Si ha^{-1} through Diatomaceous Earth along with recommended dose of fertilizers registered its superior over others. It recorded higherN,P,K uptake (146.07,23.95 and 125.88 kg ha^{-1}) at harvest and Si uptake during tillering, flowering and harvest stages (80.18,196.09 and 247.38 kg ha^{-1}), which was followed by 100 kg Si ha^{-1} through Diatomaceous Earth along with recommended dose of fertilizers. Higher nutrient uptake (N,P,K and Si) with 200 kg Si ha^{-1} through Diatomaceous Earth along with recommended dose of fertilizers could be due to increased availability of silicon and other nutrients in the soil. Moreover, the application of Si significantly improved the uptake of N,P and K in above-ground rice biomass, which is consistent with previous findings (Pati*et al.*,2016, Crooks and Prentice,2017). Despite the abundance of Si in the earth, the availability of plant –available Si in the soil solution is low and its uptake is primarily dependent on the Si-supplying ability of the soil (Jawahar and Vaiyapuri,2013). Singh *et al* (2005) reported that Si application has the potential in enhancing the availability of N in soil, resulting in an enhanced N uptake due to ample N availability. Subramanian and Gopalswamy (1991) reported an enhanced availability of P with the addition of Si fertilizer, thereby improving P uptake. Si application also increases K uptake by rice plant(Singh *et al.*,2005, Pati*et al.*,2016). This was on par with 200 kg Si ha^{-1} through Calcium Silicate + SSB plus recommended dose of fertilizers. Slow release of silicon nutrition and minimum availability of plant available Si to rice plant during critical stages causes somewhat lesser nutrient uptake in Fly ash and Calcium Silicate applied plots over Diatomaceous Earth. The lesser values for nutrient uptake of rice was recorded under recommended dose of fertilizers alone due to lack of availability of silicon nutrition. Among the interaction effect between establishment methods and sources of silicon, diatomaceous @ 200 kg Si ha^{-1} earth along with RDF and transplanting method recorded higher values for nutrient uptake of rice due to the favourable soil condition and adequate supply of silicon and other nutrients during the critical stages of crop growth.

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Silicon use efficiency

Silicon use efficiency of rice was significantly influenced by establishment methods and silicon sources (Table2). Rice seedling planted in puddle soil recorded significantly higher Silicon use efficiency(AE and ASiE) (7.22kg ha^{-1} and 15.41%)of rice over other establishment methods (wet and dry seeding). Higher Silicon use efficiency (AE and ASiE) in transplanted rice might be due to the Optimal plant spacing, ensure air circulation, adequate availability of water and nutrients and also better light interception and higher photosynthetic efficiency of rice. (Baloch *et al*., 2002). Similar finding was also reported by earlier researchers (Kundu, *et al*., 1993). Wet seeded rice was next in order and recorded theAE and ASiE at 6.44 kg ha^{-1} and 14.98%. Seeds sown on the dry pulverized soils recorded lesser Silicon use efficiency (AE and ASiE) 6.14 kg ha^{-1} and 14.88%of rice.

Among the silicon sources, Diatomaceous Earth recorded higher Silicon use efficiency (AE and ASiE), followed by Fly Ash and Calcium Silicate. Application of Diatomaceous earth @ 100 kg Si ha^{-1} along with recommended dose of fertilizers recorded higher Silicon use efficiency (AE and ASiE) (13.20 kgha^{-1}and 25.30%) of rice. Greater nutrient use efficiency at lower level is common because of efficient utilization of nutrients at lower level (Fageria and Baligar 2001). Higher silicon use efficiency in rice could be due to higher uptake of silicon in rice grain or addition of silicon through fertilizers (Kumar 2019).

Application of 100 kg Si ha^{-1} through Fly ash + SSB along with recommended dose of fertilizers was next in order. This was on par with 200 kg Si ha^{-1} through Calcium Silicate + SSB plus recommended dose of fertilizers. Among the interaction effect between establishment methods and sources of silicon, diatomaceous @ 100 kg Si ha^{-1} earth along with RDF and transplanting method recorded higher values for Silicon use efficiency of rice. It could be due to greater nutrient use efficiency at lower level of rice.

Conclusion

From this study, it can be concluded that transplanting method of establishment along with application of diatomaceous earth @200 kg Si ha^{-1}along with RDFis a viable practice to enhance the yields (grain and straw) and nutrient uptake (N, P, K and Si) of rice and Diatomaceous Earth @100 kg Si ha^{-1} + RDF is found to enhance silicon use efficiency of rice.

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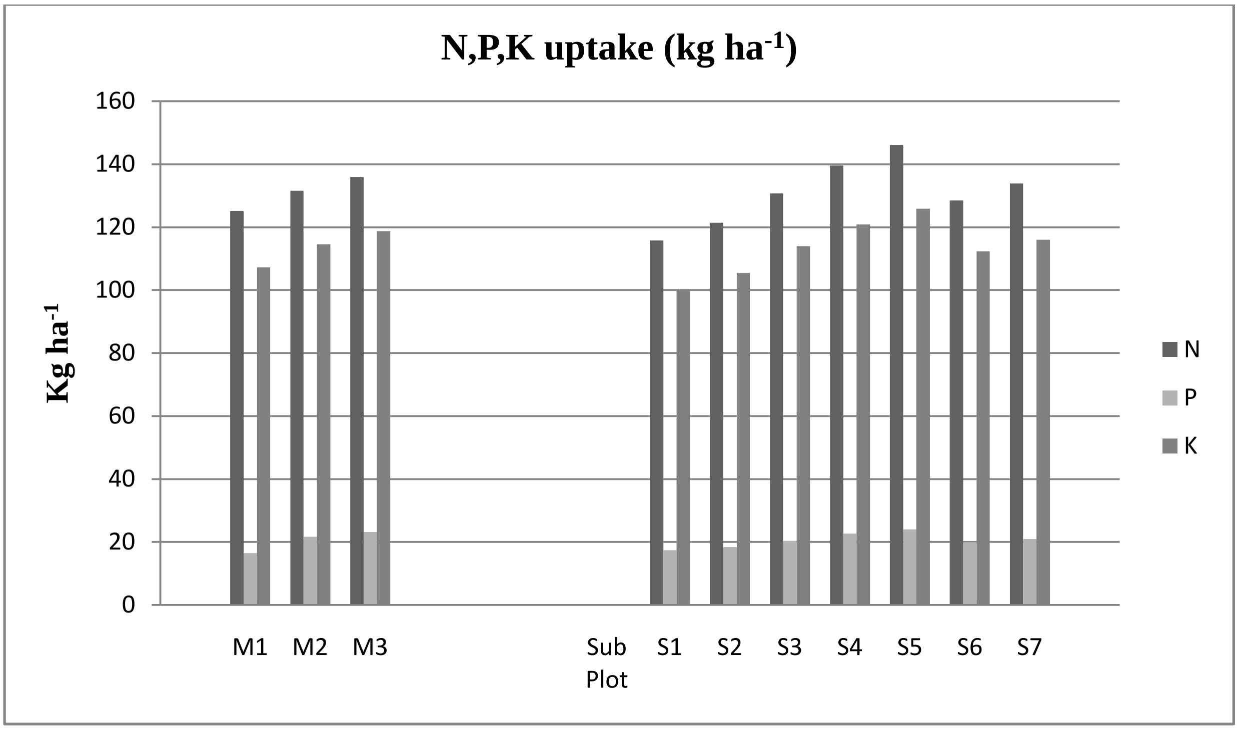
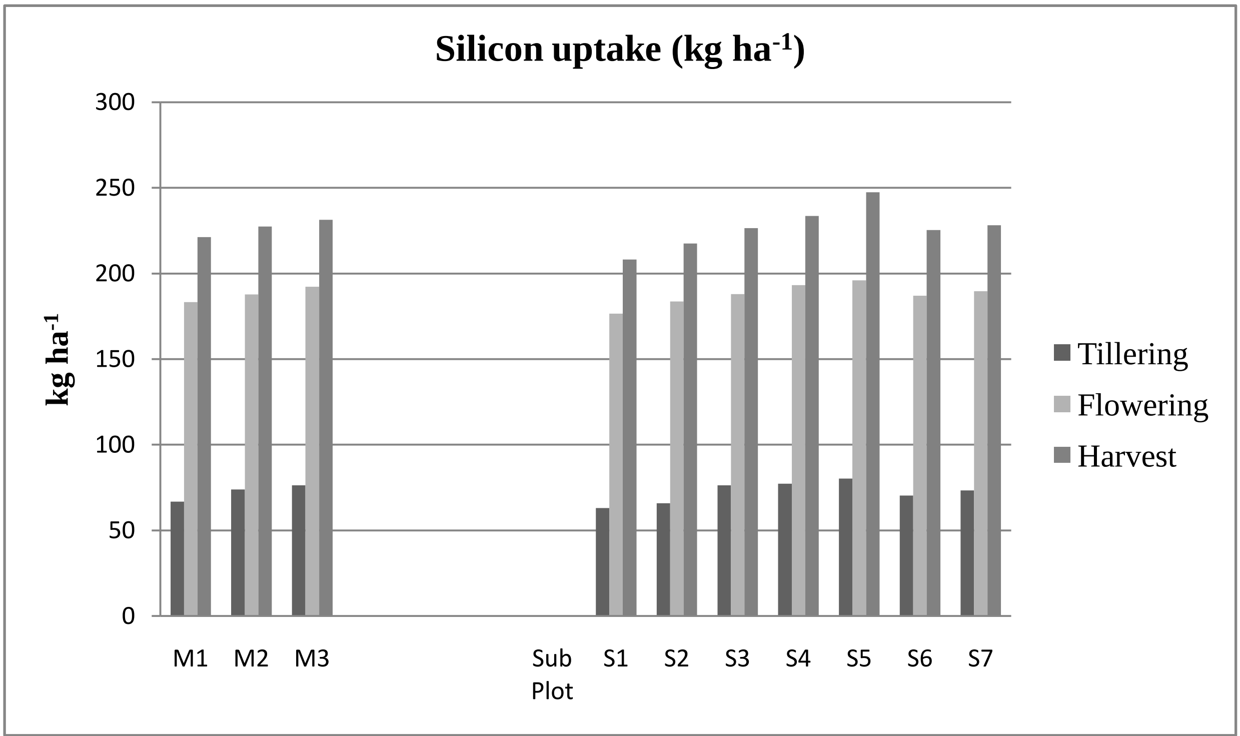


Figure 1: Effect of Silicon sources and establishment methods on N,P,K uptake (kg ha-



1) of rice

Figure 2: Effect of Silicon sources and establishment methods on Silicon uptake (kg ha-1) of rice

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Table 1.Effect of silicon sources and establishment methods on yield (grain and straw) of rice

Yield (Kg ha^{-1})								
	Grain				Straw			
Treatments	**M_1**	**M_2**	**M_3**	**Mean**	**M_1**	**M_2**	**M_3**	**Mean**
S_1	4037	4730	5059	4609	8212	9083	9171	8822
S_2	4408	5123	5512	5014	8482	9283	9371	9045
S_3	4747	5446	5890	5361	8962	9600	9911	9491
S_4	5258	6026	6501	5298	9610	10020	10220	9950
S_5	5454	6209	6662	6108	9990	10640	10920	10517
S_6	4642	5355	5790	5262	8842	9490	9791	9374
S_7	4887	5628	6063	5526	9151	9740	10011	9634
Mean	4776	5502	5925		9036	9694	9914	
	M	**S**	**MxS**	**SxM**	**M**	**S**	**MxS**	**SxM**
S.Ed	**205**	**66.8**	**277**	**97**	**108**	**59**	**204**	**283**
CD (P=0.05)	**415**	**135**	**560**	**195**	**218**	**120**	**412**	**571**

Table 2. Effect of silicon sources and establishment methods on Silicon use efficiency (Apparent Si recovery and Agronomic efficiency) of Rice

Silicon use efficiency (SiUE)								
	ANR (%)				AE(kg ha^{-1})			
Treatments	**M_1**	**M_2**	**M_3**	**Mean**	**M_1**	**M_2**	**M_3**	**Mean**
S_1								
S_2	3.71	3.93	4.53	4.06	9.19	9.24	9.64	9.36
S_3	3.55	3.58	4.16	3.76	8.99	9.05	9.30	9.11
S_4	12.21	12.96	14.42	13.2	25.08	25.11	25.83	25.34
S_5	7.09	7.4	8.12	7.54	19.22	19.52	19.97	19.57
S_6	6.05	6.25	7.31	6.54	16.88	17.05	17.53	17.15
S_7	4.25	4.49	5.02	4.59	9.79	9.88	10.16	9.94
Mean	6.14	6.44	7.26		14.85	14.98	15.41	
	M	**S**	**MxS**	**SxM**	**M**	**S**	**MxS**	**SxM**
S.Ed	**0.12**	**0.17**	**0.62**	**3.14**	**0.06**	**0.13**	**0.29**	**2.86**
CD (P=0.05)	**0.25**	**0.35**	**1.25**	**6.34**	**0.12**	**0.27**	**0.58**	**5.79**

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