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Ion dynamics in post harvest saline soil influenced by organic amendment and moisture level

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Abstract

Organic amendments might be effective and sustainable in the amelioration of saline soil if proper management put in place. Accordingly, subsequent pot and field experiments were conducted in a saline soil to determine the effects of moisture levels and organic amendments on cation exchange capacity (CEC), ion dynamics under rice cultivation. The increment of CEC of the studied post harvest soils was significant, except for the moist condition under field experiment. There were significant variations in ion dynamics among the treatments under both the experiments at saturated soil conditions. Exchangeable Na^+ contents decreased and K^+ contents increased significantly with the increased rates of treatments. Exchangeable Ca^{2+} and Mg^{2+} contents of soil followed almost the similar trends as that exhibited by K^+ but not significant. Among the anions, chloride decreased significantly under both the experiments while sulfate and bicarbonate contents increased by the applied treatments. This might be due to the inherent consequences of organic amendments on these soil properties.

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Introduction

Interpretations in the recent past indicated that due to increasing degree of salinity of some areas and expansion of salt affected area as a cause of further intrusion of saline water, normal crop production becomes more restricted (Akter *et al.,* 2017). Saline soils are an important natural resource but the area of degraded saline soils worldwide has rapidly increased due to climate change and limited rainfall, which poses a great challenge to global food security (Yupeng *et al.,* 2018). This problem may be solved through a targeted remediation program of such soils. Ions that contribute to soil salinity include Cl^-, SO_4^{2-}, HCO_3^-, Na^+, Ca^{2+}, Mg^{2+}, and, rarely, NO_3^- or K^+. Salinization affects the metabolism of the organisms present in the soil, drastically reducing soil fertility and increasing water proofing of the deeper layers (Rahman *et al*., 2014**)**.

Salinity decreases the osmotic potential of the soil, which leads to decreased turgor pressure in root cells and consequently water loss (Julkowska and Testerink, 2015). To avoid water loss, a first response of the plant is to close stomata and reduce transpiration at the cost of lower cell extension rate and growth. The maintenance of turgor is also facilitated by decreasing the osmotic potential in the roots, which is achieved by increasing the concentration of osmolytes in tissues. Osmotic adjustment is an essential plant response to salt stress, and can be achieved by the synthesis of organic compounds, or the accumulation of Na^+ and Cl^- in a cost-effective manner (Munns *et al*., 2016). In addition to the challenge of transporting water under salt stress, the plant has to deal with the salt ions (Na^+ and Cl^-) that are taken up and that are toxic at high concentrations. A recent review examines the implications of keeping ion concentrations in shoots of plants are low (Munns *et al*., 2020).

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Salinity also affects soil chemical properties, such as pH, cation exchange capacity (CEC), exchangeable sodium percentage (ESP), soil organic carbon, and alters the osmotic and matric potential of the soil solution. Most salt-affected soils are deficient in several nutrients; thus, more fertilizer applications may be required. In Bangladesh, out of about 1.689 million hectares of coastal land, 1.056 million hectares are affected by soil salinity of various degrees. About 50% of the coastal lands face different degrees of inundation, thus limiting their effective use (Islam, 2006). This situation is expected to become worse further because of the effects of climate change.

Application of organic amendments was reported to remediate saline soils, alleviate salinity and sodicity stress on crops (Seleiman and Kheir, 2018). Organic amendments could improve soil properties by accelerating leaching of sodium and other salts and reducing exchangeable sodium percentage (ESP). Organic matter decomposition and plant root action also help dissolve the calcium compounds found in most soils, thus promoting reclamation of saline soil (Gupta and Gupta, 1987). Organic amendments improve physical, chemical and biological properties of soils under saline conditions (Raafat and Tharwat, 2011). In any case, the application of organic amendments could help to increase the cation exchange capacity (CEC) and ion adsorption with all positive/negative consequences, and therefore reduce the soluble salt concentration in the soil solution. In fact, organic matter generally is considered one of the most important contributors to the CEC in the soil, determining the sign and magnitude of net surface charge of soil particles and enhancing the retention of soil salts (Oorts *et al.,* 2003). Therefore, the present research work had been undertaken to investigate the changes in saline soil CEC, exchangeable cations (Na^+, K^+, Ca^{2+} and Mg^{2+}) and water-soluble anions (Cl^-, SO_4^{2-} and HCO_3^-) under rice cultivation as influenced by organic amendments like rice hull, rice straw, sawdust and two moisture levels on pot and field experiments.

Materials and methods

The experiments were conducted under field and pot conditions during Boro and Aus seasons, respectively. Considering climatic condition and growing season, the field experiment was conducted at Musulliabad (Lata Chapli), Kalapara, Patuakhali, Bangladesh during January to June, 2017 with a T. Boro rice cultivar (BRRI dhan 64). Subsequently, a pot experiment was also conducted with a T. Aus rice cultivar (BRRI dhan 48) in the premises of the Department of Soil, Water and Environment, University of Dhaka during May to August, 2017 in order to compare the effects of treatments under open (field) and closed (pot) systems. The soil used in the pot experiment was same to the field soil. Physico-chemical characteristics of initial soil (Table I) were determined by standard methods.

Rice hull (RH), rice straw (RS) and sawdust (SD) were used as indigenous organic amendments for the studied soil. The experiments were done with rice hull (3 levels) × rice straw (3 levels) × sawdust (3 levels) having 3 replications (considered within the plot and pot) under 2 moisture levels (moist: 80% moisture and saturated: >100% moisture). Total number of treatments was 27 (for each moisture levels; Table II). Basal doses of N, P_2O_5 and K_2O were applied at the rate of 120, 60 and 80 kg ha^{-1} as Urea, TSP and MoP, respectively. The whole TSP, MoP and half of the urea were applied during soil preparation. The remaining urea was top dressed in two splits, at active tillering and panicle initiation stage.

Seedlings of BRRI dhan 64 were collected from the local experienced farmers. Thirty-days-old seedlings of BRRI dhan 64 were transplanted at the rate of 3 seedlings per hill. The hill to hill and row to row distances were 18 and 22 cm, respectively. Seedlings of BRRI dhan 48 were collected through the courtesy of BRRI (Bangladesh Rice Research Institute), Joydebpur, Gazipur. About 25 days-old seedlings of BRRI dhan 48 were transplanted at the rate of 3 seedlings per hill and 3 hills in each pot by arranging in a triangular grid.

In the case of moist condition: 80% water content seemed to be optimum for the survival of rice plant and did not allow standing water. But in the case of saturated condition: more than 100% water was maintained during irrigation throughout the growing period. Intercultural operations were performed as required.

CEC, exchangeable cations (Na^+, K^+, Ca^{2+} and Mg^{2+}) and water-soluble anions (Cl^-, SO_4^{2-} and HCO_3^-) of the soils were analyzed after harvesting the crop at maturity. MS. Excel and Stata 14 computer programs were used to analyze the experimental data. The significance of different treatments was assessed by calculating CV (Coefficient of Variation) and Tukey's Range Test of the experimental results done for the interpretation.

Results and discussion

Dynamics in cation exchange capacity (CEC)

CEC refers to the amounts of negative charges available on the surface of soil particles. It gives an indication of the

Table I. Physico-chemical properties of the studied soil on oven dry basis (After Akter *et al.,* 2017)

Properties	Values
Particle density (g cm^{-3})	2.53
Bulk density (g cm^{-3})	1.37
Porosity (%)	45.81
Moisture content (%; Black, 1965)	3.31
Textural class (Hydrometer method; Piper, 1966)	Clay loam
pH (1:2.5; Jackson, 1973)	6.90
EC (dS m^{-1}; Saturation extract, 1:5; Richards, 1954)	3.96
Organic carbon (g kg^{-1}; Nelson and Sommers, 1982)	7.80
Total Nitrogen (g kg^{-1}; Jackson, 1973)	0.60
Available Nitrogen (mg kg^{-1}; 1 N KCl; Jackson, 1973)	54.55
Available Phosphorus (mg kg^{-1}; Olsen*et al.,* 1954)	12.58
Available Potassium (mg kg^{-1}; Pratt, 1965)	25.00
Exchangeable Cations (c mol kg^{-1}; 1 N CH_3COONH_4)	
Sodium (flame photometer)	3.91
Potassium (flame photometer)	0.64
Calcium (AAS*)	1.87
Magnesium (AAS*)	3.26
Water Soluble Anions (c mol kg^{-1})	
Chloride (0.005 N $AgNO_3$; Richards, 1954)	2.87
Sulphate ($BaCl_2$; Richards, 1954)	1.45
Bicarbonate (0.05 N H_2SO_4; Richards, 1954)	0.47
Carbonate (0.05 N H_2SO_4; Richards, 1954)	ND*
Cation Exchange Capacity (c mol kg^{-1}; Black, 1965)	18.67
Sodium Adsorption Ratio (Richards, 1954)	7.72
Exchangeable Sodium Percentage (Richards, 1954)	20.92

*ND= Not in detectable range, *AAS= Atomic Absorption Spectrophotometer

Table II. Treatment combination of the experiment

Treatment					
No.	Denotation	No.	Denotation	No.	Denotation
T_1	RH_0 RS_0 SD_0	T_{10}	RH_4 RS_0 SD_0	T_{19}	RH_8 RS_0 SD_0
T_2	RH_0 RS_0 SD_4	T_{11}	RH_4 RS_0 SD_4	T_{20}	RH_8 RS_0 SD_4
T_3	RH_0 RS_0 SD_8	T_{12}	RH_4 RS_0 SD_8	T_{21}	RH_8 RS_0 SD_8
T_4	RH_0 RS_4 SD_0	T_{13}	RH_4 RS_4 SD_0	T_{22}	RH_8 RS_4 SD_0
T_5	RH_0 RS_4 SD_4	T_{14}	RH_4 RS_4 SD_4	T_{23}	RH_8 RS_4 SD_4
T_6	RH_0 RS_4 SD_8	T_{15}	RH_4 RS_4 SD_8	T_{24}	RH_8 RS_4 SD_8
T_7	RH_0 RS_8 SD_0	T_{16}	RH_4 RS_8 SD_0	T_{25}	RH_8 RS_8 SD_0
T_8	RH_0 RS_8 SD_4	T_{17}	RH_4 RS_8 SD_4	T_{26}	RH_8 RS_8 SD_4
T_9	RH_0 RS_8 SD_8	T_{18}	RH_4 RS_8 SD_8	T_{27}	RH_8 RS_8 SD_8

RH_0 RH_4 RH_8 = Rice hull at the rate of 0, 4 & 8 t ha^{-1}; RS0 RS4 RS8 = Rice straw at the rate of 0, 4 and 8 t ha^{-1}; SD0 SD4 SD8 = Sawdust at the rate of 0, 4 and 8 t ha^{-1}.

potential of the soil to hold plant nutrients, by estimating the capacity of the soil to retain cations, which are positively-charged substances. Therefore, the CEC of the soil directly affects the amount and frequency of fertilizer application.

CEC of the post harvested soils were found to be increased with the application of rice hull, rice straw and sawdust under both the moisture levels in the pot and field experiments. The coefficient of variation (CV) of different treatment means (Table III) indicate that the increment of CEC of the studied post harvested saline soils is significant ($p<0.001$) except for the moist condition under field experiment. There was significant ($p<0.05$) variation among the different treatments under pot experiment and in the field experiment under saturated soil condition.

In pot and field experiments, the highest (under pot exp.: 22.35 c mol kg^{-1}@ moist and 24.12 c mol kg^{-1} @ saturated soil conditions; under field exp.: 20.42 c mol kg^{-1} @ moist and 23.56 c mol kg^{-1} @ saturated soil conditions) and lowest values of CEC were obtained in the treatments T_{27} (RH_8 RS_8SD8) and T_1 (RH_0 RS_0 SD_0), respectively in post harvested soils (Table III). Although there was numerical variation in the CEC values in the two experiments, the trends of the increment and variation among different treatments were almost same. The results of the experiment revealed that the cation exchange capacity of

Table III. Post harvested soil CEC (c mol kg^{-1}) values under pot (BRRI dhan 48) and field (BRRI dhan 64) experiments as influenced by the application of rice hull, rice straw, sawdust and moisture conditions

Treatment		BRRI dhan 48		BRRI dhan 64	
No.	Denotation	Moist (80%)	Saturated (>100%)	Moist (80%)	Saturated (>100%)
T_1	RH_0 RS_0 SD_0	17.38 b	17.85 b	17.64	17.69 b
T_2	RH_0 RS_0 SD_4	17.67 b	17.89 b	17.68	17.81 b
T_3	RH_0 RS_0 SD_8	17.69 b	17.91 b	17.69	17.83 bc
T_4	RH_0 RS_4 SD_0	18.71 ab	18.89 ab	18.67	18.82 abc
T_5	RH_0 RS_4 SD_4	18.72 ab	18.92 ab	18.71	18.90 abc
T_6	RH_0 RS_4 SD_8	18.73 ab	19.08 ab	18.72	19.77 ac
T_7	RH_0 RS_8 SD_0	18.72 ab	18.93 ab	18.69	18.95 abc
T_8	RH_0 RS_8 SD_4	18.74 ab	19.91 ac	18.74	19.96 a
T_9	RH_0 RS_8 SD_8	18.74 ab	19.96 ac	18.76	19.13 abc
T_{10}	RH_4 RS_0 SD_0	19.68 ac	19.87 ac	19.69	19.78 ac
T_{11}	RH_4 RS_0 SD_4	19.73 ac	19.92 ac	18.71	19.92 a
T_{12}	RH_4 RS_0 SD_8	18.74 ab	19.97 ac	18.73	19.96 a
T_{13}	RH_4 RS_4 SD_0	18.74 ab	20.07 ac	18.73	19.98 a
T_{14}	RH_4 RS_4 SD_4	18.83 ab	20.17 ac	19.25	20.74 ad
T_{15}	RH_4 RS_4 SD_8	20.87 cde	21.31 ce	19.57	20.78 ad
T_{16}	RH_4 RS_8 SD_0	19.76 ac	20.15 ac	18.85	19.12 abc
T_{17}	RH_4 RS_8 SD_4	19.92 ac	21.27 ce	19.28	21.83 de
T_{18}	RH_4 RS_8 SD_8	20.03 ac	22.34 de	19.34	21.97 de
T_{19}	RH_8 RS_0 SD_0	18.69 ab	18.87 ab	18.72	18.91 abc
T_{20}	RH_8 RS_0 SD_4	18.75 ab	18.95 ab	18.71	18.95 abc
T_{21}	RH_8 RS_0 SD_8	18.79 ab	19.03 ab	18.73	19.07 abc
T_{22}	RH_8 RS_4 SD_0	19.76 ac	19.21 ab	18.83	18.91 abc
T_{23}	RH_8 RS_4 SD_4	21.84 de	22.34 de	19.26	21.84 de
T_{24}	RH_8 RS_4 SD_8	20.92 cde	23.47 d	19.27	22.93 e
T_{25}	RH_8 RS_8 SD_0	19.79 ac	20.25 ac	18.82	19.12 abc
T_{26}	RH_8 RS_8 SD_4	21.18 cde	23.76 d	19.29	22.15 de
T_{27}	RH_8 RS_8 SD_8	22.35 e	24.12 d	20.42	23.56 e
	CV	4.47***	9.07***	1.06 NS	7.25***

CV= Coefficient of Variation, *** indicates significant at o.1% level, NS= Not Significant. In a column, means followed by a common letter are not significantly different at 5% level by Tukey's Range Test.

Table IV. Post harvested soil exchangeable cations (Na^+, K^+, Ca^{2+} and Mg^{2+}) values under pot (BRRI dhan 48) experiment as influenced by the application of rice hull, rice straw, sawdust and moisture conditions

Treatment		Na^+(c mol kg^{-1})		K^+(c mol kg^{-1})		Ca^{2+}(c mol kg^{-1})		Mg^{2+}(c mol kg^{-1})	
No.	Denotation	Moist (80%)	Saturated (>100%)	Moist (80%)	Saturated (>100%)	Moist (80%)	Saturated (>100%)	Moist (80%)	Saturated (>100%)
T_1	$RH_0 RS_0 SD_0$	3.64 a	3.61 a	0.13	0.14 a	0.74	0.85	3.25	3.25
T_2	$RH_0 RS_0 SD_4$	3.63 a	3.60 a	0.14	0.19 ab	0.89	0.91	3.25	3.28
T_3	$RH_0 RS_0 SD_8$	3.59 a	3.52 a	0.15	0.22 ab	0.87	0.89	3.27	3.35
T_4	$RH_0 RS_4 SD_0$	3.61 a	3.53 a	0.19	0.23 ab	1.10	1.19	3.29	3.37
T_5	$RH_0 RS_4 SD_4$	3.57 a	3.50 a	0.36	0.41 ab	1.26	1.93	3.31	3.38
T_6	$RH_0 RS_4 SD_8$	3.54 a	3.51 a	0.37	0.42 ab	1.53	2.01	3.32	3.42
T_7	$RH_0 RS_8 SD_0$	3.61 a	3.54 a	0.29	0.54 ab	1.77	1.61	3.26	3.39
T_8	$RH_0 RS_8 SD_4$	3.58 a	3.56 a	0.49	0.66 ab	1.93	1.88	3.27	3.41
T_9	$RH_0 RS_8 SD_8$	3.57 a	3.54 a	0.60	0.88 ab	2.05	2.82	3.29	3.45
T_{10}	$RH_4 RS_0 SD_0$	3.63 a	3.60 a	0.64	0.65 ab	1.83	1.76	3.26	3.35
T_{11}	$RH_4 RS_0 SD_4$	3.62 a	3.60 a	0.67	0.71 ab	1.89	1.83	3.26	3.38
T_{12}	$RH_4 RS_0 SD_8$	3.61 a	3.56 a	0.68	0.74 ab	1.92	2.41	3.27	3.39
T_{13}	$RH_4 RS_4 SD_0$	3.63 a	3.59 a	0.69	0.76 ab	1.79	1.74	3.26	3.39
T_{14}	$RH_4 RS_4 SD_4$	2.56 ab	2.53 ab	1.71	1.78 abc	2.08	2.03	3.27	3.45
T_{15}	$RH_4 RS_4 SD_8$	2.55 ab	2.54 ab	1.72	1.80 abc	1.89	1.81	3.28	3.48
T_{16}	$RH_4 RS_8 SD_0$	3.62 a	3.57 a	0.69	0.78 ab	1.83	1.79	3.27	3.40
T_{17}	$RH_4 RS_8 SD_4$	1.57 bc	1.52 bc	1.73	1.82 abc	1.86	1.84	3.27	3.46
T_{18}	$RH_4 RS_8 SD_8$	3.53 a	3.51 a	1.73	2.18 bc	1.89	1.91	3.29	3.47
T_{19}	$RH_8 RS_0 SD_0$	3.64 a	3.60 a	0.64	0.69 ab	1.81	1.80	3.26	3.36
T_{20}	$RH_8 RS_0 SD_4$	3.61 a	3.55 a	0.68	0.73 ab	1.78	1.77	3.27	3.39
T_{21}	$RH_8 RS_0 SD_8$	3.61 a	3.53 a	0.68	0.75 ab	1.83	1.79	3.28	3.41
T_{22}	$RH_8 RS_4 SD_0$	2.57 ab	2.45 ab	0.69	0.77 ab	1.81	1.79	3.26	3.39
T_{23}	$RH_8 RS_4 SD_4$	1.56 bc	1.33 bc	1.72	2.78 c	1.91	1.78	3.27	3.46
T_{24}	$RH_8 RS_4 SD_8$	1.53 bc	1.35 bc	1.73	2.81 c	1.95	2.83	3.29	3.47
T_{25}	$RH_8 RS_8 SD_0$	2.51 ab	2.47 ab	0.70	0.75 ab	1.84	1.79	3.27	3.40
T_{26}	$RH_8 RS_8 SD_4$	1.46 bc	1.42 bc	1.73	2.80 c	1.93	2.91	3.27	3.47
T_{27}	$RH_8 RS_8 SD_8$	0.45 c	0.24 c	1.74	2.86 c	2.01	2.97	3.29	3.48
CV		2.60**	2.81***	1.08 NS	2.37**	0.43 NS	0.92 NS	0.00	0.01 NS

CV= Coefficient of Variation, *** indicates significant at o.1% level, ** indicates significant at 1% level,
NS= Not Significant. In a column, means followed by a common letter are not significantly different at 5% level by Tukey's Range Test.

soils increased with the increase rates of the treatments. Rice hull, rice straw and sawdust alone and their combination were found to be additive in increasing CEC of soils under both moist and saturated conditions in pot and field experiments. This might be due to the inherent consequences of organic amendments (rice hull, rice straw and sawdust) on soil exchangeable cations.

This result is quite similar with Chaganti *et al.* (2015) who said that the composts application increases soil CEC and decreases ESP values compared with the unfertilized control. According to Walker and Bernal (2008), the mature compost and manure application have a greater effect on the CEC increase and on SAR reduction.

Dynamics in Exchangeable Cations

The exchangeable cations especially Na^+ content decreased significantly ($p<0.05$) with the increased rates of rice hull, rice straw and sawdust. The maintenance of moisture conditions was also played a vital role in the decrement of the Na contents that might be due to the dilution effect of irrigated water resulting congenial atmosphere on soil-plant-water relationship. Application of rice hull, rice straw and sawdust alone and their combination was found to be more effective in decreasing Na^+ content in soil under saturated condition (Tables IV and V).

The maximum and minimum values of Na^+ contents were obtained in the treatment T_1 ($RH_0 RS_0 SD_0$) and T_{27} ($RH_8 RS_8 SD_8$) under both pot and field experiments. Rice hull, rice straw and sawdust decreased Na^+ content at saturated condition due to improved soil physical condition and water movement and release of Ca^{2+}, Mg^{2+} divalent cations where ion competition retarded Na content during decomposition thereby divalent cations occupy the exchange sites.

The exchangeable K^+ content of soil increased significantly ($p<0.05$) with the higher moisture content. Rice hull, rice straw and sawdust alone and in combination also increased K^+ content of the soils under both pot and field experiments (Tables IV and V). The exchangeable Ca^{2+} and Mg^{2+} contents of soil followed almost the similar trends and effects as that of K^+ exhibited (Tables IV and V).

The maximum and minimum values of K^+, Ca^{2+} and Mg^{2+} contents of the soils were recorded in the treatment T_{27} ($RH_8 RS_8 SD_8$) and T_1 ($RH_0 RS_0 SD_0$) under both pot and field experiments. The results of the present investigation are in accordance with the findings of Kaniz and Khan (2013), except for K^+ content, which might be due to high

Table V. Post harvested soil exchangeable cations (Na^+, K^+, Ca^{2+} and Mg^{2+}) values under field (BRRI dhan 64) experiment as influenced by the application of rice hull, rice straw, sawdust and moisture conditions

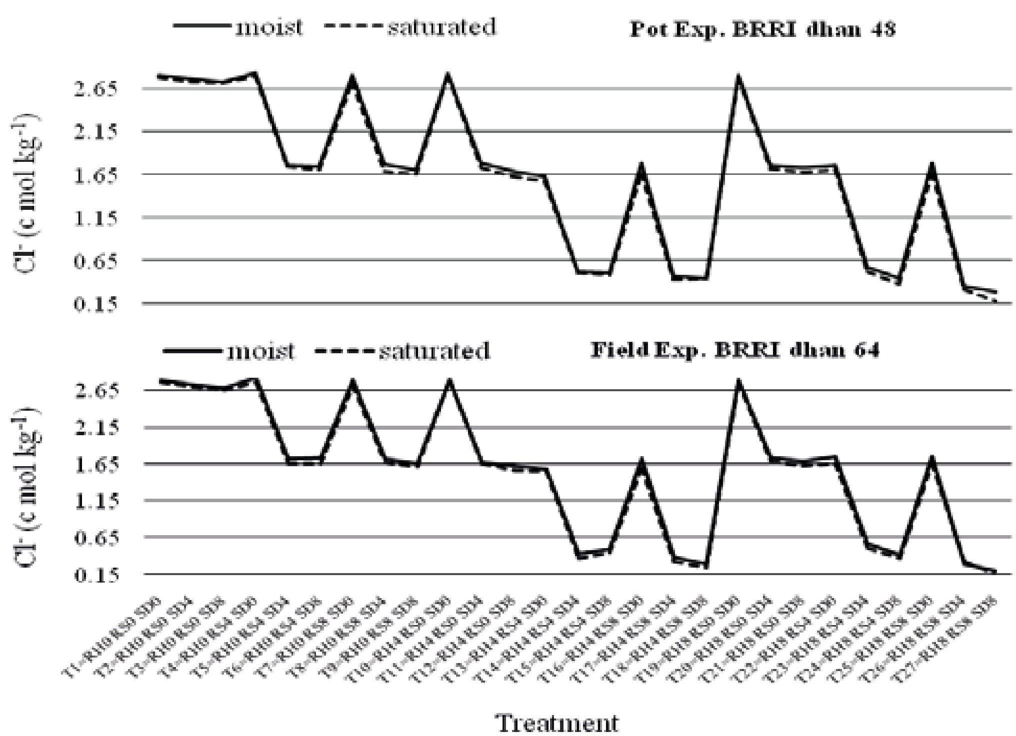
Treatment		Na^+(c mol kg^{-1})		K^+(c mol kg^{-1})		Ca^{2+}(c mol kg^{-1})		Mg^{2+}(c mol kg^{-1})	
No.	Denotation	Moist (80%)	Saturated (>100%)	Moist (80%)	Saturated (>100%)	Moist (80%)	Saturated (>100%)	Moist (80%)	Saturated (>100%)
T_1	$RH_0 RS_0 SD_0$	3.58 a	3.56 a	0.14	0.17 a	0.62	0.76	3.23	3.24
T_2	$RH_0 RS_0 SD_4$	3.55 a	3.54 a	0.15	0.23 a	0.87	0.79	3.24	3.29
T_3	$RH_0 RS_0 SD_8$	3.54 a	3.51 a	0.16	0.25 a	0.85	0.81	3.25	3.33
T_4	$RH_0 RS_4 SD_0$	3.57 a	3.53 a	0.16	0.32 a	1.08	1.15	3.24	3.29
T_5	$RH_0 RS_4 SD_4$	3.54 a	3.53 a	0.27	0.39 a	1.04	1.91	3.26	3.31
T_6	$RH_0 RS_4 SD_8$	3.51 a	3.49 a	0.28	0.41 a	1.21	1.98	3.27	3.35
T_7	$RH_0 RS_8 SD_0$	3.54 a	3.53 a	0.25	0.51 a	1.74	1.79	3.24	3.29
T_8	$RH_0 RS_8 SD_4$	3.53 a	3.52 a	0.48	0.62 ab	1.91	1.86	3.27	3.33
T_9	$RH_0 RS_8 SD_8$	3.53 a	3.51 a	0.69	0.81 ab	1.94	2.79	3.28	3.36
T_{10}	$RH_4 RS_0 SD_0$	3.57 a	3.55 a	0.64	0.68 ab	1.82	1.74	3.24	3.26
T_{11}	$RH_4 RS_0 SD_4$	3.56 a	3.53 a	0.65	0.73 ab	1.87	1.79	3.25	3.29
T_{12}	$RH_4 RS_0 SD_8$	3.54 a	3.51 a	0.66	0.75 ab	1.89	2.57	3.26	3.31
T_{13}	$RH_4 RS_4 SD_0$	3.54 a	3.53 a	0.67	0.73 ab	1.76	1.73	3.24	3.30
T_{14}	$RH_4 RS_4 SD_4$	2.51 ab	2.49 ab	1.69	1.81 abc	2.04	2.01	3.29	3.32
T_{15}	$RH_4 RS_4 SD_8$	2.49 ab	2.48 ab	1.69	1.83 abc	1.88	1.85	3.30	3.36
T_{16}	$RH_4 RS_8 SD_0$	3.51 a	3.45 a	0.69	0.75 ab	1.79	1.76	3.27	3.31
T_{17}	$RH_4 RS_8 SD_4$	1.47 bc	1.48 bc	1.68	1.82 abc	1.85	1.81	3.30	3.33
T_{18}	$RH_4 RS_8 SD_8$	3.46 a	3.43 a	1.70	2.58 bc	1.87	1.85	3.30	3.35
T_{19}	$RH_8 RS_0 SD_0$	3.53 a	3.47 a	0.65	0.69 ab	1.79	1.76	3.26	3.29
T_{20}	$RH_8 RS_0 SD_4$	3.51 a	3.45 a	0.66	0.76 ab	1.77	1.73	3.27	3.31
T_{21}	$RH_8 RS_0 SD_8$	3.51 a	3.49 a	0.67	0.79 ab	1.81	1.77	3.28	3.34
T_{22}	$RH_8 RS_4 SD_0$	2.49 ab	2.45 ab	0.67	0.76 ab	1.76	1.75	3.25	3.32
T_{23}	$RH_8 RS_4 SD_4$	1.47 bc	1.39 bc	1.69	2.82 c	1.88	1.75	3.30	3.36
T_{24}	$RH_8 RS_4 SD_8$	1.45 bc	1.38 bc	1.71	2.84 c	1.89	2.80	3.29	3.37
T_{25}	$RH_8 RS_8 SD_0$	2.49 ab	2.41 ab	0.69	0.78 ab	1.81	1.76	3.26	3.33
T_{26}	$RH_8 RS_8 SD_4$	1.45 bc	1.27 bc	1.72	2.82 c	1.85	2.83	3.31	3.37
T_{27}	$RH_8 RS_8 SD_8$	0.43 c	0.13 c	1.74	2.86 c	1.91	2.87	3.34	3.45
	CV	2.56**	2.81***	1.07 NS	2.50**	0.48 NS	0.96 NS	0.00	0.01 NS

CV= Coefficient of Variation, *** indicates significant at o.1% level, ** indicates significant at 1% level,
NS= Not Significant. In a column, means followed by a common letter are not significantly different at 5% level by Tukey's Range Test

bulk density and increased water movement created by them and release of Ca^{2+}, Mg^{2+} divalent cations during decomposition of those indigenous organic materials. Combined application of rice hull, rice straw and sawdust were better than their individual application in increasing exchangeable potassium, calcium and magnesium status of the soils. These findings are almost similar with Oo *et al.* (2015), who revealed that organic amendment like compost is a source of nutrients, cations (in particular Ca and K) and C that have an important role to promote the replacement of Na on exchange sites and increase microbial activity.

To reclaim effectively sodic and saline-sodic soils, inorganic amendments (gypsum, calcite, calcium chloride, and other chemical agents) are notoriously used as important sources of calcium to replace exchangeable Na on the exchange sites (Hanay *et al.,* 2004). In this context, the application of organic amendments can represent an important and effective practice to maintain an appropriate soil structure, supply a sufficiently available cation amount (such as Ca, Mg, K, etc.) and increase the fertility of saline and/or sodic soils. In fact, the organic matter plays a fundamental role on the structural stability of soil aggregate (Chaganti *et al.,* 2015) by binding of mineral particles to organic polymers.

Ranjbar and Jalali (2011) used leaching columns and studied the effects of several plant residues (wheat, potato, sunflower, and rape) added to a sandy loam soil, irrigated with water having three different sodium adsorption ratios. In a similar experiment, Jalali and Ranjbar (2009) evaluated the effects of poultry and sheep manure. In both leaching experiments, conducted under saturated conditions at room



	Rice cultivar	Moisture level	CV
	BRRI dhan 48	80%	2.40**
Cl^-		>100%	2.42**
(c mol kg^{-1})	BRRI dhan 64	80%	2.49**
		>100%	2.48**

Fig. 1. Contents of Cl^- (c mol kg^{-1}) at post harvest soils under pot (BRRI dhan 48) and field (BRRI dhan 64) experiments as influenced by the application of rice hull, rice straw, sawdust and moisture conditions

temperature, the organic material applied was the same and the results indicated that the application of organic amendments to soils caused an increase in CEC compared with unamended control and a greater adsorption of Ca^{2+}, Mg^{2+}, and K^{+} at the expense of Na^{+}.

Dynamics in Anions

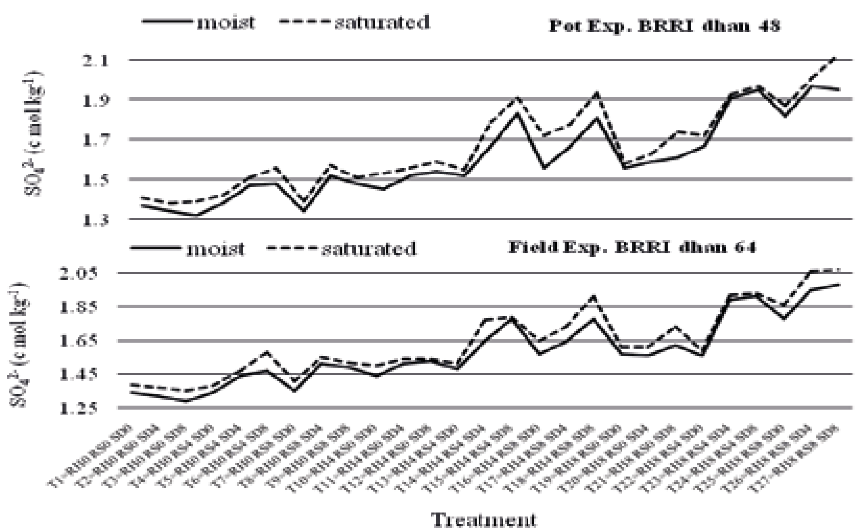
Among the water-soluble anions (Cl^{-}, SO_4^{2-} and HCO_3^{-}), chloride (Cl^{-}) was dominant and significantly decreased with irrigation under both pot (CV= 2.40** @ moist, 2.42** @ saturated condition) and field (CV= 2.49** @ moist, 2.48** @ saturated condition) experiments. Rice hull, rice straw and sawdust alone and their combination were found to be significant ($p<0.05$) in decreasing Cl^{-} ions in post harvested soils (Fig. 1).

The highest and lowest Cl^{-} contents were evaluated in the treatment T_1 (RH_0 RS_0 SD_0) and T_{27} (RH_8 RS_8 SD_8), respectively for all the varieties tested.

Sulfate content of post harvested soil increased with the application of rice hull, rice straw, sawdust and moisture conditions (Fig. 2). The higher and lower values were recorded in T_{27} ($RH_8RS_8SD_8$) and T_1 ($RH_0RS_0SD_0$) treatments under both pot and field experiments. Bicarbonate (HCO_3^{-}) contents of the post harvested soils also showed almost similar trend as those shown by sulfate contents (Fig. 3). Individual application of rice straw and saw dust were found better in increasing sulfate and bicarbonate contents while decrease chloride contents than that of rice hull treatment but their combined application was found more additive than that of their single dosage.

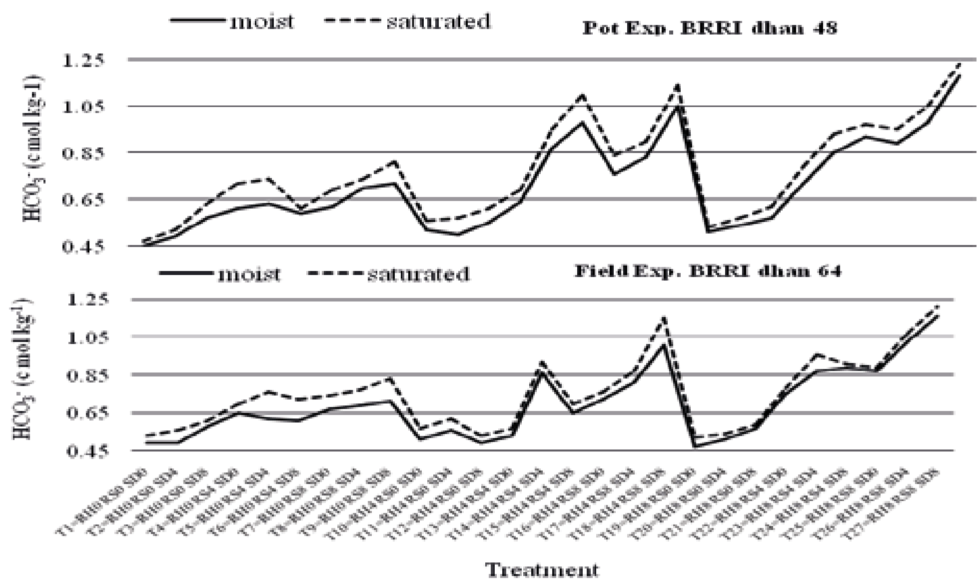
Conclusion

The present findings concluded that the application of rice hull, rice straw and sawdust as organic amendments were found to be increased CEC, exchangeable K^{+}, Ca^{2+}, Mg^{2+} and decreased Na^{+} contents of the studied saline soils. Among the water-soluble anions, Cl^{-} content was decreased, while SO_4^{2-} and HCO_3^{-} contents were increased by the application of these organic amendments under both moisture levels as maintained at the pot and field experiments. The combined application of rice hull, rice straw and sawdust each at the rate of 8 t ha^{-1} under saturated condition was attained the best performance among the treatments, which reveals that the interactions among these organic amendments were synergistic and would be effective in order to boost up the saline soil properties.



	Rice cultivar	Moisture level	CV
	BRRI dhan 48	80%	0.12 NS
SO_4^{2-}		>100%	0.14 NS
(c mol kg^{-1})	BRRI dhan 64	80%	0.12 NS
		>100%	0.13 NS

Fig. 2. Contents of SO_4^{2-} (c mol kg^{-1}) at post harvest soils under pot (BRRI dhan 48) and field (BRRI dhan 64) experiments as influenced by the application of rice hull, rice straw, sawdust and moisture conditions



	Rice cultivar	Moisture level	CV
	BRRI dhan 48	80%	0.11 NS
HCO_3^-		>100%	0.13 NS
(c mol kg^{-1})	BRRI dhan 64	80%	0.10 NS
		>100%	0.11 NS

Fig. 3. Contents of HCO_3^- (c mol kg^{-1}) at post harvest soils under pot (BRRI dhan 48) and field (BRRI dhan 64) experiments as influenced by the application of rice hull, rice straw, sawdust and moisture conditions

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