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Effect of silicon and phosphorus fertilization on growth, productivity and profitability of aerobic rice (*Oryza sativa*)

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ABSTRACT

A field experiment was conducted at ICAR- Indian Agricultural Research Institute, New Delhi during rainy (*kharif*) seasons of 2015 and 2016 to study the effect of silicon and phosphorus levels on yield, yield attributes and economics of aerobic rice (*Oryza sativa* L.). Four levels each of phosphorus (0, 30, 60 and 90 kg P_2O_5/ha) and silicon (0, 40, 80 and 120 kg Si/ha) were tested in a factorial randomized block design (FRBD) and replicated three times. Growth and yield attributes were significantly higher when phosphorus and silicon were included in the nutrient management of aerobic rice cultivation. Growth, yield, yield attributes and economics were significantly affected by the combined application of silicon and phosphorus. The highest aerobic rice grain yield (5.66 and 5.62 t/ha), net returns (₹ 92.4 × 10^3 /ha and 90.1 × 10^3 /ha) and yield attributes were recorded with 90 kg P_2O_5/ha during both the years of experimentation. However, it was at par with 60 kg P_2O_5/ha during both the years of experimentation. In case of silicon application, highest grain yield (5.53 and 5.65 t/ha), net returns (₹ 90.7 × 10^3 /ha and 92.4 × 10^3 /ha) and yield attributes were recorded with 120 kg Si/ha, however, it was at par with 80 kg Si/ha during both the years of experimentation. Therefore, the application of phosphorus and silicon should be adopted for achieving higher productivity and profitability of aerobic rice.

Key words: Aerobic rice, Economics, Grain yield, Phosphorus, Silicon

Rice (*Oryza sativa* L.) is the staple food crop for more than 3.4 billion people around the world (Khush 2004) and India has the largest area 43.9 M ha with the total production of 110 million tonnes of paddy. The productivity of paddy in India is 2505 kg/ha though increasing marginally, but is still well below the world's average yield (FAOSTAT 2017). Irrigated lowland rice system accounts for about 55% of the worlds harvested rice area and contributes about 76% of global rice production (Fageria *et al.* 2003), however the productivity of irrigated rice systems is increasingly threatened due to water scarcity. Irrigated agriculture utilizes about 90% of fresh water of this more than 50% is used in rice cultivation. Water scarcity is becoming more and more global concern and in India signs of serious water scarcity are already evident in agriculture sector. Rice has very low water-use efficiency and under irrigated conditions it consumes 3000 to 5000 l of water to produce one kg of rice. Researchers are working on various water saving technologies, such as alternate wetting and drying (Belder *et al.* 2004), continuous soil saturation (Borell *et al.* 1997), direct (dry) seeding (Tabbal *et al.* 2002) and 'aerobic rice' (Tuong and Bouman 2003). In fact, increasing water scarcity has necessitated the development of aerobic rice systems that require less water than traditional flooded rice. Aerobic rice is defined as rice grown in non-puddled and non-flooded aerobic soil conditions (Bouman 2001). Cultivation of aerobic rice could save more than 50% water and enhanced 60% higher water productivity than that of transplanted rice (Singh and Chinnasamy 2007). Comparative performance of aerobic and flooded rice in tropical areas confirmed a yield gap between aerobic and flooded rice. However, the yield loss of aerobic rice could outweigh the benefits of its water savings. One of the ways to minimize the yield gap may be through addition of silicon in nutrient management as it is an essential component of rice plants and its accumulation is helpful in maintaining sustainable production of aerobic rice (Yamaji and Ma 2006, Jinger *et al*. 2017).

Silicon (Si) is the most neglected nutrient in Indian agriculture. It did not receive much attention till the 1980's, because of the general belief that Indian soils are rich in Si. Furthermore, the demand of rice and wheat crops for nutrients, especially Si, is very high (Zanao *et al*. 2010,

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Soratto *et al*. 2012). Silicon imparts erectness to the leaves, minimizes transpiration losses and imparts resistance to diseases and pests in rice plant (Janaki and Chithra 2002). It also reduces lodging in rice and wheat (Gong and Chen 2012). Application of silicon increases grain yield of rice and wheat (Seebold *et al.* 2000). Phosphorus (P) is the second most important plant nutrient after nitrogen. Application of P aided in more vigorous root development and early tillering capacity. Since aerobic rice consumes less water as compared to transplanted rice which leads to water stress sometimes so, Si and P may be the potential nutrient to cope up the effect of water stress in aerobic rice and enhance its productivity. Under water stress, several workers have suggested that Si and P may increase the drought-tolerance of plants (Mohammadi *et al*. 2006, Datnoff *et al*. 2001). The emerging scenario necessitates the need for adoption of the practices which helps in maintaining soil health, keeps the rice production sustainable and provides qualitative food for meeting the nutritional requirement of human beings. Moreover, the effect of Si and P on aerobic rice has not been explored. Considering these facts in view, the current study was initiated to determine the effect of silicon and phosphorus fertilization on growth, productivity and profitability of aerobic rice.

MATERIALS AND METHODS

A field experiment was conducted during *kharif* seasons of 2015 and 2016 at the research farm of ICAR-Indian Agricultural Research Institute (IARI), New Delhi located between 28°40'N latitude and 77°12'E longitude at an altitude of 228.6 m above the mean sea level. The crop growing season experienced 5 to 7 °C minimum temperature and 41 to 47 °C maximum temperature. The soil of experimental site was sandy clay loam in texture (sand 51.6%, silt 22.1% and clay 26.3%) with the pH of 7.7, bulk density of 1.42 g/cm^3 and electrical conductivity 0.42 dS/m in the top 15 cm of soil. Soil had low organic carbon (0.45%) and available N (205 kg/ha), medium P (16.5 kg/ ha), K (260 kg/ha) and Si (270 kg/ha). Three times replicated experiment consisted of four levels each of phosphorus (0, 30, 60 and 90 kg P_2O_5/ha) and silicon (0, 40, 80 and 120 kg Si/ha) was conducted in a factorial randomized block design (FRBD). Phosphorus and silicon were supplied as basal dose through di-ammonium phosphate (DAP) and calcium silicate respectively. Recommended dose of nitrogen and potassium were also applied to the crop. Nitrogen was applied in 3 split by splitting 1/3rd at 10 DAS, 1/3rd at tillering (40 DAS), and 1/3rd at panicle initiation stage (70 DAS). The entire dose of phosphorus was applied as basal just before sowing in both the crops. Subsequently, it was incorporated into the soil while sowing by seed drill. Both nitrogen and phosphorus through urea and DAP was applied by broadcasting. Dry seeding through seed drill was done on 19 and 22 June during 2015 and 2016 respectively, in rows, 20 cm apart. The high-yielding rice variety Pusa 1612 was sown with a seed rate of 40 kg/ha. In order to ensure proper seed germination, seed priming (overnight soaking of seed followed by drying in shade) was done before sowing. The seed was treated with bavistin fungicide at 2.0 g/kg seed before sowing. Pendimethalin 1.0 kg/ha was sprayed next day after sowing through knapsack sprayer fitted with flat-fan nozzle using 500 l/ha spray volume. Total 14 and 11 irrigations were applied during 2015 and 2016 respectively. The crop was harvested on 21 and 23 October during 2015 and 2016. The relevant yield parameters were recorded using standard procedure. Five plants were selected randomly and tagged for taking various yield attributing observations from each net plot (12 m^2). For dry matter accumulation five plants were randomly selected and collected by cutting it on the ground level in each treatment at different stages of growth. These plants were selected from the middle of the plot to avoid the border effect by leaving two rows on all the sides. These samples were shade dried for 5-7 days and oven-dried at 65^{0}C temperature for 36 to 48 hr to obtain a constant dry weight. Total dry matter production was expressed in g/m^2 at 30, 60, 90 and 120 DAS. Grain and straw yield was expressed at 14% moisture level. Economics of the treatments were computed taking into account the prevailing market prices of inputs and crop outputs. Data were analyzed statistically in SAS @ version 9.3 for analysis of variance (ANOVA). Treatments were compared by computing the 'F-test'. The significant differences between treatments were compared by critical difference at 5% level of probability Gomez and (Gomez 1984).

RESULTS AND DISCUSSION

Dry matter accumulation

Dry matter accumulation was slow at earlier growth stages and thereafter increased rapidly and reaching at peak at physiological maturity in all the treatments (Table 1). Dry matter accumulation was non-significant up to 30 days after sowing (DAS) and thereafter significant at 60, 90 DAS and at harvest with the application of phosphorus and silicon during both the years of experimentation. Among phosphorus application, highest dry matter accumulation during 2015 and 2016 at 60 (419.5 and 432.6 g/m^2), 90 DAS (1209.8 and 1256.3 g/m^2) and at harvest (1399.1 and 1363.3 g/m^2) was recorded with application of 90 kg P_2O_5/ha which was at par with 60 kg P_2O_5/ha. This might be due to sufficient availability of phosphorus which leads to vigorous and taller plants with larger leaf area, which increased the photosythates production, resulting into enhanced dry matter production . Jain and Dhama (2006) reported that application of P up to 90 kg P_2O_5/ha significantly increased dry matter by 5-10% over no use of P (control) and 30 kg P_2O_5/ha, respectively. These results are in conformity with the findings of Singh *et al*. (2003). Among the silicon levels highest dry matter accumulation at 60 (415.7 and 428.8 g/m^2), 90 DAS (1156.7 and 1201.1 g/m^2) and at harvest (1406.7 and 1362.1 g/m^2) was obtained with 120 kg Si/ha during both the years and it was found at par with 80 kg Si/ha. The higher dry matter accumulation (DMA) may be due to the reason

Table 1 Effect of phosphorus and silicon application on dry matter accumulation of rice at different growth stages

Treatment	Dry matter accumulation (g/m^2)							
	30 DAS		60 DAS		90 DAS		Harvest	
	2015	2016	2015	2016	2015	2016	2015	2016
Phosphorus application (kg P_2O_5/ha)								
0	69.9	65.5	390.8	390.3	977.4	992.2	1169.1	1065.1
30	70.4	66.2	400.4	405.4	1025.6	1034.8	1213.7	1190.2
60	70.6	66.7	408.2	415.5	1177.6	1195.2	1352.9	1360.8
90	72.5	67.4	419.5	432.6	1209.8	1256.3	1399.1	1363.3
SEm±	0.9	0.71	5.0	8.3	21.8	27.0	42.0	45.0
CD (P=0.05)	NS	NS	14.3	23.9	63.0	77.9	121.4	129.9
Silicon application (kg Si/ha)								
0	70.1	65.7	392.0	396.2	1047.1	1054.3	1139.9	1063.1
40	70.5	66.5	401.3	401.6	1090.5	1092.7	1275.5	1231.5
80	70.6	66.6	409.9	417.2	1096.0	1130.4	1312.6	1322.7
120	72.1	67.1	415.7	428.8	1156.7	1201.1	1406.7	1362.1
SEm±	0.9	0.71	5.0	8.3	21.8	27.0	42.0	45.0
CD (P=0.05)	NS	NS	14.3	23.9	63.0	77.9	121.4	129.9

that Si fertilization enhances photosynthetic rate leading to increased dry matter production. Gerami *et al.* (2012) reported that with the increase of Si levels, the leaf area of the plant will increases which enhanced photosynthetic rate and prevents the destruction of chlorophyll and finally increased dry matter of rice. Silicon induced erectness of leaves results in increased photosynthesis, improves water usage and decrease transpiration which eventually accumulated more dry matter (Nakata *et al.* 2008).

Yield attributes

The yield attributes like effective tillers, panicle length, panicle weight and grains/panicle were significantly influenced by the silicon and phosphorus application during both the years of experimentation (Table 2). Among the phosphorus levels maximum number of effective tillers (391.9 and 394.2/m), panicle length (27.9 and 28 cm), grains/panicle (136.8 and 140.3) and panicle weight (2.33 and 2.45 g) were obtained with 90 kg P_2O_5/ha during both the years of experimentation and it was at par with 60 kg P_2O_5/ha. The highest values of growth parameters with the application of phosphorus got translated into better yield attributes of aerobic rice. This may be probably due to more absorption and utilization of available nutrients leading to overall improvement of crop growth and source-sink relationship, which in turn enhanced the yield attributes of

Table 2 Effect of phosphorus and silicon application on yield attributes of aerobic rice

Treatment	Effective tillers/m^2		Panicle length (cm)		Grains/panicle		Panicle weight (g)		1000-Grain wt. (g)	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Phosphorus application (kg P_2O_5/ha)										
0	265	259	25.5	25.0	111.8	115.3	1.97	1.97	22.3	22.3
30	311	301	26.2	26.0	122.1	125.7	2.07	2.14	22.7	22.7
60	358	363	26.8	27.0	130.1	135.5	2.23	2.31	23.9	23.9
90	392	394	27.9	28.0	136.8	140.3	2.33	2.45	24.7	23.4
SEm±	12.0	12.5	0.4	0.4	2.3	3.1	0.05	0.06	0.5	0.5
CD (P=0.05)	35	36	1.1	1.3	6.7	8.9	0.13	0.17	1.3	NS
Silicon application (kg Si/ha)										
0	290	290	25.4	24.9	119.2	122.3	2.01	2.05	22.4	22.4
40	308	307	26.4	26.0	123.8	125.7	2.04	2.12	22.5	22.5
80	349	352	27.0	27.2	126.1	132.0	2.27	2.35	24.1	24.1
120	378	367	27.6	27.8	131.7	136.7	2.29	2.34	24.5	23.2
SEm±	12.0	12.5	0.4	0.4	2.3	3.1	0.05	0.06	0.5	0.5
CD (P=0.05)	35	36	1.1	1.3	6.7	8.9	0.13	0.17	1.3	NS

aerobic rice (Sharma *et al*. 2009). The 1000-grain weight influenced significantly due to P and Si levels during first year. Highest value of 1000-grain weight (24.7 g) was recorded with 90 kg P_2O_5/ha. Among silicon treatment highest value of 1000-grain weight (24.5 g) was recorded with 120 kg Si/ha. The 1000-grain weight was found non-significant due to application of P and Si during second year. Among silicon levels highest values of all yield attributes were obtained with 120 kg Si/ha during both the years of experimentation. However, this treatment was remains at par with the 80 kg Si/ha. This may be attributed to significant increase in available nutrients like P, Si, and Mn which leads to more accumulation of dry matter and ultimately increased the values of yield attributing characters of rice as reported by Gholami and Falah (2013). Highest 1000-grain weight was obtained with 120 kg Si/ha and the lowest with control.

Yield

Grain yield, straw yield, biological yield and harvest index were significantly influenced by phosphorus application during both the years of experimentation (Table 3). Highest grain yield (5.66 and 5.62 t/ha), straw yield (7.99 and 8.41 t/ha), biological yield (13.7 and 14.0 t/ha) and harvest index (41.3 and 40.7%) were obtained with 90 kg P_2O_5/ha during both the years of experimentation and it was at par with 60 kg P_2O_5/ha. The increase in grain and straw yields was possibly due to better growth, effective tillers/m^2, grains/panicle and 1000-grain weight. Similar results were obtained by Alam *et al.* (2009). Lowest values of yields and harvest index were recorded with control. Among the silicon application, all the yield components were significantly affected by silicon levels during both the year of experimentation except harvest index (HI) during first year. Highest grain yield (5.53 and 5.65 t/ha), straw yield (8.09 and 8.57 t/ha) and biological yield (13.6 and 14.2 t/ha) were obtained with 120 kg Si/ha during both the years and remained at par with 80 kg Si/ha. The increase in yield was attributed due to increased Si and P uptake by rice which leads to increase in number of tillers/m^2; panicle length and decrease in stem borer attack and lodging. Talashikar and Savant (2001) also reported the similar findings. Lowest values of these yield components were recorded where no silicon application was done.

Economics

Economics of aerobic rice was significantly influenced by phosphorus and silicon application (Table 4). The highest cost of cultivation (₹ 46.7 × 10^3 and 48.7 × $10^{3/}$ha) was recorded under 90 kg P_2O_5/ha which was closely followed by 60 kg P_2O_5/ha during both the years. This is due to high cost involved in external input like phosphorus fertilizer and labour charge in P application. In case of silicon application, highest cost of cultivation was observed with 120 kg Si/ha (₹ 45.4 and ₹ 47.4 × 10^3/ha) which was followed by 80 kg Si/ha (₹ 44.7 and ₹ 46.8 × 10^3/ha) during both the years. This might be due to additional cost involved in calcium silicate purchasing and labour charge for silicon application. The maximum gross returns (₹ 139.0 × 10^3 and ₹ 138.8 × 10^3/ha) and net returns (₹ 92.4 × 10^3 and ₹ 90.1 × 10^3/ha) were recorded with 90 kg P_2O_5/ha which was at par with 60 kg P_2O_5/ha during both the years. This might be due to higher grain and straw yield and their lucrative market price under this treatment which brought out maximum gross returns, net returns and B:C. These results are in accordance with those of Mahmood *et al*. (2015). The highest B:C (1.98 and 1.90) was obtained with 90 kg P_2O_5/ha and 60 kg P_2O_5/ha during first and second year of experiment, respectively. Meena *et al*. (2014) revealed that cost of cultivation, gross returns, net returns and benefit: cost increased with increasing levels of phosphorus up to 90 kg P_2O_5/ha. The silicon application 120 kg Si/ha recorded highest gross returns (₹ 136.1 × 10^3 and ₹ 139.8 × 10^3/ha)

Table 3 Effect of phosphorus and silicon application on grain, straw and biological yields and harvest index of rice

Treatment	Grain yield (t/ha)		Straw yield (t/ha)		Biological yield (t/ha)		Harvest index (%)	
	2015	2016	2015	2016	2015	2016	2015	2016
Phosphorus application (kg P_2O_5/ha)								
0	4.18	4.35	6.77	7.48	10.9	11.8	38.0	36.5
30	4.66	4.75	7.26	7.67	11.9	12.4	39.0	38.2
60	5.32	5.56	7.65	8.06	13.0	13.6	40.8	39.9
90	5.66	5.62	7.99	8.41	13.7	14.0	41.3	40.7
SEm±	0.17	0.15	0.14	0.14	0.2	0.25	0.74	0.55
CD (P=0.05)	0.48	0.43	0.39	0.41	0.71	0.72	2.14	1.59
Silicon application (kg Si/ha)								
0	4.00	4.03	6.16	6.72	10.2	10.7	39.1	37.3
40	4.78	4.99	7.55	7.96	12.3	13.0	38.7	38.6
80	5.51	5.61	7.87	8.36	13.4	14.0	41.0	40.0
120	5.53	5.65	8.09	8.57	13.6	14.2	40.4	39.5
SEm±	0.17	0.15	0.14	0.14	0.25	0.25	0.74	0.55
CD (P=0.05)	0.48	0.43	0.39	0.41	0.71	0.72	NS	1.59

Table 4 Effect of phosphorus and silicon application on economics of aerobic rice cultivation

Treatment	Cost of cultivation (₹ $\times 10^3$/ha)		Gross returns (₹ $\times 10^3$/ha)		Net returns (₹ $\times 10^3$/ha)		B:C	
	2015	2016	2015	2016	2015	2016	2015	2016
Phosphorus application (kg P_2O_5/ha)								
0	42.2	44.2	104.1	109.0	61.9	64.9	1.46	1.46
30	43.7	45.7	115.5	118.4	71.9	72.7	1.64	1.59
60	45.2	47.2	130.8	136.8	85.6	89.6	1.89	1.90
90	46.7	48.7	139.0	138.8	92.4	90.1	1.98	1.85
SEm±			3.7	3.4	3.7	3.4	0.08	0.07
CD (P=0.05)			10.8	9.8	10.8	9.8	0.24	0.21
Silicon application (kg Si/ha)								
0	43.4	45.4	99.0	100.7	55.6	55.3	1.27	1.21
40	44.1	46.1	118.9	124.1	74.8	78.0	1.69	1.69
80	44.7	46.8	135.4	138.4	90.7	91.6	2.02	1.96
120	45.4	47.4	136.1	139.8	90.7	92.4	1.99	1.94
SEm±			3.7	3.4	3.7	3.4	0.08	0.07
CD (P=0.05)			10.8	9.8	10.8	9.8	0.24	0.21

and net returns (₹ 90.7×10^3 and ₹ 92.4×10^3/ha) during both the years of experimentation which was found at par with 80 kg Si/ha. The highest B:C (2.02 and 1.96) was obtained with 80 kg Si/ha during both the years of experiment. This might be due to higher yield advantages under this treatment which ultimately fetched maximum gross returns, net returns and B:C. Highest net returns and B:C ratio were recorded when Si was applied @ 120 kg/ha as full basal (Singh *et al.* 2005 a). The highest B:C was obtained when Si was applied as full basal dose due to lower cost of cultivation and higher yield (Singh *et al.* 2005 b).

Based on above findings it could be concluded that application of silicon and phosphorus are indispensable for sustainable production of aerobic rice. Application of 60 P_2O_5/ha and 80 kg Si/ha may be more productive and remunerative for aerobic rice.

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