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Research Article

EXOGENOUS SILICON FERTILIZATION AMELIORATE SALINE STRESS BY IMPROVING SOIL PROPERTIES AND EFFICIENCY OF RICE

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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, Annamalai Nagar, Tamilnadu, India during July-October, 2016. The treatments consists of viz., 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).The experiment revealed that grain and straw yield was significantly enhanced on addition of silicon, organics and their combinations over control. The highest grain and straw yield was obtained with combined application of RDF + 100% (Si + RSC) T_7 (82.10 and108.80 g pot^{-1}). 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. The application of RDF + 100% (Si + RSC) registered the lowest pH, EC, soluble cations (Mg^{2+} and Na^{2+}) and except Ca^{2+} and K^+. 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 improve the soil properties, and yield of rice in the soil.

Keywords: Silicon, organics, rice yield and nutrients

1. INTRODUCTION

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 [1]. 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 [2] and accounts for about 7% of the world's total land area [3]. Approximately 7 Mha of the total agricultural area in India is also affected by various degrees of salinity/sodicity [4]. In Tamilnadu 3.6 lakh ha of land are salt affected soils [5].Increased level of salts in soil diminish plant growth and yield by affecting three major physiological mechanisms viz. osmotic, ionic and oxidative stress [6]. In osmotic effect, water uptake in plant reduces due to more negative osmotic potential in soil. This effect also trigger chemical signalling 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 [7]. 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 [8] . 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 [9]. Rice (*Oryza sativa L)*, a Halophytic plant, is adversely affected by salinity stress and yield losses of up to 45% have been reported [10]. 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 [11]. For example the adverse effects of salt were ameliorated with an exogenous application of K^+ on wheat [12] and maize [13] and by the application of Ca^{2+} on bean [14]. 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 [15]. 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 Parangipettai, 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}, Phosphorus10.4 kg 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 2 mm 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 available macro N, P, K, and micro nutrients (Si) and Exchangeable cations.

3. RESULTS

3.1. Rice yield

On close examination of data on grain and straw yield furnished in table 1 showed that grain and straw yield was significantly enhanced on addition of silicon, organics and their combinations over control.

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

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 (79.02 and 105.30 g pot^{-1}) and T_6 (75.92 and 101.74 g pot^{-1}). The percentage increase in grain 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).

3.2. Available Nutrients (N, P, K and Si)

Addition of Si, organics and their combinations caused significant effect on soil available nutrients (N, P, K and Si) at harvest stage of crop growth over control (table 2) available nutrients (N, P, K and Si) decreased with advancement of crop stages. At harvest stages of crop growth, combined application of RDF + 100% (Si + RSC) T_7 registered the highest available nutrients (N, P, K and Si) status (210.0, 14.50, 158 kg ha^{-1} and Si 36.8 mg kg^{-1}) at harvest stage. It was significantly followed by T_8 and T_6. With respect to organics alone, application of RDF + RSC (T_4) recorded maximum available nutrients (N, P, K and Si) at harvest stage of crop growth but superior to rest of the organics alone treatments. The available nutrients (N, P, K and Si) were the lowest which did not receive silicon and organics (T_1).

Table 2: Effect of silicon and organics on available N.P, K (Kg ha^{-1}) Si (mg kg^{-1}) at harvest stage

Treatments	N	P	K	Si
T_1 - Control (RDF)	140.9	9.50	126	20.00
T_2 - RDF + Silicon (Si) @ 200kg ha^{-1}	191.5	14.20	145	31.50
T_3 - RDF + Poultry manure (P.M) @ 6.5 t ha^{-1}	172.0	13.80	132	27.00
T_4 - RDF + Rice straw compost (R.S.C) @ 14.5 t ha^{-1}	185.0	14.00	140	30.00
T_5 - RDF + FYM @ 12.5 t ha^{-1}	178.5	13.90	136	28.20
T_6 - RDF + 100% (Si + P.M)	198.0	14.30	149	33.30
T_7 - RDF + 100% (Si + R.S.C)	210.0	14.50	158	35.80
T_8 - RDF + 100% (Si + FYM)	204.0	14.40	154	34.00
SEd	2.3	0.02	1.20	0.44
CD @ 5%	4.6	0.04	2.40	0.90

Table 3: Effect of silicon and organic on soluble cations (meq.L^{-1}) and pH, EC of the soil at harvest stage

Treatments	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	pH	EC
T_1 - Control (RDF)	12.70	29.64	1.18	40.12	8.00	4.32
T_2 - RDF + Silicon (Si) @ 200kg ha^{-1}	17.53	26.91	2.50	31.28	7.68	3.07
T_3 - RDF + Poultry manure (P.M) @ 6.5 t ha^{-1}	17.58	28.97	2.37	37.96	7.92	3.38
T_4 - RDF + Rice straw compost (R.S.C) @ 14.5 t ha^{-1}	18.00	27.61	2.46	33.28	7.77	3.18
T_5 - RDF + FYM @ 12.5 t ha^{-1}	17.22	28.27	2.42	35.66	7.85	3.26
T_6 - RDF + 100% (Si + P.M)	19.32	26.91	2.54	29.54	7.60	2.98
T_7 - RDF + 100% (Si + R.S.C)	21.18	23.50	2.63	24.18	7.40	2.80
T_8 - RDF + 100% (Si + FYM)	20.59	25.37	2.59	26.63	7.51	2.89
SEd	0.09	0.18	0.02	0.28	0.02	0.02
CD @ 5%	0.18	0.36	0.05	0.56	0.05	0.05

3.3. Soluble cations (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+})

On close examination of data on soluble cations furnished in table 3 showed that soluble cations (Ca^{2+}, K^{+} and Mg^{2+}) content was significantly enhanced on addition of silicon, organics and their combinations over control.

Soluble cations (Ca^{2+}, K^{+} and Mg^{2+}, Na^{+}) content increased with addition of combined application organic and silicon but decreased in Mg and sodium content. The highest soluble cations(Ca^{2+}, K^{+}) and lowest cation (Mg^{2+}, Na^{+}) at harvest stage (20.59, 2.65 meq L^{-1}) and

23.50, 24.18 meq L^{-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 highest soluble cations (Ca, and K) and lowest Mg, Na content at harvest stage but superior to rest of the organics treatment. The lowest soluble cations (Ca, and K) and highest Mg and Na content was noticed in the treatment (T_1) which received NPK alone.

3.4. pH and EC

Addition of silicon, organics and their combinations caused a significant influence on soil pH and EC at harvest stages of crop growth over control table 3. Soil pH and EC decreased with stages of crop growth. Soil pH and EC slightly decreased from 8.30 to 7.47and 4.50 to 3.06 dSm^{-1} (tillering stage), 8.03 to 7.44 and 4.36 to 2.84 dSm^{-1} (panicle initiation stage) and 8.00 to 7.40 and 4.32 to 2.80 dSm^{-1}(harvest stage). Soil pH decreased with addition of combined application organics and silicon. The lowest soil pH and EC at (7.47and 3.06 dS m^{-1}) tillering stage, at panicle initiation stage (7.44 and 2.80 dS m^{-1}) and harvest stage (7.40 and 2.80 dS m^{-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 on of RDF + RSC (T_4) recorded lowest soil pH and EC at all stages but superior to rest of the organics alone treatment. However the soil pH and EC was higher in which receive inorganic fertilizer (NPK alone) treated pot (T_1).

4. DISCUSSION

Addition of graded dose of silicon or organics or combined application of silicon and rice straw compost causes a significant increase in grain and straw yield over control. The highest grain yield (82.10 g pot^{-1}) and straw yield (108.80 g pot^{-1}) was obtained with application RDF + 100% (Si + RSC). Grain yield response varied from 14.50 and 23.77 g pot^{-1} due to RDF + Silicon and RDF + 100% (Si + RSC) doses over control (Fig. 1).

The per cent increase in grain yield varied 24.86 and 40.75 and per cent increase in straw yield varied 20.63 and 33.63 due to RDF + Silicon and combined application of RDF + 100% (Si + RSC) over control (Fig. 2). 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

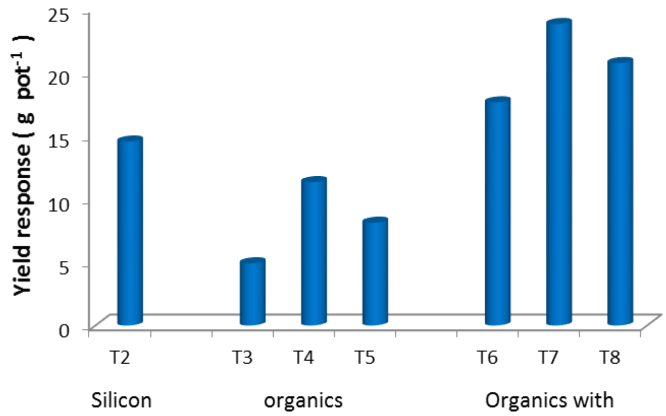

Fig. 1: Grain yield response due to silicon, organics and silicon with organics

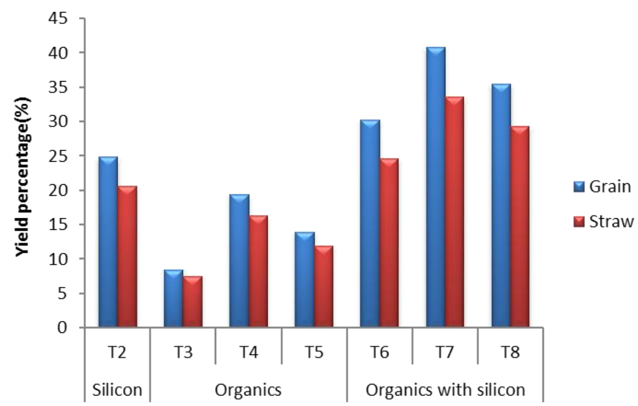

Fig. 2: Percentage increase in Grain and straw yield due to silicon, organics and organics with silicon

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 [16]. Wattanapaya Pkul *et al.* [17] 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**). With respect to organics, application of RDF + RSC recorded highest grain (69.63 g pot^{-1}) and straw yield (94.66 g pot^{-1}) respectively and was superior rest of the organics treatments. The grain yield response due to organics 11.30 g pot^{-1}(Fig. 1). The per cent increase in grain yield 19.37 due to addition of RDF + RSC over control (Fig. 2). Enhanced grain and straw yield could be due to supply of nutrients especially macro and micronutrients which induced cell division, expansion of cell wall, meristematic activity, photosynthetic efficiency, regulation of water to cells, conducive physical environment, facilitating to better aeration, root activity and nutrient absorption leading to higher rice yield [18].

Application of silicon and organics improved significantly available N, P, K and Si in soil over control. The maximum amount of available nitrogen, phosphorus, potassium and silicon was noticed with RDF + 100% (Si + RSC). Available nutrients declined with advancement of crop growth due to steady withdraw of nutrients from soil solution through crop uptake. Silicon and nitrogen has synergistic relationship which improved the N status of the soil over no silicon. In contrast, nitrogen availability in bulk soil increased due to addition of rice straw. Similarly, a study showed that the total soil N concentration increased by 10.4 % due to incorporation rice straw in a paddy soil [19]. Water soluble Si plays an important role in increasing P availability of soil by replacing adsorbed P and by decreasing the P adsorption capacity of soil [20]. Available potassium and Si has got synergistic relationship leading to more account of potassium and Si in soil on addition of silicon over control. High level of potassium and Si was maintained through the crop growth in soils treated with silicon compared to control. Availability of silicon in soil or applied as fertilizer is governed by net effect of physical, chemical and biological properties operating in soil. Increase in available silicon in soil is due increased rate of Si application to the soil. With respect to organics, application of RDF + RSC 14.5 t ha^{-1} recorded highest available nutrients since the application of rice straw compost increase the nutrients (Nitrogen). This could be due to the reason that during mineralization process rice straw releases more N from this saline paddy soil. This may result in excess N was available in this saline paddy soil and even N was also taken up by rice seedlings. Regardless of that rice straw contains numerous elements essential for plant growth including N [21]. The application of organic material could promote transformation between different forms of phosphorus. This could improve phosphorus availability in soils and Low C/P ratios leads to dominant mineralization over immobilization as reported by Zhao *et al.* [22]. Similarly, available K increased by RSC and fertilization alone or combination resulted in a significant increase effect on the available content of N, P and K. Increase in available K due to organics could be due greater capacity of the organic colloids to hold the nutrients at the exchange surface and also the reduction of K fixation and release of fixed K due to interaction of organic matter with clay besides direct addition of K to the available pool of soil [23].

Application of silicon and organic or combinations reduced significantly soluble ions (Mg^{2+}, Na^{2+}) and except Ca^{2+} K^{+} ion in soil over control. The lowest values of soluble Mg^{2+} and Na^{2+} were found with application of the RDF + 100% (Si + RSC). On the other hand, Soluble Ca^{2+} and K^{+} slightly increased as a result of amendments application RDF + 100% (Si + RSC). The benefit effect could be resulted from presence of excess Ca^{2+} in both organic matter and calcium silicate amendments. For saline or sodic soils, the addition of organic matter can accelerate the leaching of Na^{+}, decrease the ESP, SAR and EC and increase water infiltration, water holding capacity and aggregate stability [24]. The present finding agree with that obtained by Moustafa [25] who found that the application of gypsum, Farmyard manure and gypsum + farmyard manure significantly decreased the exchangeable sodium with the maximum value for gypsum + FYM treatment. This was confirmed by significant negative relationship between EC with ESP and SAR at harvest stage (Fig. 3). Also, the Liner relationship between ESP and SAR was positively (r^2 = 0.999**) (Fig. 4). This indicated the positive effect among the all studied parameters (EC, SAR and ESP). These may be due to the leaching effect.

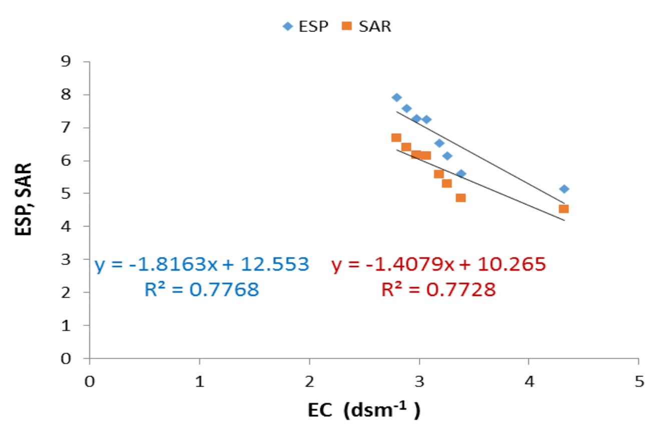

Fig. 3: Linear relationship between Ec with ESP and SAR at harvest stage

In the present investigation, the organics or silicon or combination treatment favored for a greater reduction of pH and salinity. The effect being much pronounced with the application of 100% (Si + RSC). At the all stage of crop growth, the pH was reduced as compared to over control. The reduction in pH may have been to a decrease in sodium concentration as a fraction of the cations.

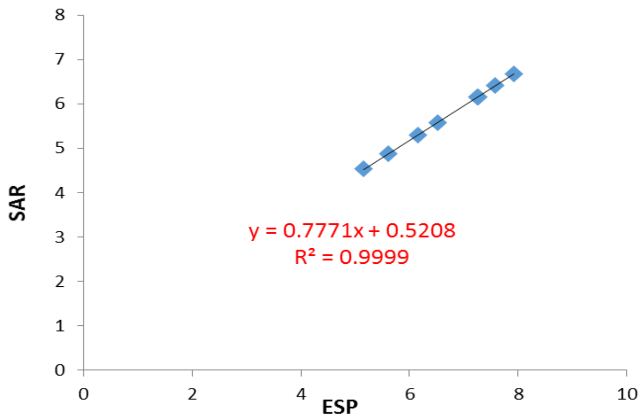

Fig. 4: Linear relationship between ESP with SAR at harvest stage

This decreasing may be due to removal of exchangeable sodium from the soil column moreover, calcium silicate solubility is also enhanced because of the increased activity coefficient of calcium and sulphate as a result of increased ionic strength of solution and the formation of the sodium sulphate ion pair. Besides, large quantities of CO_2 must have been evolved during leaching process, some of which would become soluble in soil solution giving carbonic acids. Concerning compost the decreases in soil pH in soil this illustrates the indirect effect of decreased sodium and the direct effect of organic acids, which must have been formed during decomposition of compost. Applying organic compost to saline sodic soils would help in chelating calcium and decreasing soil pH leading to an increase in solubility of $CaCO_3$ [26]. The organic amendment using rice straw compost and FYM applied with 25% GR was similar to 100% GR in terms of crop [27]. Similarly, the obtained data showed that different treatment caused pronounced reductions in the EC_e values as compared to the control the highest effect in decreasing EC_e values was obtained by the treatment of RDF + 100% (Si + RSC). This may be due to increasing leachability of soluble and exchangeable Na^+ throughout the soil profile. Beheiry *et al.* [28] reported that addition of organic manures decreased soil salinity and they attributed that to improving physical properties of the soil which in turn facilitate the leaching of salts outside from the root zone. For saline or sodic soils, the addition of organic matter can accelerate the leaching of Na^+, decreasing the ESP and electrical conductivity and increase water infiltration, water holding capacity and aggregate stability. Similarly, Iqbal *et al.* [29] found that addition of rice straw reduced the salinity within Bangladeshi saline paddy soil. This was confirmed by significant negative relationship between organic carbon with pH at harvest stage and EC at harvest stage (Fig. 5 and 6) lend support to the present findings.

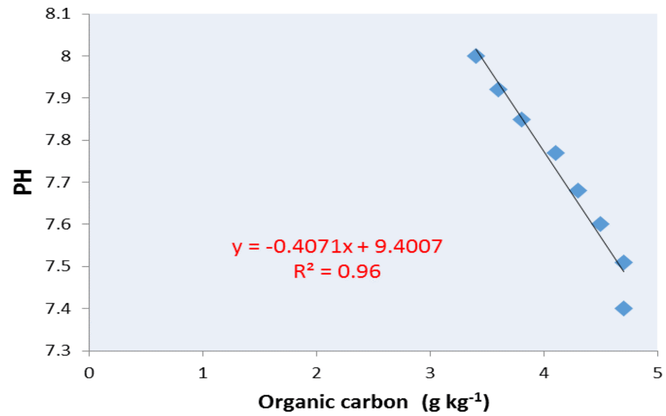

Fig. 5: Linear relationship between organic carbon and pH

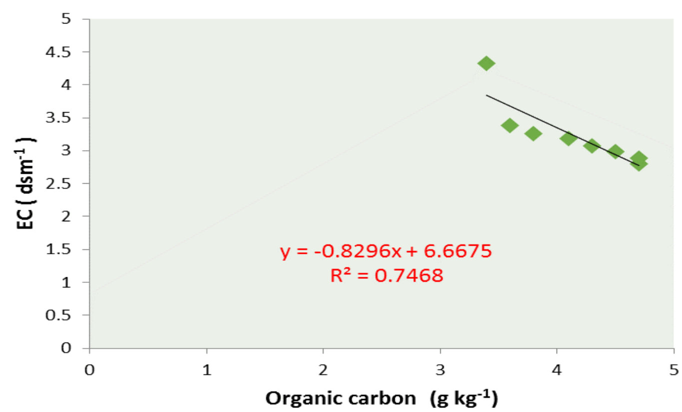

Fig. 6: Linear relationship between organic carbon and EC

5. CONCLUSION

The present investigation clearly indicated the beneficial role of silicon and organics applications in improving the soil properties and sustaining the yield of rice in coastal salt affected soils. In restoring the soil fertility status in terms of reducing pH, EC and soluble cations (Mg, Na) and available nutrient status the treatment RDF + 100% (Si @ 200 kg ha^{-1} + RSC @ 14.5 t ha^{-1}) (T_7) exhibited its superiority. This treatment also accounted for realizing higher yield of rice and also enhanced the major (N, P and K) and Si nutrition of rice.

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