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Effect of silicon and rice straw amendment on rice yield and nutrients in saline soil

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Abstract
A pot experiment was conducted in the pot culture yard of the Department of Soil Science and Agricultural Chemistry, Faculty of Agriculture, Annamalai University, during July-October, 2016. The experiment revealed that rice yield and uptake was significantly enhanced on addition of silicon, organics and their combinations over control. The highest rice yield and uptake was obtained with combined application of RDF + 100% (Si + RSC). Based on the study, it is concluded that the application of RDF + 100% (Si @ 200 kg ha^{-1} + RSC @ 14.5 t ha^{-1}) is needed to achieve the maximum rice yield and improve the soil properties in the saline soil.

Keywords: silicon, organics, rice yield and nutrients

1. Introduction

Soil salinity is conspicuous in arid and semi- arid areas, affecting 2 million km2 of agriculture land and 30- 50 % of the irrigated land of our planet [1]. It has been estimated that more than 20 % of all cultivated lands around the world containing levels of salts high enough to cause salt stress on crop plants [2]. The global population of about 6.3 billion is increasing at an alarming rate. It is estimated that it will be 9.0 billion by 2050 [3]. Efforts are underway to enhance the production of different crops to meet the food requirements of a rapidly increasing population. Salinity is one of the major factors responsible for soil degradation and low crop productivity. About one third of the world's land surface has arid or semiarid conditions (4.8×10^9 ha) of which half is estimated to be affected by salinity and accounts for about 7% of the world's total land area [4]. Approximately 7 Mha of the total agricultural area in India is also affected by various degrees of Salinity/Sodicity [5]. In Tamil Nadu 3.6 lakh ha of land are salt affected soils [6]. Increased level of salts in soil diminish plant growth and yield by affecting three major physiological mechanisms viz. osmotic, ionic and oxidative stress [7]. In osmotic effect, water uptake in plant reduces due to more negative osmotic potential in soil. This effect also trigger chemical signaling causing reduction in stomatal aperture which leads to less photosynthetic rate. Excess Na+ ions also exert ionic effects that is, reduces uptake of other ions and Na+ toxicity in cell [8]. Furthermore, excess accumulation of sodium in soil profiles also degrade soil, due to dispersion of colloids because Na+ has 2,700 times less flocculation capacity than Mg^{+2} and Ca^{+2}, increased dispersion decreases porosity of soil thus decreasing aeration to roots [9]. This together, the osmotic stress and Na^+ toxicity lead to generation of reactive oxygen species (ROS) in all cell compartments causing deleterious effects on DNA, proteins, pigments and membranes [10]. Rice (*Oryza sativa* L*)*, a Halophytic plant, is adversely affected by salinity stress and yield losses of up to 45% have been reported [11]. Several chemical, physical (engineering), and biological approaches were used for better crop production in saline soils in the past. The integrated use of these approaches was crucial due to economic and environmental limitations. Of all of the above approaches exogenous application of some mineral nutrients has gained considerable ground as a shotgun approach to ameliorate the adverse effects of salt toxicity [12]. For example the adverse effects of salt were ameliorated with an exogenous application of K^+ on wheat [13]. and [14]. maize and by the application of Ca^{2+} on bean [15]. Furthermore, some beneficial mineral nutrients have been studied that can counteract the adverse effects of salt stress such as silicon (Si), which provides significant benefits to plants at various growth stages. There are evidences that soil amendments with organic manures reduce the toxic effects of salinity in various plant species [16]. Rice straw compost, poultry manure and FYM are the farm products which can be used for reclamation of saline soils as it offers an opportunity to improve the physico-chemical conditions of the soil and also to some extent improves soil fertility.

2. Materials and Methods

2.1 Experimental locations

The pot experiment was conducted in the pot culture yard of the Department of Soil Science and Agricultural Chemistry, Faculty of Agriculture, Annamalai University, Annamalai Nagar, Tamilnadu, India during July-October, 2016. The experimental site is situated at 11°24'N latitude and 79°44' E Longitude with an altitude of + 5.79 M above mean sea level in the southern part of India and 15 km away from the Bay of Bengal coast. The experimental soil was collected from coastal area Paringipettai, Bhuvanagiri Taluk of Cuddalore District. The soil was clay loam with pH 8.34, EC 4.58 dS m^{-1}, organic carbon 3.8 g/kg and available Nitrogen 190 kg ha^{-1}, Phosphorus10.4kg ha^{-1}, potassium 134.2 kg ha^{-1} and Silicon 29.231 mg kg $^{-1}$. The soil samples were dried in shade, powdered with wooden mallet and sieved to pass through 2mm sieve, thoroughly homogenized and used for the pot experiments.

2.2 Crop husbandry

The experiment was conducted using short duration rice variety ADT 43 during July - October, 2016.Twenty kilogram of air dried homogenized soil was filled in one foot cement pots and the following treatments were applied in completely randomized design with three replications.T_1 - Control (RDF), T_2 -RDF + Silicon (Si) @ 200 kg ha^{-1}, T_3 - RDF + Poultry manure (P.M) @ 6.5 t ha^{-1}, T_4 - RDF+ Rice straw compost (RSC) @ 14.5 t ha^{-1}, T_5 - RDF + FYM @ 12.5 t $ha^{-1,}$ T_6 - RDF + 100% (Si + P.M), T_7 - RDF + 100% (Si + RSC) andT_8 - RDF + 100% (Si + FYM).Calculated quantities of organic manures namely poultry manure (P.M) @ 6.5 t ha^{-1}, Rice straw compost (RSC) @ 14.5 t ha^{-1} and FYM @ 12.5 t ha^{-1} were incorporated into the soil as per the treatment schedule. The amount fertilizer dose using a schedule of 150: 50: 50 kg ha^{-1} of N: P_2O_5: K_2O were applied to pots. Nitrogen was applied in three split doses i.e., 50% as basal, 25% each at active tillering and panicle initiation stages. The entire dose of P_2O_5 and K_2O were applied basally as per the treatment schedule and Si was applied as per the treatment schedule in the respective pots with calcium silicate used 20-30 days before transplanting. Twenty five days old rice seedling var. ADT 43 were planted in the experiments pots at 10 hills pot^{-1} with 3 seedlings $hill^{-1}$. The soil samples were collected at each stage. At harvest stages, grain and straw yield were recorded and expressed as g pot^{-1}. while the processed samples were analyzed for macro N, P, K, and micro nutrients (Si) and computed nutrient uptake.

3 Results and Discussion

3.1. Rice yield

On close examination of data on grain yield furnished in table 1 showed that grain and straw yield was significantly enhanced on addition of silicon, organics and their combinations over control. Grain and straw yield ranged from 58.33 to 82.10 and 81.42 to 108.80 g pot^{-1}. The highest grain and straw yield was obtained with combined application of RDF + 100% (Si + RSC) T_7 (82.10 and 108.80 g pot^{-1}). It was significantly followed by T_8 and T_6. The percentage increase in grain and straw yield (40.75 and 24.86: 33.63 and 20.63) was noticed with combined application of RDF + 100% (Si + RSC) and silicon alone compared to over control (T_1). With respect to organics alone application of RDF + RSC (T_4) recorded maximum grain and straw yield but superior to rest of organics treatments. The lowest grain and straw yield (58.33 and 81.42 g pot^{-1}) was observed in the absence of Si and organics (T_1). This increase in grain and straw yield might be attributed to the increase in growth and yield characteristics of rice and also due to the stimulating effect of Si in reducing biotic and abiotic stress. Results also revealed that Si helped plant growth, which might be due to the increased photosynthetic efficiency upon Si addition, and it was exerted through the number of productive tillers, panicle length, the percentage of filling grains, 1000 grain weight, and the reduction of pest and disease infestation. This corroborated the findings [17] [18]. reported that application of Si was increased the grain yield 19-43% over the control in experiment 1 and 2-14% over the control in experiment 2. In the present study, addition of silicon through soil enhanced the leaf Si concentration and silicon in the soil which would have contributed to higher grain yield. This was supported by significant positive correlation between grain yield with Si content (r = 0.985**), Si uptake (r = 0.998**) and available Si (r = 0.997**).

3.2 Nutrient Uptake (N, P, K, Si and Na)

Data on nutrient uptake (N,P, K and Si) recorded at all stage of crop growth are presented in table 2,3,4,5 and 6 perusal of the data revealed that significant variation in nitrogen uptake due to Si, organics and their combinations over control. The highest nutrient uptake (N, P, K and Si) at tillering stage (539,203,675 and 1163 mg pot^{-1}), panicle initiation stage (800, 352, 1206 and 2059mg pot^{-1}), grain (730, 196, 1282 and 1526 mg pot^{-1}) and straw (510, 205, 1282 and 2806 mg pot^{-1} was noticed with application of RDF + 100% (Si + RSC) T_7. It was significantly followed by T_8 and T_6. With respect to organics alone, application of RDF + RSC (T_4) recorded the highest nutrient uptake (N, P, K and Si) at all stages of crop growth but superior to the rest of the organics. However, nutrient uptake (N, P, K and Si) was the lowest in which did not receive silicon and organics (T_1). The sodium uptake decreased with advancement of crop growth. The sodium uptake decreased from 16.9 to 12.0 mg pot^{-1} (Tillering stage), 11.3 to 7.1 mg pot^{-1} (Panicle initiation stage), 3.3 to 2.5 mg pot^{-1} (grain) and 3.0 to 1.5 mg pot^{-1} (straw). Sodium uptake decreased with addition of combined application of organics and silicon. The lowest sodium uptake at tillering stage (12.0 mg pot^{-1}), panicle initiation stage (7.1 mg pot^{-1}), grain (2.5 mg pot^{-1}) and straw (1.5 mg pot^{-1}) was noticed with application of RDF + 100% (Si + RSC) T_7. It was significantly followed by T_8 and T_6. With respect to organics alone, application of RSC (T_4) recorded lowest Na uptake at all stages of crop growth but superior to the rest of the organics treatments. However, Na uptake was higher in which did not receive silicon and organics (T_1). The highest nutrient uptake was noticed with application of RDF + 100% (Si + RSC) (T_7) and declined with rest of the treatments ($T_{8,}$ and T_6). Among the organics alone treatments, application of RDF + RSC (T_4) recorded higher nutrient concentration and uptake and was superior to rest of the organics alone treatments. However, the lowest nutrient uptake was noticed with did not received silicon and organics (T_1). General increase in N content by silicon application over control might be due to the significant role could regulate the absorption and mobility of N in the plant and maintains optimum level of N and hence Si fertilization increase N use efficiency that result of at higher level of N (120 and 160 kg ha^{-1}) integration with Si fertilizers. Silicon has a synergistic effect with N on nutrient uptake and yield of rice [19, 20]. found that application of 150 kg Si ha^{-1} increased grain and straw uptake [21]. reported that with adequate Si, the uptake of N was increased. Silicon increased P content in grain and straw which caused higher P uptake, which is attributed to the fact that the anion monosilicic acid ($Si(OH)_3^-$) can replace the phosphate anion [HPO_4^2] from aluminum and iron phosphates there by increasing the solubility of phosphorus [22, 23]. Reported increase in soil available P and enhanced the uptake of N, P and K, thus ultimately improved wheat plant growth. The result of present study was confirmed by significant positive correlation between P uptake with available Si (r = 0.987**), Si content (r = 0.984**) and Si uptake (r = 0.996**) [24]. reported that soil application of calcium silicate at 9.6 mg kg^{-1} increased K concentration and uptake in wheat leaves. This may be due to the production of hydrogen ions during reduction of Fe and Al toxicity which would have helped in the release of K from the exchange sites or from the fixed pool to the soil solution [25]. suggested a significant increase in K uptake and a decrease in Na^+

uptake in barley under salt stress due to the increased activity of the plasma membrane H^+ - ATPase. The result observed in the present study was correlated with significant positive correlation existed between K uptake with available Si (r = 0.997**), Si content (r = 0.989**) and Si uptake (r = 0.998**). Similarly [26], reported several results of increasing the concentration of N, P and K in wheat straw when wheat was fertilized by Si.

Throughout the crop growth, there was close agreement between the expected uptake of Si and available silicon in soil. These results suggest that the soil is capable of maintaining a steady rate of silicon in solution despite repeated withdrawals. This was confirmed by significant positive correlation between silicon uptake in grain with available silicon at tillering stage (r = 0.636**) at panicle initiation stage (r = 0.999**) and at harvest stage (r = 0.994**), silicon uptake in straw with available Si at tillering stage (r = 0.956**), at panicle initiation (r = 0.972**) and at harvest stage (r = 0.974**). With respect to organic, application of RDF + RSC @ 14.5 t ha^{-1} recorded higher nutrient uptake and was superior to poultry manure and FYM. Increase in uptake of nutrients was mainly due to continuous availability of N, P, K and Si through the crop growth period as the nutrients from the inorganic sources were available to the crop in the early stages and nutrients released from organic sources become available at the later stages of the crop growth. Increasing N, P, K and Si uptake of rice straw and grain when biofertilizer and chicken manures were added with N fertilization levels in saline soil could be due to improve soil properties such as chemical and bio properties. In the present study, corroborated organic manures amended soil recorded higher nutrient availability in soil compared to control with RSC registering highest nutrient availability in soil owing to higher nutrient content present in it compared to other organics [27]. Similar findings reported by [28]. Who described that N, P, K and Si uptake by rice was significantly increased by the application of RDF and manure.

Application of RDF + 100% (Si + RSC) recorded lowest sodium (Na) uptake throughout the crop growth. However, the highest sodium uptake was noticed with did not receive silicon and organics (T_1). The stimulated H^+- ATPase enhanced the uptake and upward transport of K^+ and retarded the movement of Na^+ thus, improved the K^+; Na^+ selectivity ratio in the shoots of salt- stressed barley [25]. The concentration of toxic Na^+ was reduced in the presence of Si and the reduction in toxic Na^+ was paralleled by an increase in root elongation. It is reported that the Na^+ contents in the rice shoot were nearly 50% of those in the shoots of plants which were not supplemented with soluble silicates in their growth medium [29]. Under salinity stress, deposition of Si in plant roots precluded the bypass of Na^+, which resulted in decreasing Na^+ concentration in plant tissues [30]. This was confirmed by significant positive relationship between grain yield with K concentration in straw (r = 0.963**) and a negative relationship with Na concentration in straw (r = -0.573**) (Fig. 1_a &1_b). Similarly, straw yield was positively correlated with K^+ concentration in straw (r = 0.961**) and negatively correlated with Na^+ concentration in straw (r = -0.589**) (Fig. 2_a &2_b).

Table 1: Effect of silicon and organics on grain and straw yield of the rice crop

Treatments	Grain Yield (g pot^{-1})	Straw Yield (g pot^{-1})
T_1 - Control (RDF)	58.33	81.42
T_2 - RDF + Silicon (Si) @ 200 kg ha^{-1}	72.83	98.22
T_3 - RDF + Poultry manure (P.M) @ 6.5 t ha^{-1}	63.23	87.52
T_4 - RDF + Rice straw compost (R.S.C) @ 14.5 t ha^{-1}	69.63	94.66
T_5 - RDF + FYM @ 12.5 t ha^{-1}	66.43	91.10
T_6 - RDF + 100% (Si + P.M)	75.92	101.74
T_7 - RDF + 100% (Si + R.S.C)	82.10	108.80
T_8 - RDF + 100% (Si + FYM)	79.02	105.30
SEd	1.29	1.79
CD @ 5%	2.77	3.30

Table 2: Effect of silicon and organics on the nitrogen uptake (mg/pot) at different growth stages

Treatments	Tillering stages	Panicle initiation stage	Grain	Straw
T_1 - Control (RDF)	257	476	418	267
T_2 - RDF + Silicon (Si) @ 200kg ha^{-1}	415	659	596	411
T_3 - RDF + Poultry manure (P.M) @ 6.5 t ha^{-1}	303	524	473	314
T_4 - RDF + Rice straw compost (R.S.C) @ 14.5 t ha^{-1}	377	607	549	377
T_5 - RDF + FYM @ 12.5 t ha^{-1}	341	564	510	345
T_6 - RDF +100% (Si + P.M)	453	703	636	446
T_7 - RDF + 100% (Si + R.S.C)	539	798	730	510
T_8 - RDF + 100% (Si + FYM)	494	750	678	472
SEd	2.52	3.3	2.51	4.26
CD @ 5%	5.42	7.1	5.40	9.17

Table 3: Effect of silicon and organics on phosphorus uptake (mg/pot) at different growth stages

Treatments	Tillering stages	Panicle initiation stage	Grain	Straw
T_1 - Control (RDF)	71	170	86	80
T_2 - RDF + Silicon (Si) @ 200 kg ha^{-1}	140	277	144	156
T_3 - RDF + Poultry manure (P.M) @ 6.5 t ha^{-1}	87	190	100	95
T_4 - RDF + Rice straw compost (R.S.C) @ 14.5 t ha^{-1}	122	253	131	131
T_5 - RDF + FYM @ 12.5 t ha^{-1}	103	230	112	109

T_6 - RDF + 100% (Si + P.M)	159	301	158	171
T_7 - RDF + 100% (Si + R.S.C)	203	352	196	205
T_8 - RDF + 100% (Si + FYM)	178	326	172	188
SEd	3.61	4.39	4.59	2.50
CD @ 5%	7.77	9.45	9.87	5.38

Table 4: Effect of silicon and organics on potassium uptake (mg/pot) at different growth stages

Treatments	Tillering stages	Panicle initiation stage	Grain	Straw
T_1 - Control (RDF)	268	583	150	650
T_2 - RDF + Silicon (Si) @ 200 kg ha^{-1}	488	916	268	1030
T_3 - RDF + Poultry manure (P.M) @ 6.5 t ha^{-1}	327	666	195	786
T_4 - RDF + Rice straw compost (R.S.C) @ 14.5 t ha^{-1}	431	828	242	955
T_5 - RDF + FYM @ 12.5 t ha^{-1}	377	745	219	864
T_6 - RDF + 100% (Si + P.M)	548	1012	302	1118
T_7 - RDF +100% (Si + R.S.C)	675	1206	360	1282
T_8 - RDF + 100% (Si + FYM)	613	1107	330	1999
SEd	11.82	4.85	4.82	5.2
CD @ 5%	25.42	10.44	10.37	12.40

Table 5: Effect of silicon and organics on the silicon uptake (mg/pot) at different growth stages

Treatments	Tillering stages	Panicle initiation stage	Grain	Straw
T_1 - Control (RDF)	567	1279	903	1676
T_2 - RDF + Silicon (Si) @ 200 kg ha^{-1}	905	1709	1258	2316
T_3 - RDF + Poultry manure (P.M) @ 6.5 t ha^{-1}	672	1390	1010	1880
T_4 - RDF + Rice straw compost (R.S.C) @ 14.5 t ha^{-1}	824	1598	1175	2166
T_5 - RDF + FYM @ 12.5 t ha^{-1}	747	1490	1088	2021
T_6 - RDF + 100% (Si + P.M)	986	1832	1343	2491
T_7 - RDF + 100% (Si + R.S.C)	1163	2059	1526	2806
T_8 - RDF + 100% (Si + FYM)	1076	1940	1437	2642
SEd	4.43	5.67	3.81	2.99
CD @ 5%	9.53	12.20	8.21	6.43

Table 6: Effect of silicon and organics on the Na uptake (mg/pot) at different growth stages

Treatments	Tillering stages	Panicle initiation stage	Grain	Straw
T_1- Control (RDF)	1.51	1.40	0.46	1.00
T_2 - RDF + Silicon (Si) @ 200 kg ha^{-1}	1.16	1.05	0.35	0.43
T_3 - RDF + Poultry manure (P.M) @ 6.5 t ha^{-1}	1.34	1.23	0.39	0.47
T_4 - RDF + Rice straw compost (R.S.C) @ 14.5 t ha^{-1}	1.25	1.14	0.37	0.45
T_5 - RDF + FYM @ 12.5 t ha^{-1}	1.43	1.32	0.38	0.46
T_6 - RDF + 100% (Si + P.M)	0.99	0.88	0.34	0.41
T_7 - RDF + 100% (Si + R.S.C)	0.84	0.69	0.30	0.35
T_8 - RDF + 100% (Si + FYM)	0.92	0.81	0.32	0.40
SEd	0.01	0.001	0.002	0.002
CD @ 5%	0.02	0.002	0.005	0.005

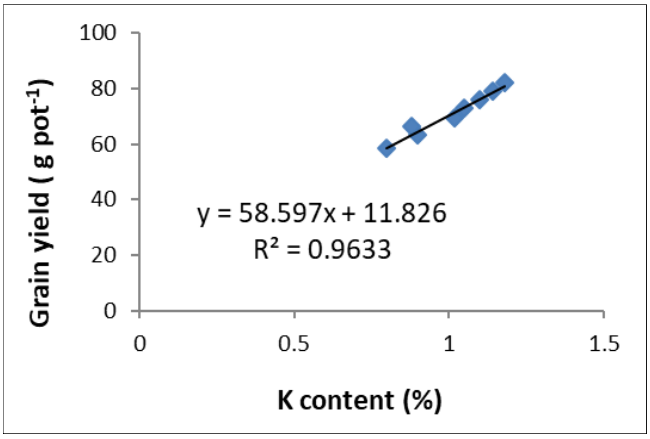

Fig 1a: Linear relationship between grain yield and K concentration in straw

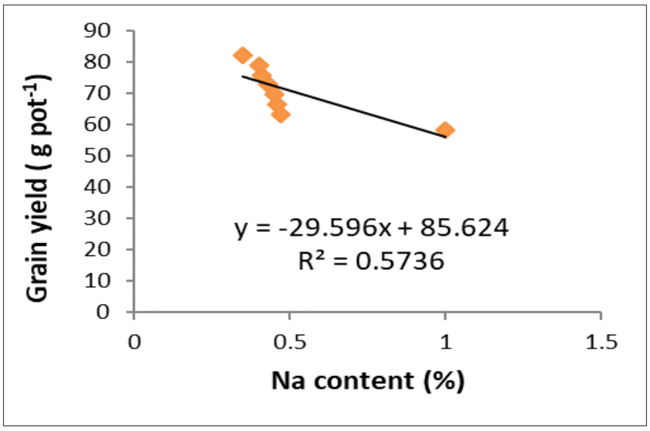

Fig 1b: Linear relationship between grain yield and Na concentration in straw

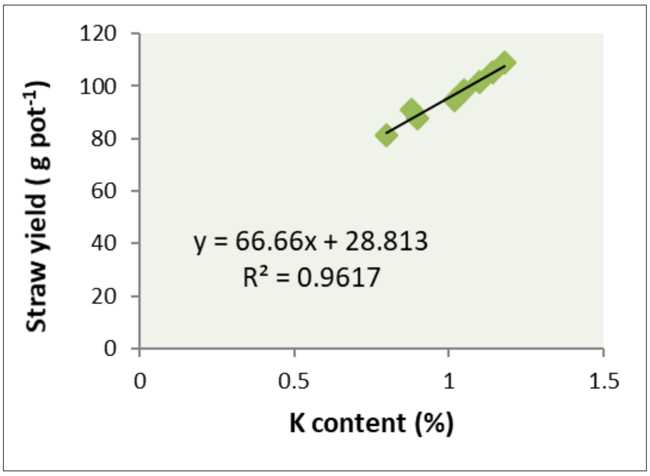

Fig 2a: Linear relationship between straw yield and K concentration in straw

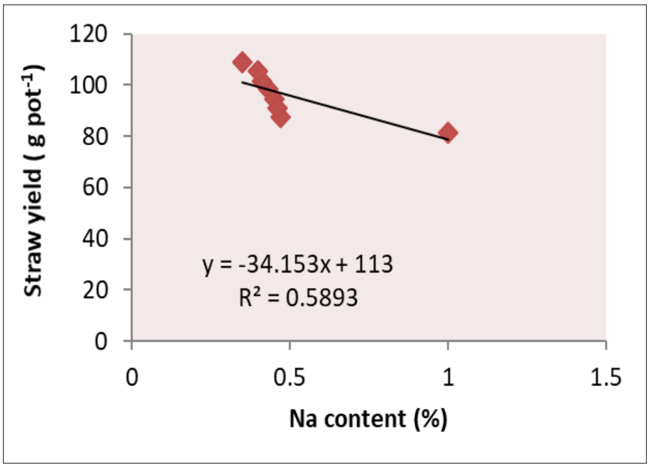

Fig 2b: Linear relationship between straw yield and Na concentration in straw

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