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Interactive effects of potassium and saline water on yield, nutrient accumulation and uptake by rice

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Abstract
A pot culture experiment was conducted to assess the interaction effects of salinity and potassium nutrition on rice during 2018. A pot experiment was conducted in CRD with three replications and twelve treatments consist of four levels of saline water (0, 2, 4 and 8 dS m^{-1}) and three doses of potassium (60, 120 and 180 kg ha^{-1}). The crop received a common dose of N @ 120 kg ha^{-1} (in splits) and P @ 60 kg ha^{-1}. The crop received saline water irrigation up-to saturation point at 30, 45, 60 and 80 DAP (days after planting). The study indicated that the cumulative application of saline water @ 4 and 8 dS m^{-1} decreased the grain yield and straw yield, yield components, potassium content and uptake by rice whereas, sodium content and uptake increased significantly at higher level of salinity (4 and 8 dS m^{-1}). The adverse effect of Na was reduced with application of potassium. The grain and straw yield, yield component, potassium content and uptake by rice was increased with increasing the dose of potassium. The sodium content and uptake by rice was reduced significantly with higher dose of potassium (180 kg ha^{-1}) application. Based on the present study, split application of potassium @ 180 kg ha^{-1} is recommended for rice in saline soil. The K^+/Na^+ ratio in soil and plant can be considered as a best indicator in evaluating crop performance in saline soil.

Keywords: Coastal salinity, osmotic stress, K^+/Na^+ ratio, nutrient uptake, rice yield

Introduction
Soil salinity is one of the major abiotic stress which limits agricultural productivity and food supply worldwide. It was reported that overall 20% of total farming and 33% of irrigated agricultural land were affected due to salinity. Further, the salinized areas are increasing at a rate of 10% per year for different reasons which includes low precipitation, high surface evaporation, weathering of native rocks, irrigation with saline water and poor cultural practices (Shrivastava and Kumar, 2015) [24]. Jamil *et al.* (2011) [13] reported that more than 50% of the arable land would be salinized continuously by the year 2050. In India, about 7 million hectares of land are salt affected out of which the coastal and in-land saline soils occupy 2.1 million hectares (Patel *et al.*, 2011) [20]. The coastal saline soils are recognised by high plant mortality, uneven and stunted plant growth and low rice yield during kharif season due to inundation of sea water through rivers and creeks (Jena, 1991) [14]. The underground water table is shallow and enriched with high salt content. During Rabi season, the land remained fallow due to lack of good quality irrigation water and accumulation of toxic amounts of salt on soil surface.

Soil salinity leads to ion toxicity, osmotic stress, nutrient deficiency and oxidative stress on plants and thus limits water uptake from soil (Shrivastava and Kumar, 2015) [24]. The nutrients, such as sodium, chlorine and boron have the toxic effects on plants. Excessive accumulation of sodium in cell walls can quickly prompt osmotic stress and cell death (Munns, 2002) [18]. In addition to specific toxic effects, high level of Na^+ can cause imbalance in uptake and utilization of other cations. Sodium ion competes with K^+ in the process of transport across the cell membrane during uptake inhibits plants to obtain K^+ from saline soils. Several studies on the agricultural crops showed that K^+ accumulation in plants decreases as the Na^+ salinity or Na^+/K^+ or Na^+/Ca^{2+} ratios in the root media is increased (Graifenberg *et al.*, 1995; PeÂrez Alforcea *et al.*, 1996) [6, 21]. Sodium induced potassium deficiency has been reported in growth and yield reduction in various crops (Song and Fujiyama, 1996; Lopez and Sathi, 1996) [26, 17]. Adverse effects of Na^+ can be alleviated by addition of K^+ to the substrate under saline condition (Grattan *et al*., 1997) [7].

The salt tolerance or sensitivity of a crop depend on its ability to extract water and nutrients from saline soils and to avoid excess tissue accumulation of salt ions (Kaleem *et al*. 2018) [15]. Several studies showed that rice is sensitive to salinity during early seedling growth and flowering. Maintaining a low Na^+/K^+ ratio in soil may benefit the rice crop. Application of potassium increased rice yield and nutrient uptake by improving K^+/Na^+, K^+/Mg^{2+}, K^+/Ca^{2+} ratios in soil. The selective uptake of K^+ as opposed to Na^+ is considered as one of the important physiological mechanisms contributing to salt tolerance in many plant species (Brenda *et al.*, 2015) [4]. Under saline conditions, K fertilization management should be modified because of K competition with different cations especially Na in the plant (Bar-Tal *et al*. 1991) [1]. Considering all these factors, the objectives of the present study were to: (i) study the interaction effects of potassium nutrition and saline stress on yield, yield components, nutrient accumulation and uptake of rice and (ii) test the possibility of diminishing damage to crop by applying elevated levels of potassium.

Materials and Methods

A pot culture experiment was conducted during August 2018 in the greenhouse of Institute of Agricultural Sciences (IAS), S'O'A Deemed to be University, Bhubaneswar, Odisha to study the interaction effects of potassium nutrition and salinity on yield, yield component, nutrient accumulation and uptake of rice. The experiment was conducted in a completely randomized (4×3) factorial design with three replications. The treatments consist of three levels of potassium @ 60, 120 and 180 kg ha^{-1} (on weight basis) designated as K1, K2 and K3 respectively. Each potassium treatment was superimposed with three levels of saline water irrigation having EC- 2, 4 and 8 dS m^{-1} including one control (good quality water). The salinity levels were designated as SW1 (control), SW2 (2 dS m^{-1}), SW3 (4 dS m^{-1}) and SW4 (8 dS m^{-1}).

The coastal saline soil used for the study was collected from surface layer (0-15 cm depth) of a rice field located in Sasan Damadarpur village in Sadar block of Puri district. The field is situated about 32 km from Chilika Lake (Saline water) and used for mono cropping with rice during rainy season. The land remained fallow during winter and summer on account of high salinity and absence of good quality irrigation water. The collected soil sample was air dried, processed and used for pot culture study. The saline water used in the study was brought from Bay of Bengal at Puri seashore having EC 34.56 dS m^{-1}. The sea water was diluted to EC 2, 4 and 8 dS m^{-1} and used as irrigation water. The polythene lined earthen pots were rinsed in 0.1 N HCl followed by deionised water. Each pot received a common dose of N @ 180 Kg ha^{-1} (weight basis) through diammonium phosphate and granular urea. The nitrogen fertilizer was applied in three splits as 25, 50 and 25% at basal, tillering, and primordia initiation stage, respectively. A common dose of P @ 60 kg ha^{-1} (weight basis) through diammonium phosphate was applied at transplanting. Potassium through muriate of potash (KCl) was applied as per the treatments in three splits as 50, 25 and 25% at transplanting, tillering and primordia initiation stage, respectively.

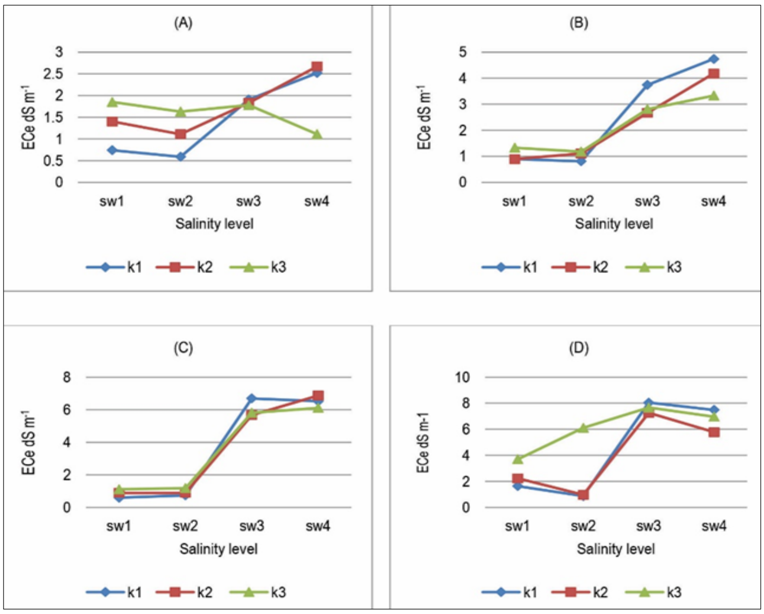
On weight basis, basal fertilizer doses were calculated and mixed thoroughly with 6 Kg of soil. The soil was saturated with normal water, mixed thoroughly and brought to puddled condition. Two hills of rice seedlings (each hill consists of 3 seedlings) of Pooja variety (150 days duration) was transplanted on 29th August 2018. Top dressing of N and K was done through solution. Plant protection measures were taken as and when necessary. The crop was irrigated with saline water up-to saturation point at 30, 45, 60 and 80 days after transplanting. The crop was harvested at fully matured stage. Soil, plant and root samples were collected at harvest. During crop growth, soil samples were also collected at 30, 45, 60 and 80 days after planting just before application of saline water.

The soil was analysed in the laboratory following standard procedures. Particle size was determined by Bouyocous hydrometer method (Bouyoucos, 1962) [3], pH by glass electrode with calomel as standard (Jackson, 1973) [12]. The bulk density, particle density and porosity were determined as per the methods outlined by Black (1965) [2]. The organic carbon content of soil was estimated by wet digestion method of Walkley and Black (1934) [31]. The cation exchange capacity was determined by Schollenberger and Simon (1945) [23]. Available N in soil was determined by modified alkaline permanganate method (Subbiah and Asija, 1956) [27] and available P by Olsen's method (Olsen *et al.* 1954) [19]. Water soluble K and Na was determined in 1:5 (Soil: water) ratio as outlined by Gerwal and Kanwar (1966) [8]. The available K and Na which includes water soluble and exchangeable forms was extracted with neutral normal ammonium acetate and estimated with a flame photometer (Model: Systonic 128) as described by Hanway and Heidel (1952) [10]. The exchangeable K and Na is computed from the difference of neutral normal NH_4OAc and water-soluble K or Na. The sodium and potassium content in grain and straw was estimated by wet digestion method (Jackson, 1973) [12].

Results and Discussions

The soil used for the study is slightly alkaline in reaction (pH 7.65) with electrical conductivity of saturated paste 3.2 dS m^{-1}. The texture is loamy sand with sand, silt and clay content of 87.6, 8.4 and 4%, respectively. The soil had B.D of 1.21 gm cm^{-3}, P.D 2.46 gm cm^{-3}, porosity 42.5% and moisture content of saturated paste 27%. The soil is medium in organic carbon (0.67%), low in available N (200 Kg ha^{-1}) and Olsen's P (8.15 Kg ha^{-1}). The available, water soluble and exchangeable K content of soil was 0.68, 0.08 and 0.60 c mol (+) Kg^{-1} soil indicating low potassium status. The soil was rich in Na. The available, water soluble and exchangeable Na content was 2.8, 2.0 and 0.8 c mol (+) Kg^{-1} soil, respectively. The sea water used in the study is alkaline in nature with pH 7.99 and EC of 34.56 dS m^{-1}. The content of soluble ions Na^+, K^+, Ca^{2+} and Mg^{2+} was 5.1, 0.20, 0.19 and 0.56 gm L^{-1}, respectively.

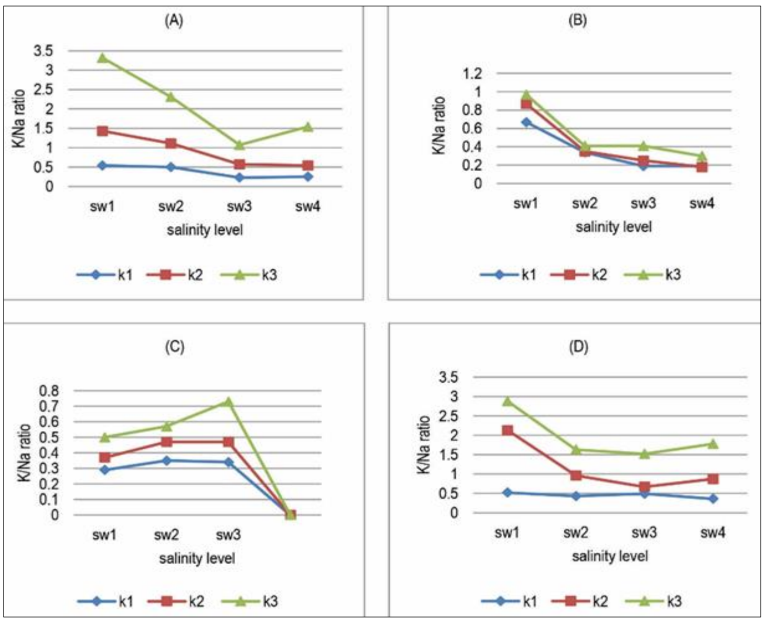
Effect of potassium and saline water on electrical conductivity (ECe) of soil: Electrical conductivity is a soil parameter that indicates the total concentration of soluble salts and is a direct measurement of salinity. The electrical conductivity of saturated paste (ECe) at different growth stages was influenced by levels of saline water irrigation and potassium (Fig. 1). In normal soil (Control), the ECe values varied between 0.59 to 3.70 dS m^{-1} during 30-80 days after planting (DAP) which were lower than the critical salinity levels (4 dS m^{-1}). However, the ECe values increased with increasing the level of saline water irrigation which varied between 0.59 to 6.10 dS m^{-1} in SW2, 1.78 to 8.04 dS m^{-1} in SW3 and 1.11 to 7.48 dS m^{-1} in SW4. Further, the ECe values increased with passes of time due to cumulative effect of saline water irrigation. There was significant effect of potassium application on ECe. The magnitude of salinity decreased with increasing the levels of potassium in SW3 and SW4 but, a reserve trend was observed in SW2. This is possible since, potassium and sodium although co-exist in soil exchange complex and soil solution, but both cations exert antagonistic effect. At higher level of saline water irrigation (SW4), the ECe values increased from 4.74 to 7.48 dS m^{-1} in K1, 4.18 to 6.96 dS m^{-1} in K2 and 3.33 to 5.77 dS m^{-1} in K3 during 45-80 DAP of rice crop. The magnitude of increase was in the order of K1 > K2 > K3. Ghuman *et al.* (2010) [5] reported that the soil ECe increased significantly with increasing the level of salinity. The ECe was increased from 3.4 to 12 dS m^{-1} when irrigated with saline water of 8.7 dS m^{-1}. Similar observation was made by Tedschi and Aquila (2005) [29].



DAP- Days after planting

Fig 1: Effect of Salinity and potassium on ECe of soil at different stages of rice growth: (A) 30 (B) 45 DAP (C) 60 DAP

Effect of salinity and potassium on K^+/Na^+ ratio in soil: High concentration of Na^+ and Cl^- in saline soils may depress nutrient ion activities and produce extreme K^+/Na^+ ratio as a result, the plants get susceptible to osmotic and specific ion injury as well as nutritional disorders that may result in reduced yield and quality. The data (Fig.2) indicated that application of saline irrigation water had negative impact on K^+/Na^+ ratio might be due to increase in both water soluble and exchangeable Na^+ in soil. The K^+/Na^+ ratio decreased with increasing level of salinity at all stages of growth. Irrespective of the levels of salinity, the K^+/Na^+ ratio increased with increasing the dose of potassium. Maximum K^+/Na^+ ratio was recorded in K3 at all levels of salinity and at all stages of growth. Higher K^+/Na^+ ratio at 30 and 80 DAP indicated the effect of potassium top dressing at peak tillering and primordia initiation stage. Maintenance of higher K^+/Na^+ ratio in soil benefits the plant to take up more K as compared to sodium.



DAP- Days after planting

Fig 2: Effect of salinity and potassium on K+/Na+ ratio in soil at different stages of rice growth: (A) 30 DAP (B) 45 DAP (C) 60 DAP

Effect of salinity and potassium on rice grain yield: The grain yield of rice presented in (Table.1) showed that application of lower level of saline water (2 and 4 dS m^{-1}) was found beneficial and increased the grain yield by 50% in SW2 (2 dS m^{-1}) and 27% in SW3 (4 dS m^{-1}) over the control (13.57 g pot^{-1}). However, the yield was slightly declined (0.3% over control) when the crop was irrigated with saline water at 8 dS m^{-1} (SW4). Potassium has positive impact on grain yield. Averaged over the salinity level, the yield in K1 (60 Kg ha^{-1-}) was 13.37 g $pot^{-1}$and increased by 18% in K2 (120 Kg ha^{-1}) and 42% in K3 (180 Kg ha^{-1}). The synergistic effect of salinity and potassium was observed in SW4K3 treatment with highest yield level of 25 gm pot^{-1}. Adverse effect of salinity was observed in straw yield. Application of lower level of saline water (2 dS m^{-1}) induced higher straw yield (93.27 g pot $^{-1}$) and recorded 3% higher yield over the control treatment (90.27 g pot^{-1}). But, when the level of saline water was increased to 4 and 8 dS m^{-1}, there was decline in straw yield by 2 and 10%, respectively. The reduction in grain and straw yield with saline water irrigation was consistent with the finding of Taffouo *et al.*, (2009) [28]. Positive impact of potassium application was reflected on straw yield. With application of higher dose of K, the straw yield increased by 11% in K2 and 25% in K3 over K1 (78.54 g pot $^{-1}$). The adverse impact of salinity can be mitigated with application of higher dose of potassium. The synergistic interaction effect between salinity and potassium was observed in SW2K3 with highest straw yield of 110.33 gm pot^{-1}. Gupta *et al.*, (1989) [9] reported that application of potassium improved growth and yield under water stress condition (caused due to salinity) presumably by resulting photosynthesis.

Table 1: Effect of salinity and potassium application on rice yield and yield attributing characters

Treatments	Grain yield (g Pot^{-1})	Straw yield (g Pot^{-1})	Tiller numbers per hill	Plant height (Cm)	Panicle length (Cm)	Chaff Percent
Levels of salinity						
SW1	13.57^{b}	90.27^{a}	14.95^{a}	72.80^{a}	15.81^{a}	49.88^{a}
SW2	20.15^{a}	93.27^{a}	15.89^{a}	76.02^{a}	18.24^{a}	52.44^{a}
SW3	17.16^{ab}	88.44^{a}	14.27^{a}	77.86^{a}	16.53^{a}	55.55^{a}
SW4	13.43^{b}	80.99^{a}	13.79^{a}	76.89^{a}	15.17^{a}	59.44^{a}
Levels of potassium						
K1	13.37^{b}	78.54^{b}	13.63^{b}	73.07^{b}	15.13^{b}	60.41^{a}
K2	15.77^{ab}	87.45^{ab}	14.45^{b}	75.73^{ab}	16.11^{ab}	55.75^{ab}
K3	19.02^{a}	98.45^{a}	15.66^{a}	78.87^{a}	18.07^{a}	46.83^{b}

*****Means followed by the same letter are not significantly different within levels of salinity and potassium according to Duncan's test ($P\leq 0.05$)

Biometric Observations: The biometric observations like number of tillers per hill, plant height, panicle length and chaff percent of rice is presented in table.1. The tiller number, plant height and panicle length were increased at lower level of saline water irrigation but, decreased at higher level of saline water. There was 6% increase in tiller number per hill in SW2 (2 dS m^{-1}) over SW1 (14.95) but declined by 5 and 8% when the crop received the saline water @ 4 and 8 dS m^{-1}, respectively. Increasing levels of K application improved tiller number, plant height and panicle length. Under normal dose of K (60 Kg ha^{-1}) the tiller number per hill was 13.63 which increased by 6 and 15% when the K dose was increased to 120 and 180 Kg ha^{-1}, respectively. Similar trend was observed in plant height and panicle length. The reduction in tiller number is consistent with findings of Shorabi *et al*., (2008) [25]. The chaff percent was increased by 5, 11 and 19% when the crop was irrigated with saline water at 2, 4 and 8 dS m^{-1}, respectively than that in control (49.88%). On the other hand the chaff percent decreased by 8% when the K dose increased from 60 to 120 Kg ha^{-1} and 22% at 180 Kg ha^{-1}. Lower dose of potassium did not impact much on boldness of rice grain since, more than 50% of chaff was recorded in K1 and K2 at each level of salinity. However, higher dose of K (180 Kg ha^{-1}) significantly reduced the chaff percent below 50% at all levels of salinity.

Potassium and sodium content in rice grain

The data (Table.2) indicated that accumulation of K in grain decreased with increasing the level of saline water irrigation. The K content in grain in SW1 treatment was 88.1 mM Kg^{-1} dry weight and decreased by 38, 44 and 44% at 2, 4 and 8 dS m^{-1} saline water irrigation, respectively. However, the K content in grain increased with increasing the dose of potassium at each level of salinity. Addition K @ 120 and 180 Kg ha^{-1} resulted in 27 and 35% higher K accumulation, respectively than that recorded with 60 Kg ha^{-1}(49.02 mM Kg^{-1} dry weight).The Na accumulation in grain increased with increasing level of salinity but, decreased with K application. Content of Na in grain was 11.59 mM Kg^{-1} weight when irrigated with normal water but, increased by 50 and 121% when the level of salinity increased to 4 and 8 dS m^{-1} respectively. However, there was reduction in Na accumulation by 30 and 54% when the K dose increased to 120 and 180 Kg ha^{-1}, respectively indicating positive impact of higher dose of K under saline condition. Among the treatments, lowest accumulation of Na was recorded in SW2K3 and SW3K3 treatments. But, when the salinity level was increased to 8 dS m^{-1} (SW4), higher dose of K (180 Kg ha^{-1}) failed to reduce adverse effect of Na.

Table 2: Effect of salinity and potassium on K/Na ratio, K and Na content and uptake by rice

Treatments	Content in grain (mM Kg dry $weight^{-1}$)		Content in Straw (mM Kg dry $weight^{-1}$)		Uptake (mg Pot^{-1})		K^+/Na^+ Ratio	
	K	Na	K	Na	K	Na	Grain	Straw
Levels of salinity								
SW1	88.10^{a}	11.59^{a}	341.16^{a}	44.48^{c}	1278.03^{a}	94.39^{a}	10.60^{a}	8.07^{a}
SW2	54.23^{b}	11.12^{a}	320.84^{a}	76.91^{bc}	1223.37^{a}	160.70^{a}	7.90^{a}	4.94^{a}
SW3	48.93^{b}	17.38^{a}	321.41^{a}	124.38^{ab}	1197.07^{a}	275.13^{a}	3.93^{a}	3.07^{c}
SW4	45.46^{b}	25.26^{a}	310.58^{a}	172.16^{a}	1061.57^{a}	313.09^{a}	2.73^{a}	2.04^{c}
Levels of potassium								

K1	49.02^{b}	22.81^{a}	300.08^{c}	123.71^{a}	956.81^{b}	205.49^{a}	4.60^{b}	3.53^{b}
K3	62.20^{a}	15.94^{b}	326.96^{b}	102.46^{a}	1182.67^{ab}	222.12^{a}	5.20^{ab}	4.54^{ab}
K3	66.30^{a}	10.50^{b}	343.45^{a}	87.28^{b}	1430.50^{a}	204.88^{a}	9.07^{a}	5.52^{a}

*****Means followed by the same letter are not significantly different within levels of salinity and potassium according to Duncan's test ($P \leq 0.05$)
MM- milli moles of K^+ or Na^+ present in 1 Kg dry mass

Potassium and sodium content in rice straw: Content of potassium in straw was higher than grain (Table.2). With increasing the level of salinity, K content decreased by 6% in SW2 and SW3 and 9% in SW4 over SW1 (341.16 mM Kg dry weight^{-1}). Higher dose of K had positive effect on K accumulation at each level of salinity. It was 300.08 mM Kg dry weight^{-1} in K1 and significantly increased by 9 and 14% when the K dose increased to 120 and 180 Kg ha^{-1}, respectively. Maximum K accumulation was recorded in SW1K3 treatment. Antagonistic effect of salinity on K accumulation was observed at all levels of salinity. Unlike potassium, accumulation of Na was higher in straw than grain. The Na content increased with increasing level of salinity but, decreased at higher level of K. Under normal condition (Control), the Na content was 44.48 mM Kg dry weight^{-1} and increased by 73, 180 and 287% when the salinity level increased to 2,4 and 8 dS m^{-1},respectively.The beneficial effect of potassium on Na accumulation was observed at all levels of salinity. Content of Na at normal dose of K (60 Kg ha^{-1}) was 123.71 mM Kg dry weight^{-1} but, reduced by 17 and 29% when the K dose increased to 120 and 180 Kg ha^{-1}, respectively. Among the treatment combinations, lowest Na accumulation was recorded in SW1K3 treatment.

Potassium-sodium ratio in rice: The K^+/Na^+ ratio in grain increased with increasing the dose of K but, decreased with salinity levels (Table. 2). Under normal water irrigation (control) the ratio was 10.60 but, decreased by 25, 63 and 74% when the level of saline water irrigation increased to 2,4 and 8 dS m^{-1}, respectively. On the other hand, the K^+/Na^+ ratio increased over K1 (4.60) by 13 and 97% when the K dose increased to 120 and 180 Kg ha^{-1}, respectively. Positive interaction effect of salinity and potassium was recorded in SW1K3 and SW2K3 treatments. The K^+/Na^+ ratio in straw was lower than grain might be due to higher accumulation of Na in straw as compared to grain. Averaged over the K levels, the K^+/Na^+ ratio in SW1 was 8.07 and decreased by 39, 62 and 75% when the salinity level was increased to 2,4 and 8 dS m^{-1}, respectively. However, potassium application enhanced the K^+/Na^+ ratio in straw at all levels of salinity. It was 3.53 in K1 and increased by 29 and 56% when the K dose increased to 120 and 180 Kg ha^{-1}, respectively.

Potassium and sodium uptake by rice: Total potassium uptake by rice (grain and straw) was 1278.03 mg pot^{-1} in SW1 (Control) and decreased by 4, 6 and 17% in SW2, SW3 and SW4, respectively (Table. 2). Application of K @ 120 and 180 Kg ha^{-1} increased the K uptake over K1 (956.81 mg pot^{-1}) by 24 and 50%, respectively. Kibria *et al*. (2015) [16] reported that K uptake and K^+/Na^+ ratio in rice increased by application of potassium fertilizer under saline condition. They suggested that higher dose of K in splits improved rice production in saline condition. Similar findings were also reported by Vidican *et al*. (2014) [30]. Total Na uptake by rice increased with increasing level of salinity. It was 94.39 mg Pot^{-1} in SW1 and increased by 70, 191 and 232% in SW2, SW3 and SW4, respectively. Higher dose of potassium did not have much effect on Na uptake. With increasing the level of potassium from K1 to K3, the Na uptake either slightly increased or remained constant might be due higher biomass yield in all potassium treatments.

Potassium and sodium content and K^+/Na^+ ratio in rice root: Content of K in rice root was lower than grain and straw (Fig. 3). In SW1 treatment, it was 28.5 mM Kg dry weight^{-1} and decreased by 4, 14 and 39% in SW2, SW3 and SW4, respectively. Accumulation of K in root increased with increasing level of K. It was 16.3 mM dry weight^{-1} in K1 and increased by 64 and 87% in K2 and K3, respectively. Sodium content in root was lower than grain and straw. It was increased with increasing the level of saline water irrigation at all levels of K. The content of Na in SW1 was 11.6 mM Kg dry weight^{-1} and increased by 9, 20 and 53% in SW2, SW3 and SW4, respectively. However, addition of K decreased the Na content by 32% in K2 and 44% in K3 over K1 (18.7 mM Kg dry weight^{-1}). Similar trend was observed in K^+/Na^+ ratio. The K^+/Na^+ ratio in SW1 (control) was 2.73 and decreased by 10, 29 and 60% in SW2, SW3 and SW4, respectively. Cumulative application of saline water increased the Na^+ content and decreases the K^+/Na^+ ratio. However, K addition had positive effect on the ratio might be due to higher K content in soil and the ratio was increased by 144% in K2 and 239% in K3 over K1 (0.90). Further, the data showed that the trend of K^+/Na^+ ratio in different parts of rice plant was in the order of grain>straw>root. Lower K^+/Na^+ ratio in root indicates higher accumulation of Na^+ as compared to K^+. Higher K^+/Na^+ in grain and straw might have happened due to lower transport of Na from root to shoot because of antagonistic effect of K on Na. Rabie *et al.* (2005) [22] reported similar finding in rice. The K^+/Na^+ ratio in rice decreased gradually with increasing the level of salinity.

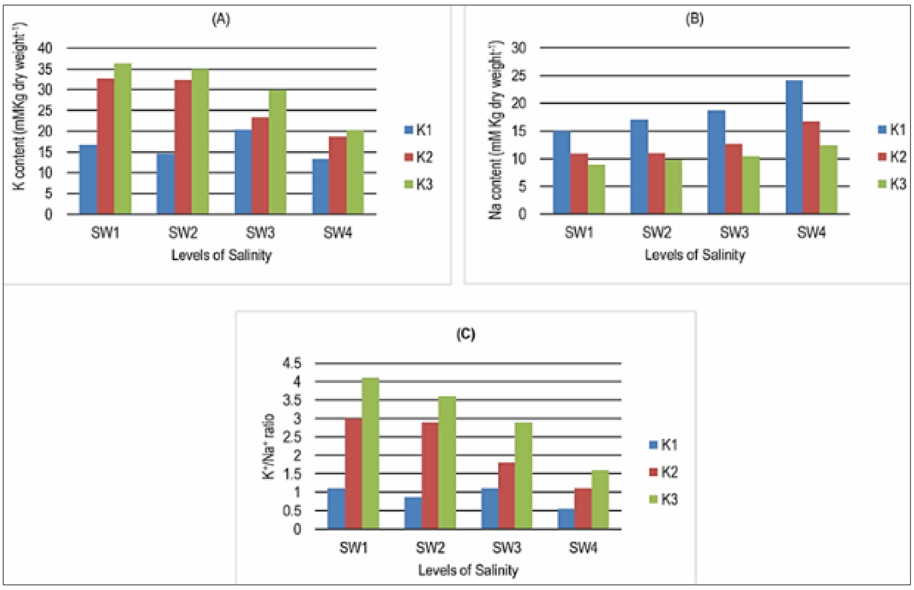


Fig 3: Effect of salinity and potassium on: (A) K content in root (mM Kg dry weight^{-1}); (B) Na content in root (mM Kg dry weight^{-1}); K^+/Na^+ ratio in root

Post-harvest soil properties: After harvest of rice crop there was no specific trend in change of soil pH within different treatments (Table.3). The initial soil pH was 7.65 which was decreased in all treatments after harvest of rice crop. It varied between 6.88 to 6.96 in SW1, 6.73 to 6.79 in SW2, 6.42 to 6.80 in SW3 and 6.48 to 6.61 in SW4. There was slight decrease in soil pH with increasing the level of salinity. The electrical conductivity of soil paste (ECe) at beginning of the experiment was 3.2 dS m^{-1}. At the end of cropping period, there was decreased in ECe values in all treatments might be due to crop removal and leaching of Na^+ below the root zone. The ECe values in different saline water treatments varied between 0.82 to 1.12 dS m^{-1} in SW1, 0.88 to 1.19 dS m^{-1} in SW2, 0.97 to 1.44 dS m^{-1} in SW3 and 0.84 to 1.70 dS m^{-1} in SW4, but, all the values were below the critical level of salinity. Further the data showed that, the ECe values increased with increasing the level of K in SW1 and SW2 might be due to lower grain yield and Na uptake. On the other hand, at higher salinity level (SW3 and SW4), the ECe values decreased with increasing the dose of potassium because of antagonistic effect of Na and K.

Initial exchangeable potassium in soil was 0.60 c mol (+) kg soil^{-1} and increased at all levels of salinity and potassium. It varied between 0.77 to 1.21, 0.79 to 1.13, 0.79 to 1.14 and 0.91 to 1.32 c mol (+) kg soil^{-1} in SW1, SW2, SW3 and SW4, respectively. Further the data showed that the exchangeable K increased with increasing the level of potassium application. The exchangeable Na content of the initial soil was 0.80 c mol (+) kg soil^{-1} and increased with levels of salinity and potassium. It varied between 1.36 to 1.55, 1.60 to 1.90, 2.24 to 2.76 and 2.83 to 3.50 c mol (+) kg soil^{-1} in SW1, SW2, SW3 and SW4, respectively. The cumulative effect of saline water addition resulted in higher exchangeable Na content at harvest of the crop, although a major part of it was removed by crop. The K^+/Na^+ ratio in soil at beginning was 0.24 and increased at all level of salinity and potassium. It varied between 0.50 to 0.89, 0.49 to 0.71, 0.29 to 0.51 and 0.26 to 0.47 in SW1, SW2, SW3 and SW4, respectively indicating decrease in ratio with increasing the level of salinity. Further the data indicated that, the K^+/Na^+ ratio was increased with increasing the dose of potassium. Addition of higher dose of potassium suppressed the activity of sodium might be due to antagonistic effect. Hauser and Horie (2010) [11] observed high K^+/Na^+ ratio in soil with rice crop was high at low salinity, than plant. But, under high salinity, the K^+/Na^+ ratio in plant was higher than soil. Similar pattern of K^+/Na^+ in soil and plant was observed in present study.

Table 3: Effect of salinity and potassium on post- harvest soil properties

Treatment	pH	ECe dS m^{-1}	Exchangeable K c mol (+) Kg^{-1}	Exchangeable Na c mol (+) Kg^{-1}	K^+/Na^+ Ratio
SW1 K1	6.88	0.82	0.77	1.55	0.50
SW1 K2	6.91	1.07	0.81	1.42	0.57
SW1 K3	6.96	1.12	1.21	1.36	0.89
SW2 K1	6.79	0.88	0.93	1.90	0.49
SW2 K2	6.74	1.15	0.79	1.72	0.50
SW2 K3	6.73	1.19	1.13	1.60	0.71
SW3 K1	6.42	1.44	0.79	2.76	0.29
SW3 K2	6.80	0.90	0.82	2.56	0.32
SW3 K3	6.72	0.97	1.14	2.24	0.51
SW4 K1	6.61	1.70	0.91	3.50	0.26
SW4 K2	6.48	1.01	1.20	3.26	0.37
SW4 K3	6.52	0.84	1.32	2.83	0.47
Initial	7.65	3.20	0.60	0.80	0.24

Based on the results following conclusion were drawn: Cumulative application of saline water @ 4 and 8 dS m^{-1} increased the ECe above the critical limit during 30-80 DAP, but the ECe decreased marginally with application of potassium. Saline water irrigation @ 4 and 8 dS m^{-1}resulted in reduction of biomass yield, tiller number/hill but, increased chaff percent. Higher level of saline water application (8 dS m^{-1}) significantly increased the content and uptake of Na by rice whereas, K content and uptake was reduced. The adverse effect of Na was decreased by use of potassium. Under saline condition, higher dose of potassium increased the grain yield, straw yield, plant height, number of tillers/hills, panicle length and reduced chaff percentage. Potassium application @ 180 kg ha^{-1} significantly increased the K content and uptake by rice but, decreased Na content and uptake. The K^+/Na^+ ratio plays a vital role in evaluating crop performance in saline soil. The K^+/Na^+ ratio in soil and plant was decreased with level of saline water irrigation but, increased with potassium application. The pattern of K^+/Na^+ ratio in soil and plant at higher level of salinity (8 dS m^{-1}) and potassium (180 kg ha^{-1}) was in the order of soil < root < straw< grain.

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Conflict of interest
No potential conflict of interest is reported by the authors

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