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

Angshuman Mohapatra, Dr. Dinabandhu Jena, Poonam Preeti Pradhan, Debasis Pattnaik, Dr. AK Pal and Dr. MR Pattanik

DOI: https://doi.org/10.22271/chemi.2021.v9.i1ao.11676

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., 2000) [29]. 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) [18]. 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) [19]. 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⁺/Ca²⁺ ratios in the root media is increased (Graifenberg et al., 1995; PeÁrez Alforcera 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 (Gragan 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+/Mg2+, K+/Ca2+ 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) [11]. 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 (4x3) 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 available, water soluble and exchangeable K content in grain and straw was 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\(_4\)OAc 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\(^{-3}\), particle density and porosity were determined as per the methods outlined by Black (1965) [2]. The organic 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 (1996) [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\(_4\)OAc and water-soluble K or Na. The sodium and potassium content in grain and straw was estimated by wet digestion method (Jackson, 1973) [12].

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 transplanting (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) 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).

**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

**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 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**

DAP- Days after planting
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) [25]. 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≤ 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\(^{-1}\) 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 |
|------------|------------------------------------------|------------------------------------------|--------------------------|------------|
| Levels of salinity | | | | |
| K | Na | K | Na | K | Na | Grain | Straw |
| SW1 | 88.10\(^{a}\) | 11.59\(^{a}\) | 341.16\(^{a}\) | 44.48\(^{e}\) | 1278.03\(^{a}\) | 94.39\(^{a}\) | 10.60\(^{a}\) | 8.07\(^{a}\) |
| SW2 | 54.21\(^{b}\) | 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\(^{ab}\) | 275.13\(^{ab}\) | 3.93\(^{a}\) | 3.07\(^{a}\) |
| 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 | | | | | | |

~ 2939 ~
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) 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). 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 Kg 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) reported similar finding in rice. The K⁺/Na⁺ ratio in rice decreased gradually with increasing the level of salinity.
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. 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. Further the data showed 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.

Acknowledgement
We wish to express our sincere gratitude to Sikaha “O” Anusandhan University, Bhubaneswar for providing all the necessary facilities to carry out the present research work.

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

References
1. Bar-Tal A, Feigenbaum S, Sparks D. Potassium-salinity interactions in irrigated corn. Irrigation Science 1991, 12(1). Doi: 10.1007/bf00190706.
2. Black CA. Methods of soil analysis Vol.1. Am. Soc. Agron. Madison, Wisconsin, U.S.A 1965.
3. Bouyoucos GJ. Hydrometer Method Improved for Making Particle Size Analysis of Soils. Agronomy Journal 1962;54:464-465.
4. Brenda R, Igor A, Vinicius D, Vanessa D, Fabio S. Growth of eucalyptus plants irrigated with saline water. African Journal of Agricultural Research. Doi: 10.5897/ajar2014.9087 2015;10(10):1091-1096.
5. Ghuman BS, Choudhary OP, Dhalwal MS, Chawala N. Yield and quality of two tomato (Solanum lycopersicum L.) cultivars as influenced by drip and furrow irrigation using waters having high residual sodium carbonates. Irrigation Science 2010;58:265-272.
6. Graifenberg A, Giustiniand L, Temperini O, Lipucci di Paola M. Allocation of Na, Cl, K and Ca within plant tissues in globe artichoke (Cynara scololium L.) under saline-sodic conditions. Sci. Hort 1995;63:1±10.
7. Grattan SR, Shannon MC, Grieve CM, Poss JA, Suarez DL, Francoise LE. Interactive effects of salinity and boron on the performance and water use of eucalyptus. Proceeding 2nd International Symposium on Irrigation of Horticultural Crops. In: Chartzoulakis, K.S. (Ed.), September 8±13, 1996, Chania, Crete, Greece. Acta Hort 1997;449:607±613.
8. Grewal JS, Kanwar JS. Forms of potassium in Punjab soils. Journal of the Indian Society of Soil Science 1966;14(1):63-67.
9. Gupta A, Berkowitz G, Pier P. Maintenance of Photosynthesis at Low Leaf Water Potential in Wheat. Plant Physiology, doi: 10.1104/pp.89.4.1358 1989;89(4):1358-1365.
10. Hanway JJ, Heidel H. Soil analysis methods as used in Lowa state college, Soil testing Laboratory, Lowa state college Bulletin 1952;57:1-131.
11. Hauser F, Horie T. A consented primary salt tolerance mechanism mediated by HKT transporters: a mechanism for sodium exclusion and maintenance of high K+/Na⁺ ratio in leaves during salinity stress. Plant Cell & Environment. doi: 10.1111/j.1365-3040.2009.02056.x 2010;33(4):552-565.
12. Jackson JL. Soil chemical analysis. Prentice Hall of India, Pvt. Ltd. New Delhi 1973.
13. Jamil A, Riaz S, Ashraf M, Foolad M. Gene Expression Profiling of Plants under Salt Stress. Critical Reviews In Plant Sciences, doi: 10.1080/07352689.2011.605739 2011;30(5):435-458.
14. Jena D. Soil related constraints in coastal saline soils of Orissa. J Indian Soc. Coastal Agric. Res 1991;9(1&2)183-186.
15. Kaleem F, Shabir G, Aslam K, Rassul S, Manzoor H, Shah SM, Khan AR. An review of the genetics of plant response to salt stress: Present status and Way forward. Applied Biochemistry and Biotechnology. October 2018.
16. Kibria MG, Haque MF, Islam MS, Hoque MA. Increasing crop productivity in coastal areas by proper management of potassium fertilizers. Progressive Agriculture 2015;26:115-121.
17. Lopez MV, Sathi SME. Calcium and potassium-enhanced growth and yield of tomato under sodium chloride stress. Plant Sci 1996;114:19±27.
18. Munns R. Comparative physiology of salt and water stress. Plant, Cell and Environment, doi: 10.1046/j.0016-8025.2001.00808.x 2002;25(2):239-250.
19. Olsen SR, Cole CV, Watanabe FS, Dean LA. Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate. U.S. Department of Agriculture Circular No. 939. Bandersis A.D., D.H. Barter and K. Anderson. Agricultural and Advisor 1954.
20. Patel BB, Patel Bharat B, Dave RS. Studies on infiltration of saline-alkali soils of several parts of Mehsana and Patan districts of north Gujarat. J Appl. Technol. Environ. Sanitation 2011;1(1):87-92.
21. PeÂrez-Alfoecas FA, Balibrea ME, Santa Cruz A, Estan AMT. Agronomical and physiological characterization of salinity tolerance in a commercial tomato hybrid. Plant Soil 1996;180:251±257.
22. Rabie G, Aboul-Nasr M, Al-Humiany A. Increased Salinity Tolerance of Cowpea Plants by Dual Inoculation of an Arbuscular Mycorrhizal FungusGlomus clavatum and a Nitrogen-fixerAzospirillum brasilense. Mycobiology, doi: 10.4489/myco.2005.33.1.051 2005;33(1):51.
23. Schollenberger CJ, Simon RH. Determination of Exchange Capacity and Exchangeable Bases in Soil-Amonium Acetate Method. Soil Science 1945;59:13-24.
24. Shrivastava P, Kumar R. Soil Salinity: A serious environmental issue and plant growth promoting bacteria as one of the tools for its alleviation. Saudi Journal of Biological Sciences. doi:10.1016/j.sjbs.2014.12.001 2015;22(2):123-131.
25. Sohriabi Y, Heldari G, Esmaipoor B. Effect of salinity on growth and yield of desi and kabuli chickpea cultivars, Pak J Biol Sci 2008;11:664-667.
26. Song JQ, Fujiyama H. Difference in response of rice and tomato subjected to sodium salinization to the addition of calcium. Soil Sci. Plant Nutr 1996;42:503±510.
27. Subbiah BV, Asija GL. A rapid procedure for determination of nitrogen in soils. Current Science 1956;25:259-260.
28. Taffouo VD, Kouamou JK, Ngalangue LMT, Ndjeudji B, Ako. Effects of salinity stress on growth, ions partitioning and yield of some cowpea (*Vigna unguiculate* L. Walp.) cultivars. Int J Bot 2009;5:135-143.

29. Tedeschi A, Dell’Aquila R. Effects of irrigation with saline waters at different concentrations on soil physical and chemical characteristics. Agricultural Water Management 2005;77:308-32.

30. Vidican R, Monica N, Rotar I, Stoian V, Pop R, Miclea R. Plant nutrition affected by soil salinity and response of rhizobium regarding the nutrients accumulation. Pro Environment 2014;7:71-75.

31. Walkley AJ, Black IA. Estimation of soil organic carbon by the chromic acid titration method. Soil Sci 1934;37:29-38.