Original Research Article

Interactive effect of salinity and potassium on maize yield

ABSTRACT

A pot culture experiment was undertaken during the month of January 2021, in green house of Institute of Agriculture Science (IAS), SOA Deemed to be University, Bhubaneswar, Odisha to study the interactive effects of salinity and potassium levels on biomass yield, accumulation and uptake of K and Na by maize. The experiment was conducted in 2-factorial CRD with three replications and twelve treatments consists of: two level of saline water (0.8 dS m^{-1}), two sources of K fertilizers (KCl and K_2SO_4) and three doses of K (0,60,120 kg ha^{-1}). The results showed that continuous application of saline water (8 dS m^{-1}) increased the soil ECe (Electrical Conductivity of a saturated soil Extract) by 182-360 % over saline control treatments. Application of K (120 kg ha^{-1}) significantly decreased ECe by 29% over K control. Application of K @120 kg ha^{-1} significantly increased the biomass yield (24%), K accumulation (14%) and K uptake (41%) over K control. The Na content was reduced by 17%. K^+/Na^+ ratio in maize in saline treatments decreased by 64% over saline control. Application of K @120 kg ha^{-1} significantly increased the K^+/Na^+ ratio by 27% over K control. In saline stress environment, K^+/Na^+ ratio in plant fairly correlated with biomass yield (R^2=0.73), K content (R^2=0.79) and Na content (R^2=0.89) in plant. K^+/Na^+ ratio in soil failed to correlate well with biomass yield. K^+/Na^+ ratio in plant can be considered as a best indicator in evaluating crop performance in saline soil.

Key word: maize, salinity, potassium, biomass yield, K^+/Na^+ ratio

1. INTRODUCTION

Salinity is an agro-environmental problem in arid and semi-arid regions of the world and has a significant impact on crop productivity. It reduces agricultural yields, prevents the use of previously cultivated land, and industrial raw material production. Human-induced salinity, combined with the natural, limits food production in most semi-arid regions of the world [1]. The majority of the world's water is salty containing 30 g of sodium chloride per liter. The availability of saline water is greater than fresh water [2]. Safe use of saline water in agriculture through soil management techniques will be beneficial to improve food security in developing countries.

Salinity affects plants in different ways such as osmotic stress, specific-ion toxicity and nutritional disorders [3]. Osmotic stress is linked to ion accumulation in the soil solution whereas, nutritional imbalance and specific ion toxicity are connected to ion build up, mainly sodium and chloride to toxic levels which interferes with the availability of other essential elements such as calcium and potassium. Ionic imbalance and ion toxicity leads to substitution of potassium with sodium resulting reduction in K^+/Na^+ ratio in plants. Toxic levels of sodium in plant organs reduces plant growth and effects photosynthesis, respiration, starch metabolism and nitrogen fixation leading to losses in crop yield.

Among the cereals, maize (Zea mays L.) is the third most important cereal crop, cultivated in165 million hectares of land producing 850 million tons of grain with an average grain yield of 5200 kg ha^{-1} [4]. Maize is typically classified as a moderately salt sensitive crop and a salt sensitive cereal, showing the signs of stress including wilting even when there is adequate soil moisture. Seed germination and early seedling growth stages are more sensitive to salinity than later developmental stages. Hyper-osmotic stress and toxic effects of sodium and chloride ions may delay or inhibit germination, reduces plant growth and leads to severe nutritional imbalances in maize. Along with other mineral nutrients, potassium is very important for maintaining turgor and membrane potential, balancing osmotic potential, controlling stomatal movement and activating enzymes [5]. The stress mitigating role of potassium in plant under drought, salinity and on pathogenic infection was reported by Cakmak [6]. Thus, under saline condition, potassium may be considered as an important management strategy because of its competition with sodium in plants.

Keeping in view the beneficial effects of potassium on crops under saline stress condition, a pot culture experiment was undertaken: to study the interaction effects of salinity and potassium on maize biomass yield, nutrient accumulation and uptake and to test the possibility that salinity damage can be reduced by elevating the rates of different potassic fertilizers.

2. MATERIALS AND METHODS

2.1 Experimental Site

The interaction effects of salinity and potassium on biomass yield, nutrient acquisition and uptake of maize crop was studied through a pot experiment. The experiment was conducted in green house of Institute of Agriculture Science (IAS), SOA Deemed to be University, Bhubaneswar, Odisha during the month of January 2021.

2.2 Experimental Design and Treatments

The experiment was conducted in a 2-factorial completely randomized design with three replications and 12 treatment combinations consist of two levels of salinity (SW0-saline control, SW1- saline water irrigation @8dS m^{-1}), three doses of potassium (K1- control, K2- 60 kg ha^{-1}, K3- 120 kg ha^{-1}) and two sources of potassium fertilizers (F1- KCl and F2- K_2SO_4).

The sandy loam saline soil used in the pot culture study was collected from Brahmagiri village in Puri district during October, 2020. The field was mono cropped with rice during kharif season. During rabi season the land remained fallow because of high salinity and lack of good quality irrigation water. The surface soil (0-15 cm depth) in bulk was collected from the field and brought to the laboratory, air dried, processed and used for pot culture study. The characteristics of soil is discussed in result section. The saline water used in the study was brought from the Bay of Bengal at Puri seashore. The EC of sea water was 35.5 dS m^{-1} which was diluted to 8 dS m^{-1} for use as irrigation water in the study.

The polythene lined earthen pots were rinsed in 0.1N HCl followed by de -ionised water. Seven kg of air-dried soil was transferred into each pot. Each pot received a common dose of N @ 120 kg ha^{-1} (on weight basis) through DAP and granular urea. The nitrogen fertilizer was applied in two splits as 50% at sowing and 50% at knee heigh stage. A common dose of phosphorous @ 60 kg ha^{-1} (on weight basis) through DAP was applied at seeding time. Potassium through KCl and K_2SO_4 was applied in two splits

(50% at seeding and 50% at knee heigh stage) as per the treatments. Each pot received chemical grade of gypsum @ 15 mg pot^{-1} through solution.

All the pots were saturated with normal water up to field capacity and 8 number of hybrid sweet corn seeds (CV.4226) of 90 days duration were sown on 9th January2021. Emergence of seedlings was recorded on 16th January 2021. After seedling emergence, 4 seedlings were kept in each pot. First saline water irrigation was applied to SW1 treatments on 25th January 2021 up to saturation point. In SW0 treatments, the maize crop received irrigation through normal water. In SW1 treatments, same quantity of irrigation water was applied through normal water and saline water alternatively. The crop received 14 number of saline water irrigation (250 cc in each time) during the crop growth period.

Plant protection measures were taken as and when required. The crop was harvested at 64 th day of emergence. Plant samples were collected at harvest, processed and analysed for K and Na. Soil samples were collected at 21^{th} day of seedling emergence and at harvest, processed and kept for analysis.

2.3 Soil and plant analysis

The soil was analysed in the laboratory following standard procedures. Particle size was determined by Bouyoucos hydrometer as given by Piper (1950)[7], pH by glass electrode with calomel as standard (Jackson, 1973)[8].Electrical conductivity (EC) of soil was determined in 1:2 soil-water suspension by conductivity meter (ELICOCM 180 conductivity meter) as suggested by Jackson (1973)[8].The bulk density, particle density and porosity were determined as per the methods outlined by Black (1965)[9].The organic carbon content of soil was estimated by wet digestion method of Walkley and Black (1934)[10]. Available N in soil was determined by modified alkaline permanganate method (Subbiah and Asija, 1956) [11] and available P by Olsen's method (Olsen *et al*. 1954) [12]. Water soluble K and Na was determined in 1:5 (soil: water) ratio. The available K and Na which includes water soluble and exchangeable forms was extracted with neutral normal ammonium acetate and estimated with flame photometer (Model:Systonic128) as described by Hanaway and Heidel (1952)[13]. The sodium and potassium content in maize plant was estimated as per the method outlined by Jackson (1973) [8] .

3. Results and Discussion

The soil used in the study is slightly acidic in reaction (pH 6.49) having electrical conductivity of saturated soil paste 2.57 dS m^{-1} , B.D 1.21 gm cm^{-3}, P.D 2.46 gm cm^{-3} and porosity 42.5%. The soil was high in O.C (1.02%) with organic matter content of 1.75%. The soil was low in available N (112 kg ha^{-1}) and available P (8.50 kg ha^{-1}). The water soluble K, exchangeable.K and non-exch.K content in soil was 27.85, 270.52 and 1043.63mg kg^{-1}, respectively. The soil was rich in sodium having available, water soluble and exchangeable sodium content of 56.1, 25.5 and 30.6 mg kg^{-1}, respectively.

3.1 Effects of saline water irrigation and potassium on soil ECe

Continuous use of saline water leads to accumulation of neutral soluble salts in soil that impacts crop growth. Long term application of saline water resulted in higher EC and accumulation of soluble salts in the soil rhizosphere which adversely affect plant growth [14].

Application of saline water significantly increased the ECe values over SW0 (normal water) by 182 % at 21d of seedling emergence and by 360 % at harvest. It varied between 5.82 to 7.39 dS m^{-1} at 21 days and 7.40 to 12.33 dS m^{-1} at harvest (Table 1 and Fig.1). Similar results were reported by Mahdy [15] and Tedeschi and Aquila [16].

Application of K through K_2SO_4 resulted in lower ECe (6%) as compared to KCl at both stages, although the values were non-significant . Decrease in ECe values in K_2SO_4 treatments might be due to presence of associate sulphate ion as against chloride ion. Several findings showed that the ECe of soil increases with increasing the concentration of chloride ions. Similar findings were reported by Marcio A. Cameiro *et al* [17].

Application of different doses of K (K_0, K_{60} and K_{120}) significantly decreased the ECe at harvest stage, but was non-significant at 21 days of growth. Application of potassium @ 120 kg ha^{-1}significantly reduced the ECe over potassium control treatment by 29% at harvest and 8% at 21 days of growth . This is possible since, potassium and sodium although co-exist in soil exchange complex and soil solution, but both cations exert antagonistic effect.

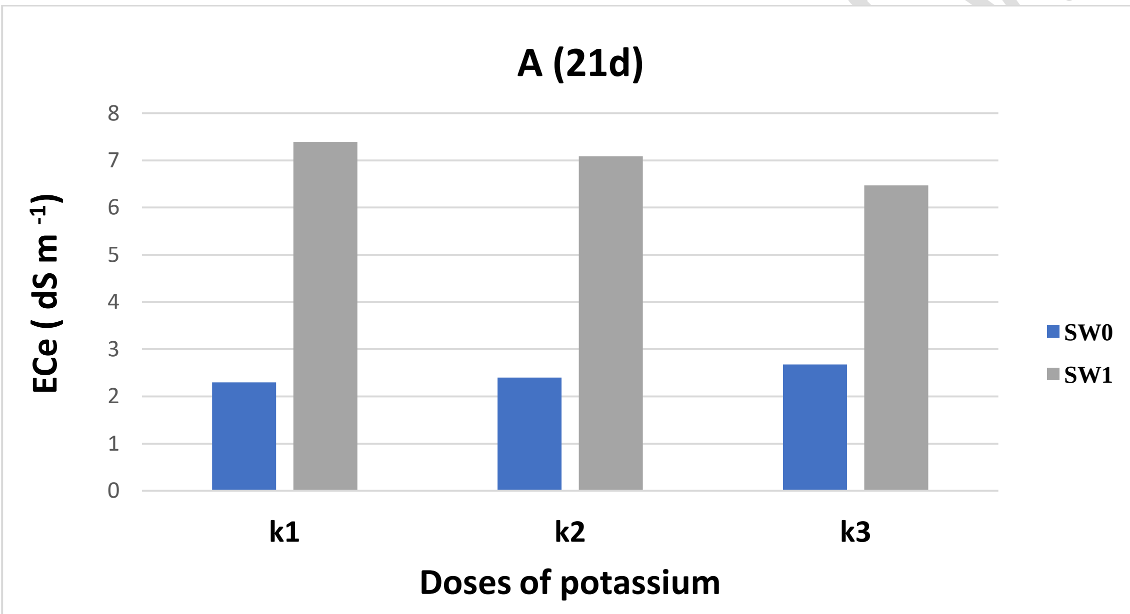
Table 1 . Effect of salinity and potassium on soil ECe (dS m^{-1})

Treatment	21 Days	Harvest
	Tr. Mean	Tr. Mean
Sw0 F1 K1	2.30^{d}	2.04^{d}
SW0 F1 K2	2.40^{d}	2.36^{d}
SW0 F1 K3	2.68^{d}	2.75^{d}
SW0 F2 K1	2.12^{d}	1.75^{d}
SW0 F2 K2	2.30^{d}	2.22^{d}
SW0 F2 K3	2.60^{d}	2.20^{d}
SW1 F1 K1	7.39^{a}	12.33^{a}
SW1 F1 K2	7.10^{ab}	11.37^{ab}
SW1 F1 K3	6.47^{bc}	7.57^{c}
SW1 F2 K1	7.23^{ab}	12.10^{a}
SW1 F2 K2	6.59^{abc}	10.46^{b}
SW1 F2 K3	5.82^{c}	7.40^{c}

Factors	C.D (0.05)	C.D (0.05)
SW	0.336	0.503
F	NS	NS
SW X F	NS	NS

K	NS	0.616
SW X K	0.582	0.871
F X K	NS	NS
SW X F X K	NS	NS

Each value is an average of 3 replications. Figures not showing the same letter(s) in column differ significantly at 5% probability level according to Duncan's Multiple Range Test.



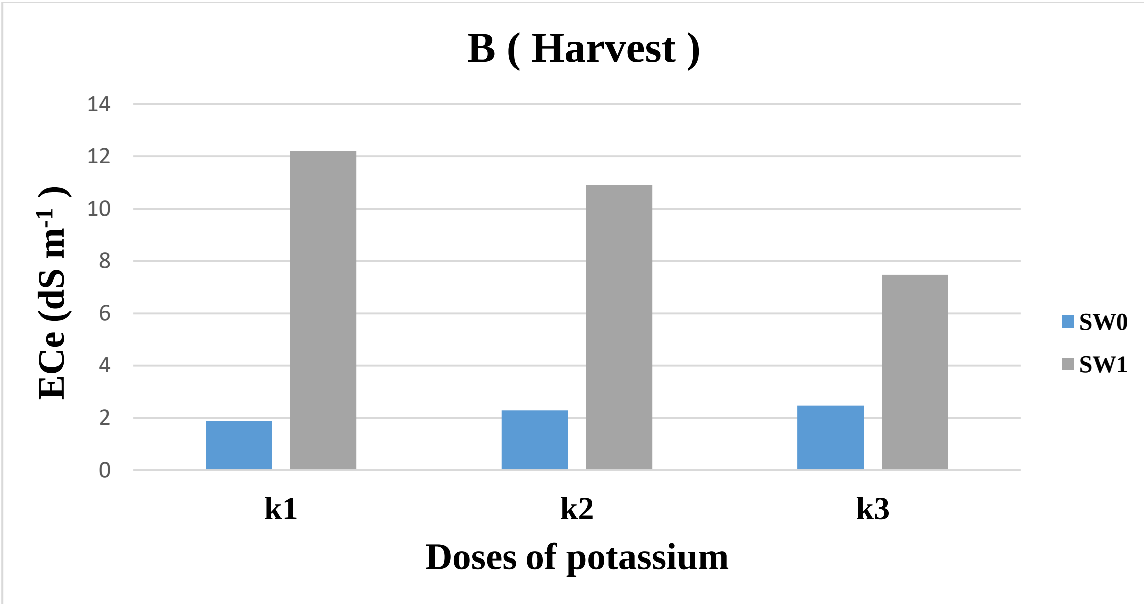


Fig 1. Effect of salinity and potassium on ECe (dS m^{-1}) at 21 d (A) and at harvest (B)

3.2 Effects of salinity and potassium on biomass yield

The biomass yield of maize was significantly influenced by the saline water irrigation and potassium doses (Table 2). Continuous use of saline water irrigation significantly increased the biomass yield by 11% over saline control treatment might be due to higher release of K from exch. and non-exch. K sources . Among the two K fertilizers tested, addition of K_2SO_4 recorded higher biomass yield (3%) as compared to KCl , because of lower electrical conductivity in K_2SO_4 treatments than KCl treatments. Further, the presence of SO_4^{-2} ion in K_2SO_4 meet the S requirement of crop, whereas Cl^- ion in KCl is detrimental to maize crop .

Significant effect of potassium dose was observed in saline and non-saline treatments (Fig.2). When the K doses was increased from 0 to 60 -120 kg ha^{-1}, the biomass yield increased by 34 to 37% in saline control and 11-24% in saline treatments.

The reduction in response of potassium application under saline environment might be due to adverse effect of sodium. Further, the data indicated that averaged over SW0 and SW1 treatments, the response to K application over potassium control was 21% in K2 (60 kg ha^{-1}) and 24% in K3 (120 kg ha^{-1}) indicating that the adverse effect of Na is suppressed at higher level of potassium application.

Several authors reported that application of K improved growth and yield under stress (caused due to salinity) possibly by resulting photosynthesis [18]. The adverse effect of Na on plant growth and yield can be reduced by K application [19].

3.3 Effect of salinity and potassium on K and Na accumulation and their uptake

Accumulation of K and Na

Application of saline water and potassium significantly influenced the accumulation of K and Na in maize crop (Table 2). With application of saline water, the content of K significantly decreased by 6% as compared to normal water irrigation whereas, Na content increased by 167% over saline control treatments (Table 3and 4).

Application of higher dose of potassium has beneficial effect on K accumulation. It reduced the adverse effect of Na under saline environment. When the K dose increased from 0 to 60 and 120 kg ha^{-1}, the K content in maize increased by 5 and 14%, respectively, over K control. On the other hand, accumulation of Na decreased by 17%, when the maize was fertilized with 120 kg ha^{-1} K. Application of recommended dose of K (@60 K kg $ha^{-1}$for maize) did not affect much in reducing adverse effect of Na.

There was no significant difference between the effect of KCl and K_2SO_4 on K and Na accumulation in maize plant (Table 2). However, application of K_2SO_4 reduced Na accumulation by 17% over KCl. But, had no effect on potassium accumulation.

Uptake of K and Na

Application of saline water significantly increased the Na uptake whereas, K uptake was non-significant (Table 2). The uptake of K was increased by 4% and the Na uptake by 186% with application of saline water (SW1) over saline control (SW0) treatments might be due to higher biomass yield in saline treatments.

Application of K either through KCl or K_2SO_4 did not affect much on K or Na uptake.Application of different doses of K significantly increased the K uptake. When the K dose increased from 0 to 60 and 120 kg ha^{-1}, the K uptake was increased by 27 and 41%, respectively, over potassium control treatments.

On the other hand, K application suppressed the uptake of Na although higher biomass yield was recorded in K treatments. Non-significant increase in Na uptake by 11% in K2 (60 kg ha^{-1}) indicated that in spite of higher biomass production, application of K suppressed the uptake of Na.

Excessive buildup of Na^+ and Cl^- ions in root zone cause several nutritional imbalances in maize due to strong interference of these ions with other essential nutrients. Under saline conditions, nutrient imbalance reduced nutrient uptake including K^+ and ion toxicity are resulted because of high Na^+ and Cl^- concentrations [20], Nabipour *et al.* [21] reported that the yield of wheat decreased with increasing salinity. By increasing salinity, sodium content of leaf, stem, root, spike and seed increased but potassium content decreased. Similar results were reported by Vidican *et al*. [22], Shabala *et al*. [23].

Table 2. Effect salinity and potassium on biomass yield, K &Na content %, K & Na uptake, K^+/ Na^+ ratio in maize plant

Treatments	Treat. Mean					
	Biomass yield(g/pot)	**K (%)**	**Na (%)**	**K uptake (g/pot))**	**Na uptake (mg/pot)**	**K^+/ Na^+ ratio in maize**
Sw0 F1 K1	150.7^{c}	2.25^{bcd}	0.03^{c}	3.39^{e}	45.21^{b}	43.84^{a}
SW0 F1 K2	205.5^{ab}	2.31^{bcd}	0.03^{c}	4.75^{bc}	61.52^{b}	49.19^{a}
SW0 F1 K3	210.0^{ab}	2.55^{ab}	0.03^{c}	5.34^{ab}	62.46^{b}	53.89^{a}
SW0 F2 K1	160.5^{c}	2.28^{bcd}	0.03^{c}	3.66^{de}	48.15^{b}	44.42^{a}
SW0 F2 K2	210.5^{ab}	2.50^{abc}	0.03^{c}	5.23^{ab}	62.08^{b}	51.34^{a}
SW0 F2 K3	215.0^{ab}	2.62^{a}	0.03^{c}	5.64^{a}	64.83^{b}	53.85^{a}
SW1 F1 K1	193.1^{b}	2.21^{cd}	0.09^{a}	4.27^{cd}	173.59^{a}	14.46^{b}
SW1 F1 K2	216.6^{ab}	2.25^{bcd}	0.08^{ab}	4.87^{abc}	173.79^{a}	17.18^{b}
SW1 F1 K3	220.7^{a}	2.50^{abc}	0.07^{b}	5.52^{ab}	154.49^{a}	20.87^{b}
SW1 F2 K1	200.1^{ab}	2.09^{d}	0.08^{ab}	4.18^{cde}	158.8^{a}	15.44^{b}
SW1 F2 K2	218.0^{ab}	2.25^{bcd}	0.08^{ab}	4.92^{abc}	174.4^{a}	16.43^{b}
SW1 F2 K3	225.5^{a}	2.39^{abcd}	0.07^{b}	5.39^{ab}	150.58^{a}	21.11^{b}
Factors	**C.D (0.05)**					
SW	9.618	0.106	0.006	NS	13.726	6.569
F	NS	NS	NS	NS	NS	NS
SW X F	NS	NS	NS	NS	NS	NS
K	11.779	0.130	NS	0.361	NS	NS
SW X K	16.658	NS	NS	NS	NS	NS
F X K	NS	NS	NS	NS	NS	NS
SW X F X K	NS	NS	NS	NS	NS	NS

Each value is an average of 3 replications.

Figures not showing the same letter(s) in column differ significantly at 5% probability level according to Duncan's Multiple Range Test.

Table 3. Interaction effect of salinity and different levels of potassium-on-potassium content (%) in maize plant

Sources	K1	K2	K3	Mean	% Decrease over SW0
SW0	2.27	2.41	2.58	2.42	-
SW1	2.15	2.25	2.45	2.28	5.79
Mean	2.21	2.33	2.52		
% Increase over k1	-	5.43	14.03		

Table 4. Interaction effect of salinity and different levels of potassium on Na content (%) in maize plant

Sources	K1	K2	K3	Mean	% Increase over SW0
SW0	0.03	0.03	0.03	0.03	-
SW1	0.09	0.08	0.07	0.08	166.67
Mean	0.06	0.06	0.05		
% Decrease over k1	-	-	16.67		

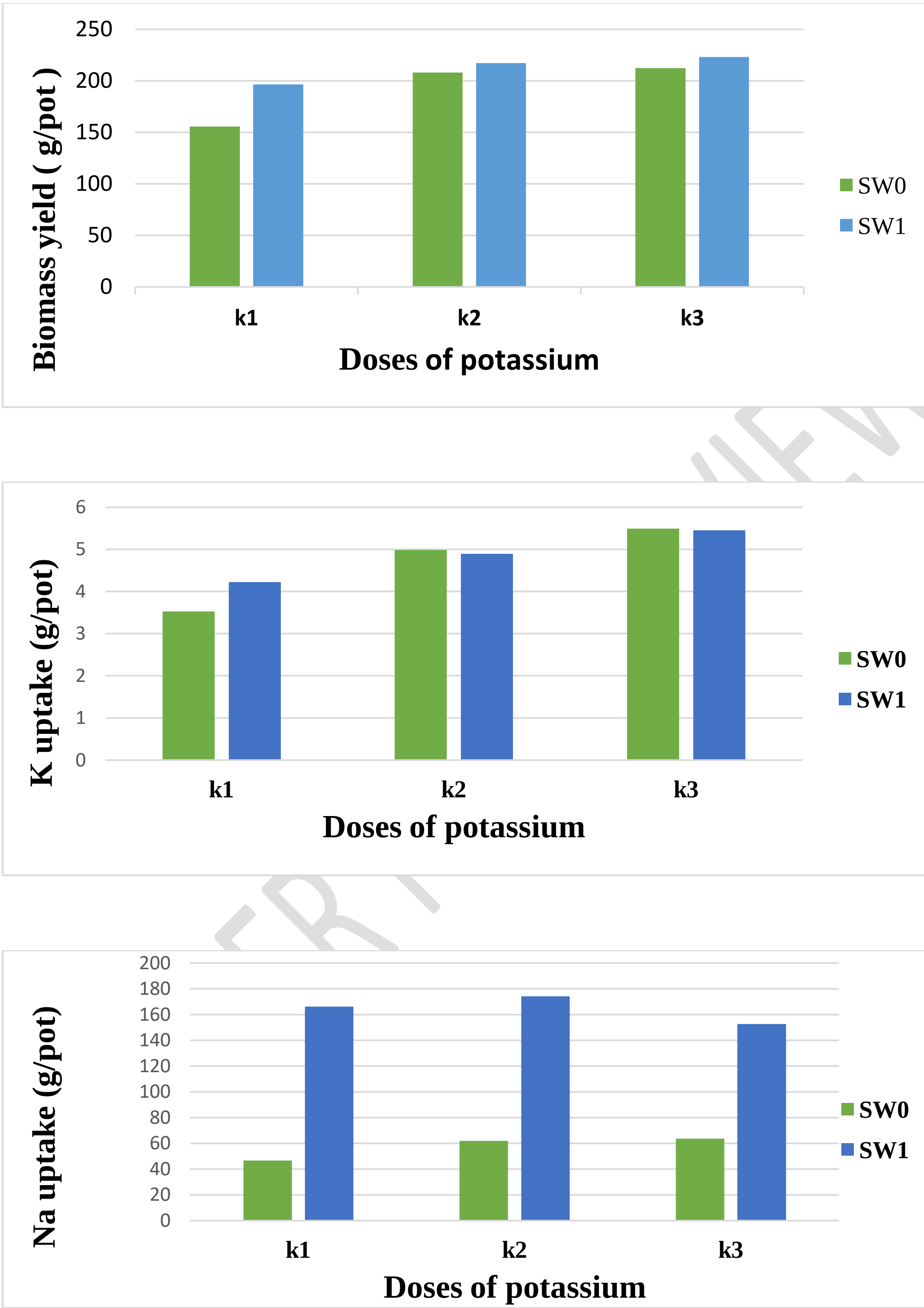


Fig 2. Effect of salinity and potassium on biomass yield, K uptake, Na uptake (g/pot)

* SW0- saline control , SW1-saline water

3.4 Effect of salinity and potassium on K^+/Na^+ in maize plant

The K^+/Na^+, being another indicator (Except ECe) of the plant response to high salinity decreases in many plant after saline water irrigation [24].

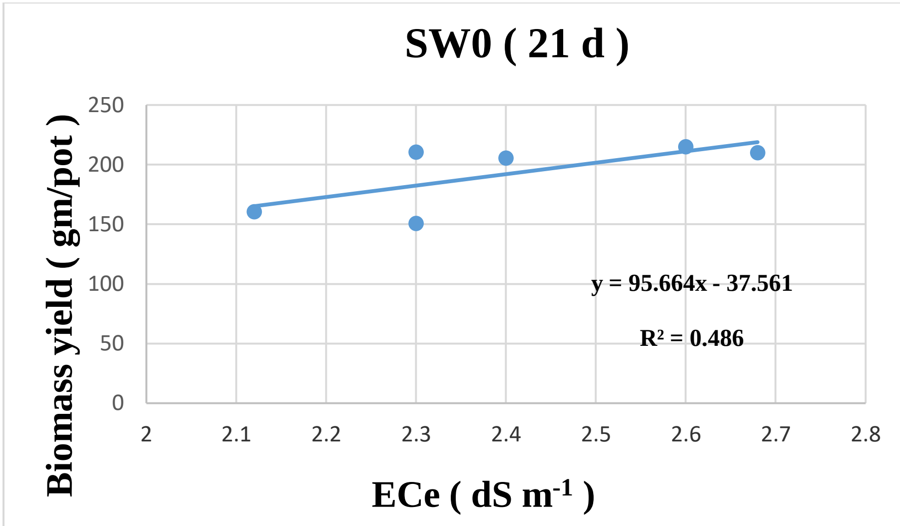
The data presented in (Table 2) showed that application of saline water significantly reduced K^+/Na^+ ratio in plant. Under normal water irrigation, the ratio increased with level of K application which ranged from 43.84 to 53.89 in F1 (KCl) and 44.42 to 53.85 in F2 (K_2SO_4), but all the values were at par.

Application of saline water significantly decreased the K^+/Na^+ ratio by 64% over SW0 (normal water) treatments. However, with application K fertilizers, there was improvement in the ratio over potassium control treatments. The K^+/Na^+ ratio increased by 14 and 27% when the K dose increased from 0 to 60 and 120 kg ha^{-1}, respectively.

Similar observations were reported by Mohapatra [25] for rice and by Patel [26] for maize crop. Folkard *et al* [27] observed that leaf K^+/Na^+ ratio predicts salinity induced yield loss in irrigated rice.

3.5 Correlation between soil properties and several plant parameters

A positive relationship exists between ECe at 21 days with biomass yield having R^2 value of 0.4868 in saline control treatments. However, under saline condition, the biomass yield of maize significantly decreased with increasing ECe at 21 days with R^2 value of 0.741 (Fig.3).



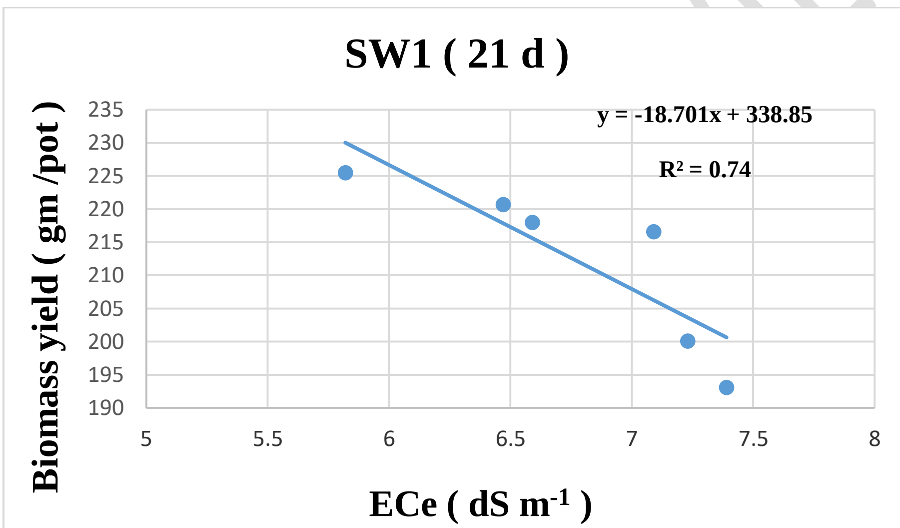


Fig 3. Correlation between ECe at 21 days and biomass yield in saline control (SW0) and saline (SW1) treatments.

The K^+/Na^+ ratio in maize fairly correlated with biomass yield both in saline control (R^2=0.896) and saline treatments (R^2=0.73) (Fig.4). However, the correlation between K^+/Na^+ in soil and biomass yield was non-significant.

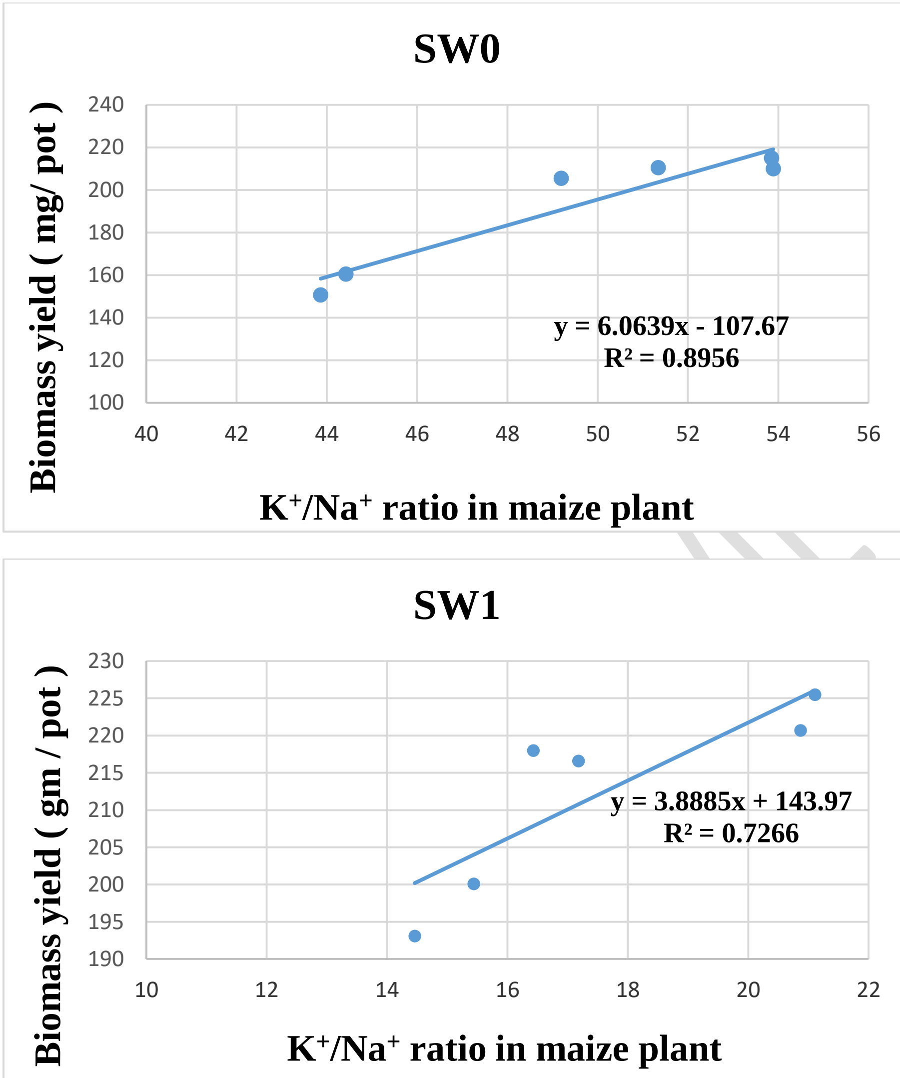
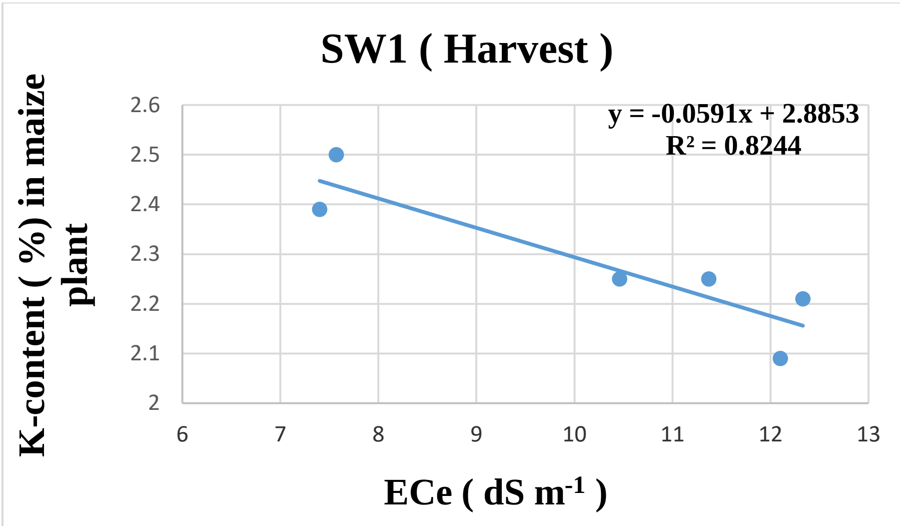


Fig 4. Correlation between K^+/Na^+ ratio in maize plant and biomass yield in saline control (SW0) and saline (SW1) treatments

The K content in maize plant decreased with ECe at harvest, whereas, Na content increases. The data presented in fig.5 showed that a negative relationship exists between ECe (at harvest) and K content in plant with R^2 value of 0.83. On the other hand, a positive correlation ship exists between ECe (at harvest) and Na content in maize with R^2 value of 0.83.



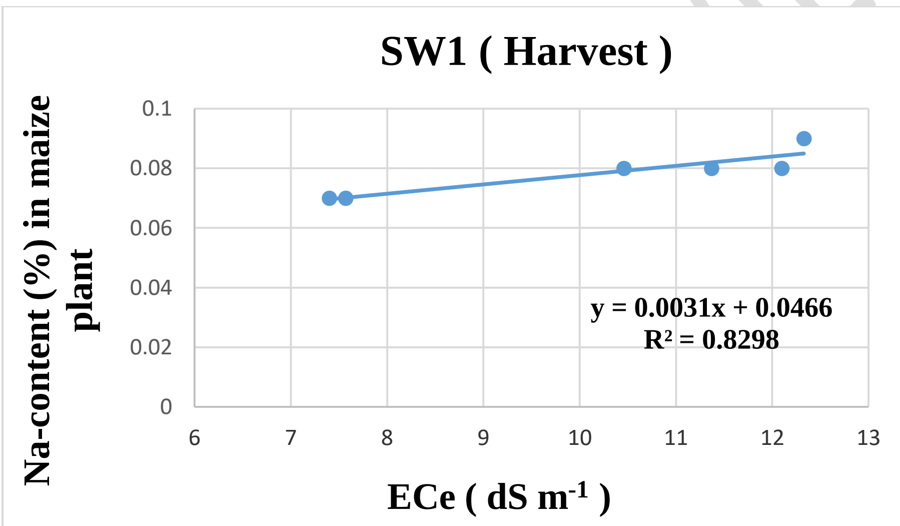


Fig 5. Correlation between ECe at harvest and K or Na content in maize plant in saline treatments (SW1)

Potassium content in maize increased with increasing in K^+/Na^+ ratio in maize under saline environment (SW1) whereas, Na content decreases. A fair positive relationship exists between K^+/Na^+ ratio and K^+ content in plant (R^2 value of 0.79). On the other hand, the K^+/Na^+ ratio in plant negatively correlated with Na content with R^2 value of 0.89 (Fig.6),indicating that Na content decreased with increasing the K^+/Na^+ ratio.

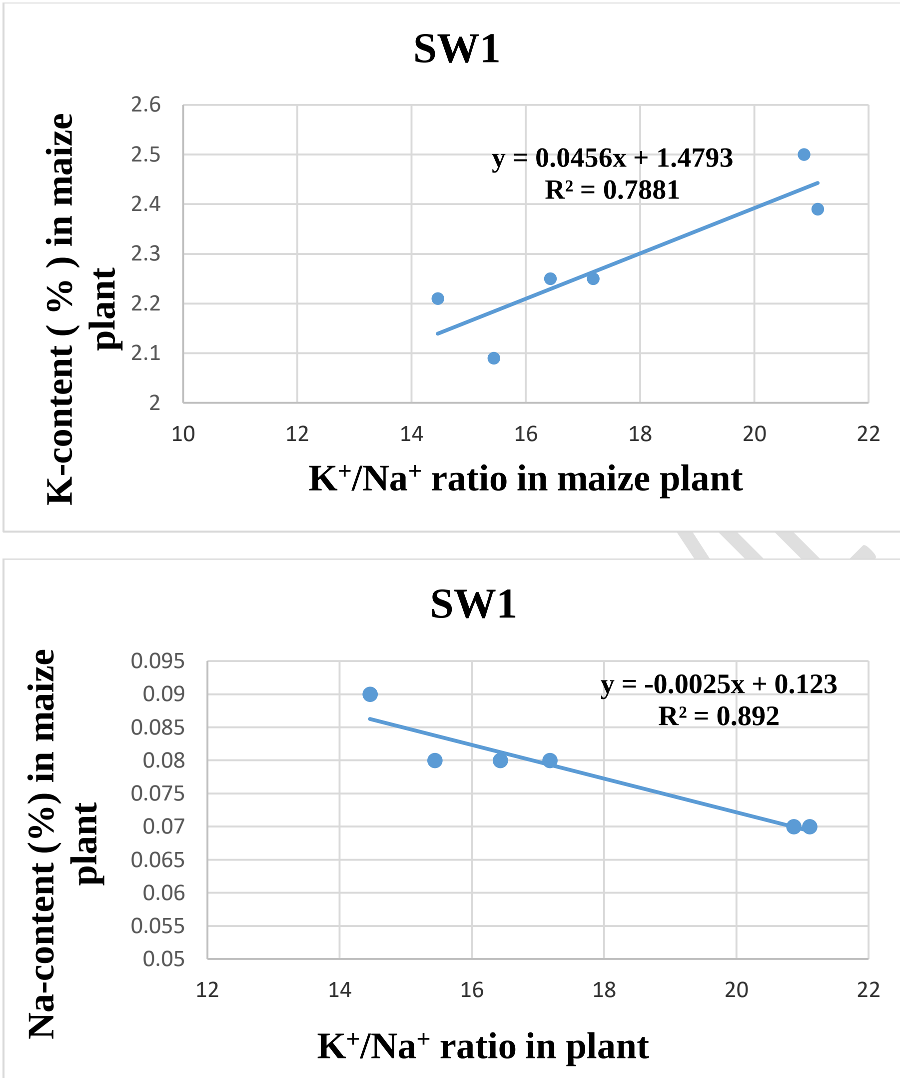
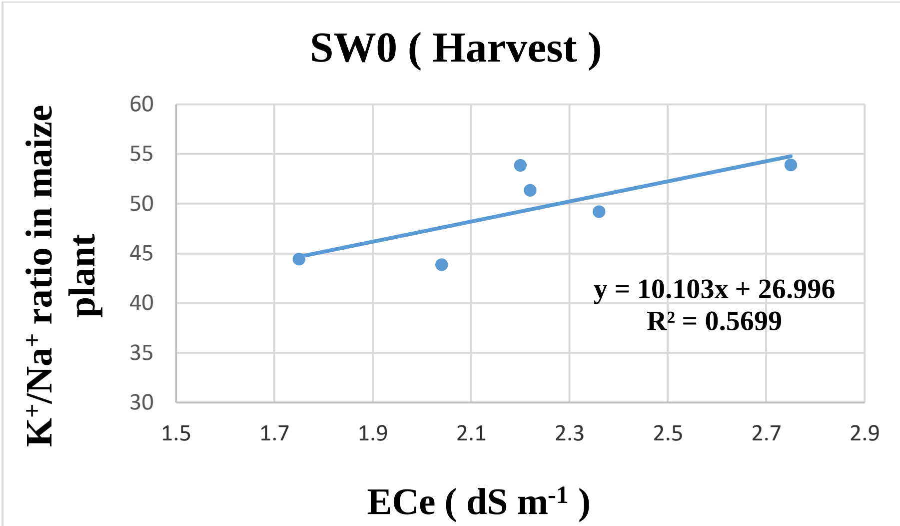


Fig 6. Correlation between K^+/Na^+ ratio in plant and K or Na content in maize plant in saline treatments (SW1)

The K^+/Na^+ ratio in maize increased with increasing the ECe (at harvest) with R^2 value of 0.57 in saline control treatments (SW0) whereas, the ratio decreases with increasing ECe in saline treatments (R^2=0.95) (Fig.7).This showed that continuous addition of saline water to maize crop decreased the K absorption in plant leading to lower K^+/Na^+ ratio.

Several studies showed that they can be elevated by addition of K^+ to the substrate. Sodium concentration impairs K^+ nutrition and has adverse effect on uptake and translocation of K^+ by plants grown under saline environment. Therefore, maintenance of K^+/Na^+ ratio is an important guide under salt stress environment [28] and [23].



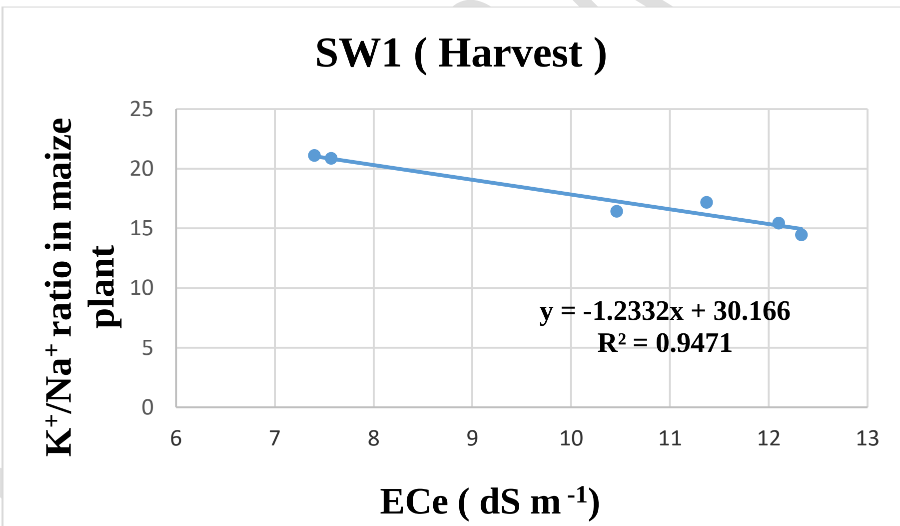


Fig 7. Correlation between ECe at harvest and K^+/Na^+ ratio of maize plant in saline control (SW0) and saline (SW1) treatments

The absorption of K^+ in maize is influenced by K^+/Na^+ ratio in soil. Accumulation of K increased with increasing the K^+/Na^+ ratio in soil. The results of this study showed that a positive relationship exists between the K^+/Na^+ ratio in plant and K^+/Na^+ ratio in soil (Fig.8).

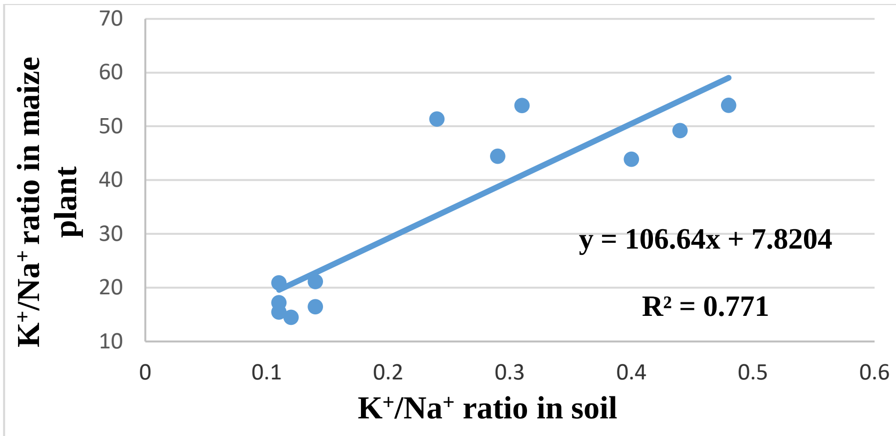


Fig 8. Correlation ship between K^+/ Na^+ ratio in soil and plan

4. CONCLUSION

Based on the results cited above, it can be concluded that continuous application of saline water (8 dS m^{-1}) significantly increased soil ECe above the critical limit (4 dS m^{-1}). Application of K @120 kg ha^{-1} significantly reduced the toxic effect of Na. Use of KCl fertilizer resulted in higher salinity than K_2SO_4 .Application of higher dose of K (@120 kg ha^{-1}) significantly decreased the deleterious effect of Na by increasing the biomass yield, accumulation and uptake of K. The Na accumulation and uptake decreased significantly. K^+/Na^+ ratio in plant is considered as a good indicator to evaluate plant response to K application in saline stress environment. K^+/Na^+ ratio in plant fairly correlated with biomass yield, accumulation and uptake of K and Na by maize. Application of K through K_2SO_4 was better than KCl in saline environment. It decreased soil ECe (6%). The biomass yield (3%), K uptake (3%) and K^+/Na^+ ratio in plant (2%) was higher in K_2SO_4 than KCl .

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