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RESEARCH PAPER

Comparison of different potassium application methods for maize (*Zea mays* L.) growth under salt-affected soils

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Key Massage: The present study evaluated the effect of potassium application methods in maize under salt-affected soils. Generally, subsurface application method gave the significant results especially for shoot fresh weight, shoot dry weight, relative water contents and K concentration in leaves.

Abstract: Potassium (K) is considered as an important nutrient element for maize growth because its availability varies from different K sources to different soil conditions. Therefore, in this study, a pot experiment was conducted to investigate the efficiency of different K fertilization methods in maize under salt-affected soils. The different application methods (mixing, surface, band placement, and fertigation) were compared by considering the different sources of K, e.g., potassium chloride (KCl) and potassium sulfate (K_2SO_4). For subsurface application method, the significant increase in shoot fresh weight (SFW) was recorded 272 g and 285 g for KCl, and K_2SO_4, respectively. For shoot dry weight (SDW), both sources of K either KCl (44.91 g) or K_2SO_4 (68 g) also showed significant results for subsurface application. On the contrary, for electrolyte leakage, the surface (43.34%) and mix (43.58%) application methods on an average showed the significant results compared with other methods. The relative water contents were higher in the subsurface application method. The K concentration trend showed the significantly decreased K^+ contents in the mix (19.95 mg) and significantly increased the results in the subsurface (25.25 mg) method than fertigation (21.90 mg) and surface (20-83 mg) from the application of KCl. However, for K^+ concentration, significant and best results were found in subsurface (27.15 mg) for K_2SO_4 source of K compared with the surface, mixing, and fertigation methods. The K fertigation and subsurface placement in pots registered maximum K recovery and the agronomic efficiency of maize. Hence the current research recognizes which application method and source of K could provide the maximum benefits to maize crop, and results under the saline-sodic soil are very useful and beneficial for maize production for the future studies. © 2021 Department of Agricultural Sciences, AIOU

Keywords: KCl, K_2SO_4, Maize, Potassium application methods, Saline-sodic soils

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Introduction

Soil salinity, water scarcity, environmental pollution, and growing world population are considered significant threats to global food supply and security in the 21st century (Singh et al., 2020). The reduction in available agricultural land resources for crops cultivation is more worsening due to the increasing global population day by day and big challenges for researchers (Shrivastava & Kumar, 2015; Folberth et al., 2020). Crop production and cultivation have been severely affected by the various environmental stresses, e.g., extreme temperature, drought, radiations, flood, and soil salinity. The increased concentration of salts in the soil (salinity and sodicity) is critical for environmental stresses (Corwin, 2020; Kamran et al., 2020; Sindhu et al., 2020). It causes a significant reduction in cultivable land area and reduces crop production (Shahbaz & Ashraf, 2013; Nawaz et al., 2020). It has also been estimated that high salinity has afflicted the globally 20% of the cultivated land and 33% of the irrigated agricultural lands, especially in the world's arid and semi-arid regions (Singh et al., 2020). For these areas, evapotranspiration needs more water, but an insufficient amount of water unable to remove the salts from the soil profile (Minhas et al., 2020). The higher concentration of salts in the subsurface soil requires scientific knowledge for proper mineral nutrition to grow crops in such soil environment. Moreover, the use of osmotica element like potassium (K) makes the plants to combat against the water starvation due to higher salt in the root zone (Wakeel, 2013). The balanced nutrition in combination with K helps the crop plants to uptake water from soil solution (Shabala & Cuin, 2008; Wang et al., 2013). Nevertheless, soil salinity has a substantial effect on plant growth, development, and yield of many crops, including the cereal (rice, wheat, and maize), pulses crops (chickpea, peas, and pigeon pea), forage, and horticultural crops (Husain et al., 2019; Singh et al., 2020). However, maize is known relatively more susceptible crop to the higher salt concentration (Bänziger & Araus, 2007; AbdElgawad et al., 2016).

Globally, maize (*Zea mays* L.) ranks third most important crop after rice and wheat, grown for grains and forage purposes (Shahzad et al., 2017; Abbas et al., 2020). It is produced in both seasons because of its wider adaptability, i.e., spring and autumn on ~1.23 M ha area in Pakistan (Ahmad et al., 2018), and more than 50% of the total grain production of a country comes from the spring maize. The increased production percentage manifests the advancement in research activities of maize crop. Owing to changing climatic conditions, including biotic and abiotic stresses, cause the substantial losses in maize yield and quality (Li et al., 2019; Mesterházy et al., 2020). Among these, soil salinity is considered vital abiotic stress that causes yield loss in maize crop (Tahjib-Ul-Arif et al., 2018). It is a known as a dominant environmental factor that limits the crop production of major crops maize that is quite sensitive to salinity (Farooq et al., 2015; Zörb et al., 2019). Ions that contribute to salinity/sodicity into the soil include the Na^+, Mg^{2+}, Ca^{2+}, SO_4^{2-}, HCO^{3-}, Cl^-, and seldom, K^+ or $NO3^-$ (Singh et al., 2020). The main risk for agriculture sustainability is the increasing human population and arable land reduction (Shahbaz & Ashraf, 2013). In recent decades, the rate of arable land salinization has increased (Pitman & Läuchli, 2002). In the saline-sodic soils, poor soil physicochemical properties, nutritional toxicities and imbalance, and high osmotic stress result in poor crop establishment lead to a decline in crop productivity (Läuchli & Epstein, 1990; Xu et al., 2016). Plants that grow in saline soil cannot absorb the most crucial elements due to increased salt concentration and results in nutritional imbalance (Blaylock, 1994). Increased Na+ ions in the cell wall of plants lead to the osmotic blast and cell death (Munns, 2002). Additionally, toxicity in plants is also increased by aggregation of some other elements as sodium (Na), chloride (Cl) and boron in cytosol of cell (Munns, 2002; Shahbaz & Ashraf, 2013). Therefore, finding innovative technologies are matter of great interest to offset the salinity and improve the nutrients uptake in maize crop.

The selection of the certain type of fertilizers, especially the application techniques and methods, are the most important cultural practices that significantly affect increasing the yield (Drazic et al., 2020). The selection of fertilizer and its time of application in sufficient quantity is imperative (Latković et al., 2009; McDaniel et al., 2020). The investigators believe that through intensive cultivation, the demand for K will be increased. In maize cultivation, the farmers only pay great attention to nitrogen fertilizer, and P and K application levels are often very low, mostly lack of K fertilization (Goulding et al., 2008). K is considered the third most critical nutrient element afterward N and P for plant nourishment). K also plays a significant role in the development and growth of maize. It also supports plants to absorb nitrogen in the soil and increase corn grain yields (Hickman, 2002). Moreover, the availability or lack of certain elements can distress soil fertility. K is a soil-accumulating element that positively affects soil physical properties and crop production (Hamza & Anderson, 2003). Plants constantly absorb K in the form of K^+, and the most commonly used K sources are potassium chloride (KCl), potassium sulfate (K_2SO_4), potassium magnesium sulfate and potassium nitrate (Mengel et al., 1998). Placement of K fertilizers with or near the seed is usually the most effective and efficient fertilizer method. However, it has not been extensively studied using different application methods, i.e., surface, subsurface, mixing, and fertigation based on K source fertilizers, e.g. KCl and K_2SO_4. For that reason, there is an urgent need to consider the different potential application methods of fertilization in maize crop to evaluate their effect on plant biomass and nutrients uptake in maize crop.

Therefore, the present research was aimed at a comprehensive evaluation of fertilizer application methods by using various sources of K (e.g. KCl and K_2SO_4) for maize crop under saline-sodic soil conditions. However, to the best of our knowledge, this study, for the first time, investigated the effect of different application methods based KCl and K_2SO_4 fertilizers. The key objectives were (1) to examine the effect of different application methods on plant biomass and nutrients uptake; (2) to identify which source of K fertilizer and application method gives the significant results.

Materials and Methods

Description of experiment area and design

The present study was carried out in Bahauddin Zakariya University (BZU), Multan, Punjab, Pakistan (Fig. 1) during 2018. Geographically it is located 030° 11' 32" North at the latitude and 071° 27' 57" East at longitude. The soil samples were collected at a depth of 0-15 cm from the experimental farm of BZU, and the soil was saline-sodic. These were subjected air-dried, and sieved from 2mm sieve size. A representative sample of the soil was taken into the laboratory to study the basic different physicochemical characteristics of the soil, shown in Table 1. To check the growth of maize under saline-sodic soils, we used the four different application methods, i.e., mixing, surface, subsurface, and fertigation by using two potassium (K) source fertilizers, potassium chloride

(KCl), and potassium sulfate (K_2SO_4). We used three replications for each treatment (application method), and total 24 pots were prepared (Fig.1 b). Each pot was filled with 10 Kg of soil, and provided with basal dose of nitrogen (N) and phosphorous (P) at 100 mg kg^{-1} of soil. Finally, seeds of maize were grown in pots.

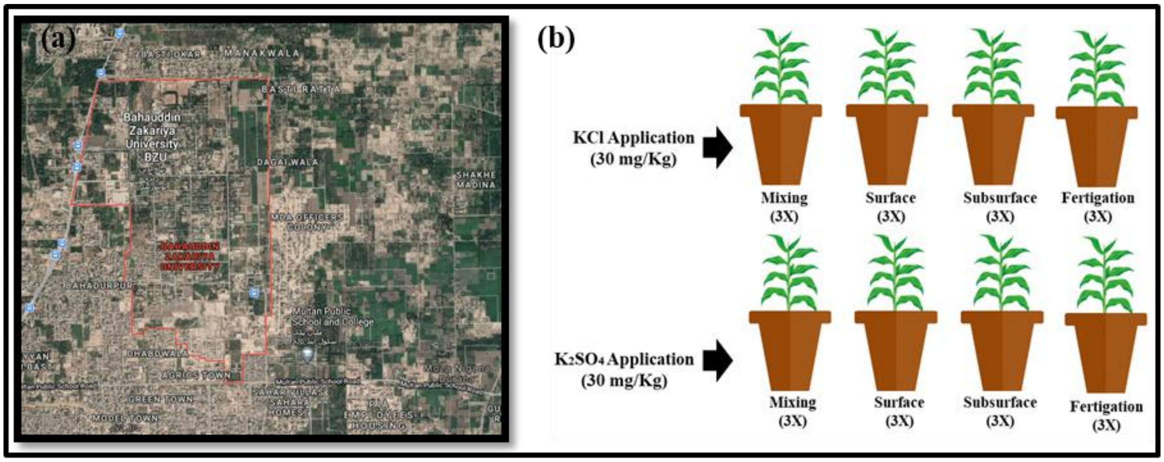

Fig. 1 (a) Map showing the study area (BZU, Multan, Pakistan) **(b)** application methods by using the potassium chloride and potassium sulfate.

Table 1 Basic soil physicochemical properties

Parameters	Sand	Silt	Clay	Calcium carbonate	Organic matter	EC	pH	Available potassium
Units	%	%	%	%	%	dS m-1		mg kg-1
Values	43	37	20	4.7	0.6	4.1	8.6	118

Analytical procedures

Plant harvest

After 45 days of sowing**,** the plants were harvested, and roots and shoots samples were used to determine root fresh weight (RFW), and shoot fresh weight (SFW), respectively. The roots and shoots samples were oven-dried to measure root dry weight (RDW), and shoot dry weight (SDW) (Muneer et al.,2020 a&b).

Determination of electrolyte leakage and relative water contents

We selected three leaves from each pot for electrolyte leakage and excised four discs from each leaf and kept into the test tubes with distilled water for 2 hours at the room temperature. We measured the first time electrical conductivity, and called it EC_1. After that, then it was autoclaved at 121^0C for 15 minutes, and test tubes were put in the desiccator for cooling and then measured the electrical conductivity again called EC_2 (Jungklang et al., 2017). Finally, we measured the electrolyte leakage by following equation:

$$\text{Electrolyte leakage} = \left(\text{EC2} - \frac{\text{EC1}}{\text{EC1}}\right) \times 10$$

For relative water contents (RWC) determination, fresh leaf samples were selected from each plant, and it was cut from the lower and upper side in such a way that we finally got 1cm leaf of the middle part, and fresh weight (FW) was measured. After that, we put the leaf samples into the test tubes with distilled for four hours, and hydrated leaves weight was recorded again, and called it (HW). Finally, the leaf samples were dried overnight and named it dry weight (DW). RWC was calculated by the following equation:

$$\text{Relative water contents} = \left[\frac{\text{FW} - \text{DW}}{\text{HW} - \text{DW}}\right] \times 100$$

Determination of potassium and sodium in leaf

To determine the K contents in the plants, 1g of dry leaf samples were taken from each treatment, and kept it in the 50 ml centrifuge tube with digestion mixer at room temperature for one day. After that, these centrifuge tubes were kept on hot plate for 1 hour to digest the leaves until the solution get colorless. After leaves digestion, final volume was made up to 50 ml by addition of distilled water. Finally, K contents in the leaves were calculated with flame photometer by following the K standards (Borkiewicz et al., 2020). We followed the same procedure for the determination of Na in plants by using the standards of sodium as we did above for K determination in plants.

Statistical analysis

One-way analysis of variance (ANOVA) was performed to analyze the effect of different application methods on different traits. We performed the least significant difference (LSD) test at α = 0.05 and Duncan's new multiple range test to analyze the difference between the treatments using the SPSS 25.0 software. OriginPro 2018 was used for the figures.

Results and Discussion

Maize (*Zea mays* L.) is one of the most important cereal crops of Pakistan. The deficiency of micronutrients and macronutrients has significantly affected the maize crop yield and growth performance, e.g. K deficiency. The availability of K from various sources, for example KCl and K_2SO_4, showed the synergetic effect on the plants growth with different application methods. Therefore, in this study, we used different application methods (surface, subsurface, mixing, fertigation) with varying sources of k to check their effect on the maize growth.

Effect of different application methods on plant biomass

Shoot and root fresh weight

We found the significant results for shoot fresh weight (SFW) in the subsurface application method compared with other methods, for both sources of K application, i.e. KCl (272g) and K_2SO_4 (285 g). The significant minimum values were recorded under the surface application method about 217g for KCl and 202g for K_2SO_4 (Fig. 2a). It could explain that subsurface application may decrease the K localization from the root zone and improve the K uptake efficiency. Besides, subsurface application regulates the provision of nutrients at high concentration around the growing that facilitate to uptake more easily (Shear & Moschler, 1969; Griffith et al., 1977; Ketcheson, 1980; Mackay et al., 1987; Karathanasis & Wells, 1990; Karlen et al., 1991). Thus, subsurface application significantly improves the yield by the provision of K at higher concentration, especially in such areas that have optimum to high K concentration (Belcher & Ragland, 1972).

For root fresh weight (RFW), the application methods of surface (77 g) and mix (70 g) showed the significant results for KCl source. The subsurface and fertigation application methods showed the significant best results for K_2SO_4 source (Fig. 2b). It has also been found that nutrients uptake efficiency is changed with application of various methods. We also found similar results that different application methods yield the different results. Moreover, we found that the subsurface application method for SFW and surface or mixing for RFW gave significant results under saline-sodic soils because different crop species exhibit an inclusive range of genetic variation for salt tolerance (Ashraf et al., 2002). Therefore, it would be quite helpful to find the genetic diversity that could help the breeders to produce the salt tolerant crop species (Ashraf et al., 1999). Additionally, the plant roots are susceptible to salinity and the first tissue that encounters the problem of salinity (Cramer et al., 1988). Hence, it suggests that our results under the saline-sodic soil are very useful and beneficial for maize production for the future studies.

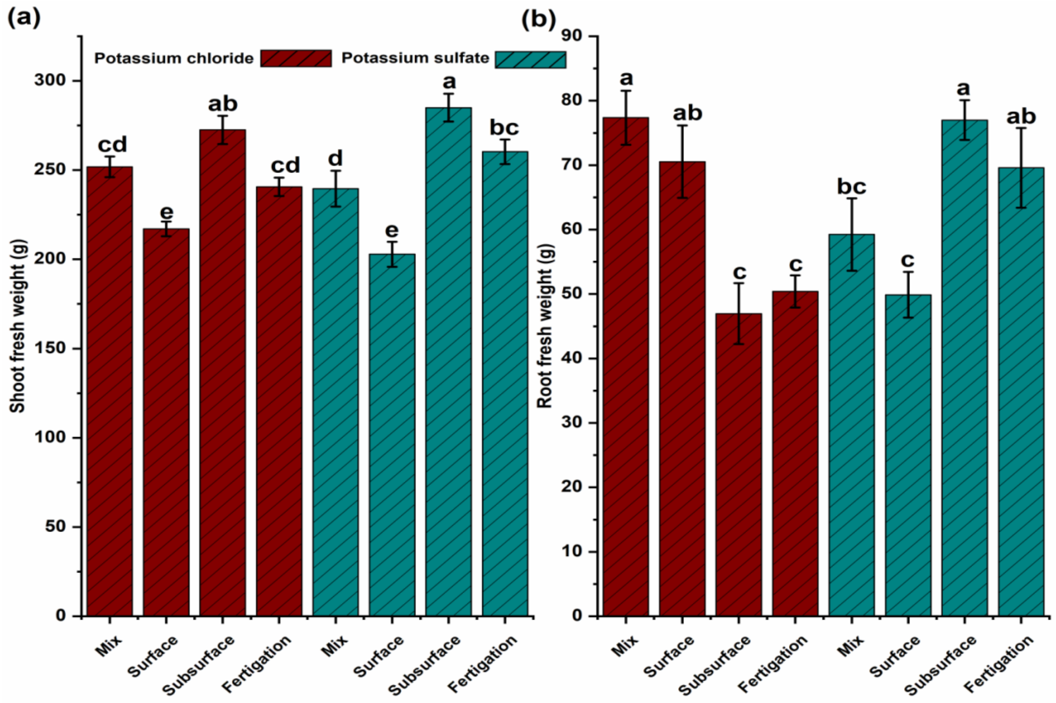

Fig. 2. Comparison of the effect of potassium application methods and sources on plant fresh weight. The different lowercase letters indicate a significant difference at $P < 0.05$ among different treatments (means ± standard deviation).

Shoot and root dry weight

For shoot dry weight (SDW), under both sources of K, the significant results were found under subsurface method, while fertigation application method showed promising results for K_2SO_4 source compared with mixing and surface methods (Fig. 3a). Root dry weight (RDW) showed the significant results under the surface and mix methods for KCl. Whereas, under K_2SO_4 source, the RDW was recorded significant for subsurface application and fertigation also showed promising results (Fig. 3b).

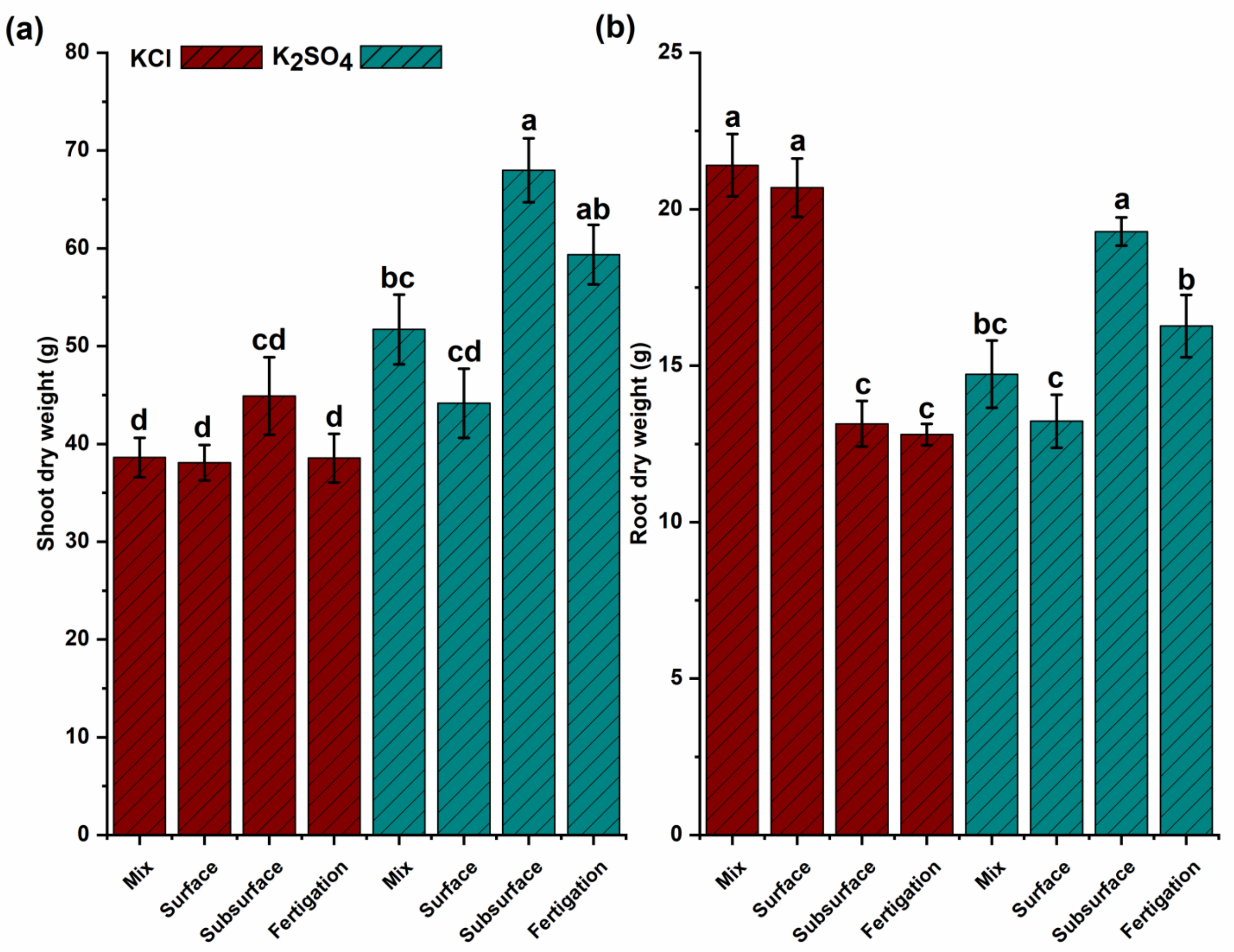

Fig. 3. Comparison of the effect of potassium application methods and sources on plant dry weight. The different lowercase letters indicate a significant difference at $P < 0.05$ among different treatments (means ± standard deviation).

It has been reported that K has a significant effect on improving the dry matter and plant growth. However, in this study, we found that subsurface and mixing application methods gave the considerable results for dry matter production. It could be owing to more K availability than sodium (Na) in the root zone by homogenized mixing of the applied fertilizer into the soil through application in the subsurface compared with surface and fertigation methods. The higher concentration of salts into the agricultural soils results in hard soil that affects the root growth and results in plant's water balance disturbance. On the other hand, high concentration of salts causes the plant tissue toxicity, inhibition of seed germination, effect on plant physiology, leaf anatomy, and photosynthesis (Parida & Das, 2005; Degl'Innocenti et al., 2009).

Electrolyte leakage and relative water contents

Electrolyte leakage and relative water contents (RWC) were significantly affected in maize by various application methods with different sources of K. RWC, and electrolyte leakage (membrane stability index) were significantly improved by KCl and K_2SO_4. For electrolyte leakage, subsurface and fertigation methods gave the significant results under KCl and K_2SO_4, respectively (Fig. 4a). On the contrary, for RWC, the subsurface method showed significant results for both sources of K (Fig. 4b).

RWC is described as an index representing the amount of water in the plant tissues, and as well demonstrating the plant's ability to conserve the water under the stress conditions (Abbaszadeh et al., 2008). Due to Na+ toxicity under the saline conditions, plant growth is reduced because of low RWC, poor antioxidant enzymatic activity, and increased reactive oxygen species (ROS) that result in poor chlorophyll contents and membrane stability under the salt stress. Moreover, it has also been studied that K fertilization has significant effects in improving the crop physiological characteristics and also increased the water use efficiency (WUE) of the crops (Marschner, 1995; Egilla et al., 2005). RWC as significantly higher for both sources, i.e. KCl and K_2SO_4 under application of subsurface compared with surface and fertigation (Fig. 4b). It could be explained on the basis that K uptake was effective, and the results in no K accumulation, and reduced the K losses. The fertigation application methods also showed the significant results for RWC for KCl and K_2SO_4. On the contrary to RWC, we found the best results for surface and mixing application methods for both sources of k compared with fertigation and subsurface application methods. It could be owing to the application of K on the surface reduces the salt rise and also maintains the soil moisture contents (Saeed & Ahmad, 2013).

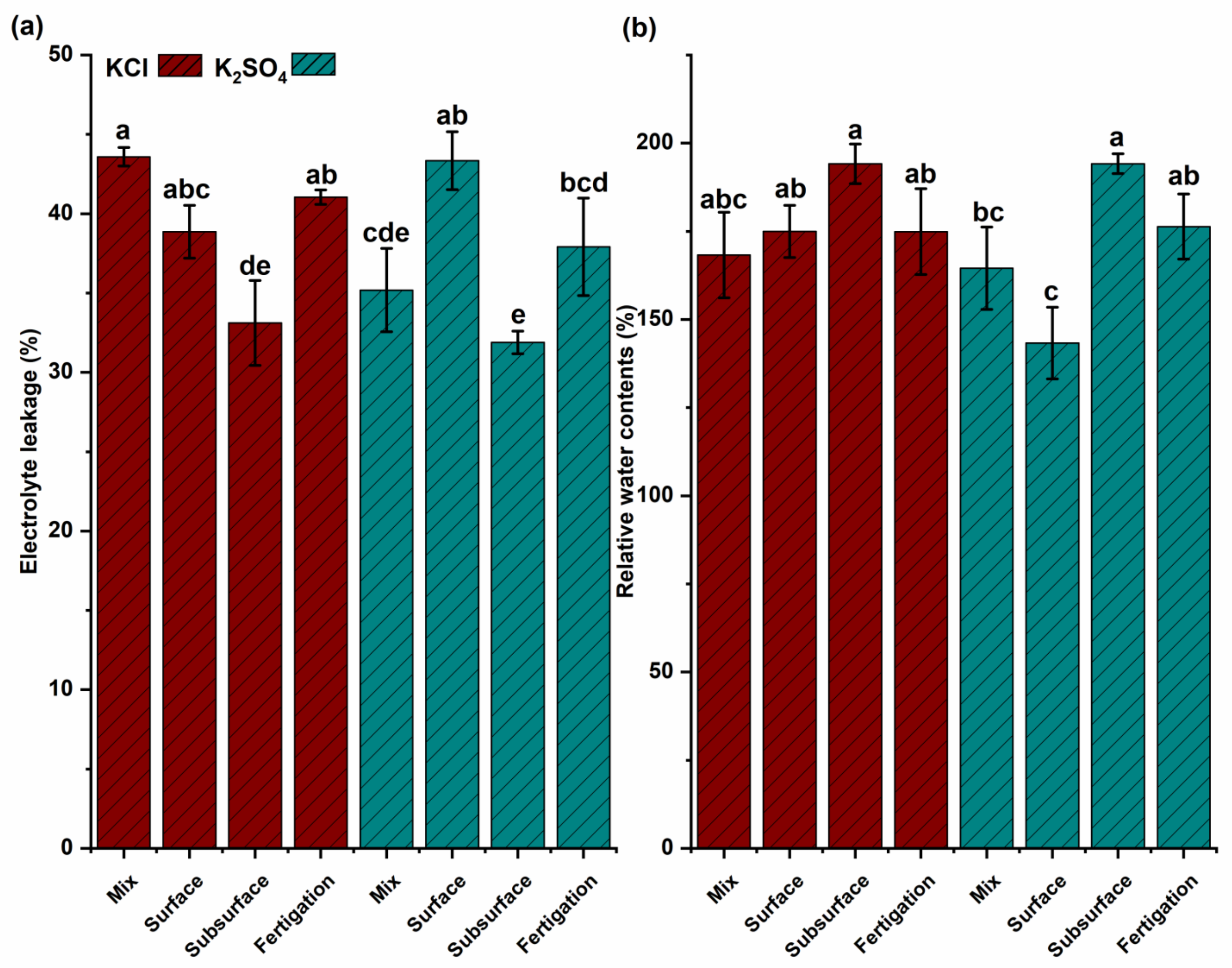

Fig. 4. The effect of K application methods and their sources (KCl and K_2SO_4) on electrolyte leakage and relative water contents. The different lowercase letters indicate a significant difference at $P < 0.05$ among different treatments (means ± standard deviation).

Leaf Na^+ and K^+ concentration (mg g^{-1})

For Na^+ and K^+ contents, significant differences were observed under saline-sodic soils in the maize plant under different application methods and sources of K. The minimum Na^+ concentration was noted under subsurface method, and the maximum value was recorded in the fertigation application method for KCl, while for K_2SO_4, the subsurface application method showed the best results compared with (Fig. 5a). For K^+ concentration in the leaves, the subsurface application method showed significant best results under KCl source of K (Fig. 5b).

To improve the plant growth and development under the saline-sodic soils, it is necessary to maximize the uptake of K^+, while minimizing the uptake of Na^+. The more uptake of Na^+ in the plants is mainly because of higher concentration of salts in the soil, and it is guided via non-selective the cations channels (White, 1999; Tester & Davenport, 2003). Na^+ competes with K^+ for uptake by the plant species and higher contents of K^+ absorption through the plant's root zone facilitates the K in such competition. The Na^+ and K^+ interaction has been explored by the various researchers (Maathuis & Amtmann, 1999; Demidchik et al., 2002; Cuin et al., 2003; Cuin & Shabala, 2005; Cuin et al., 2008). A comprehensive understanding of Na^+ and K^+ interaction and their communication in the plants have prime importance for in-depth exploration of their uptake and transportation mechanisms under the saline-sodic soils. Hence, the present was focused on providing a crucial overview of K interaction regarding different application methods and K sources that are extremely important for optimizing the growth and production by maintaining the optimum concentration of K in the plant tissues under the saline-sodic soils.

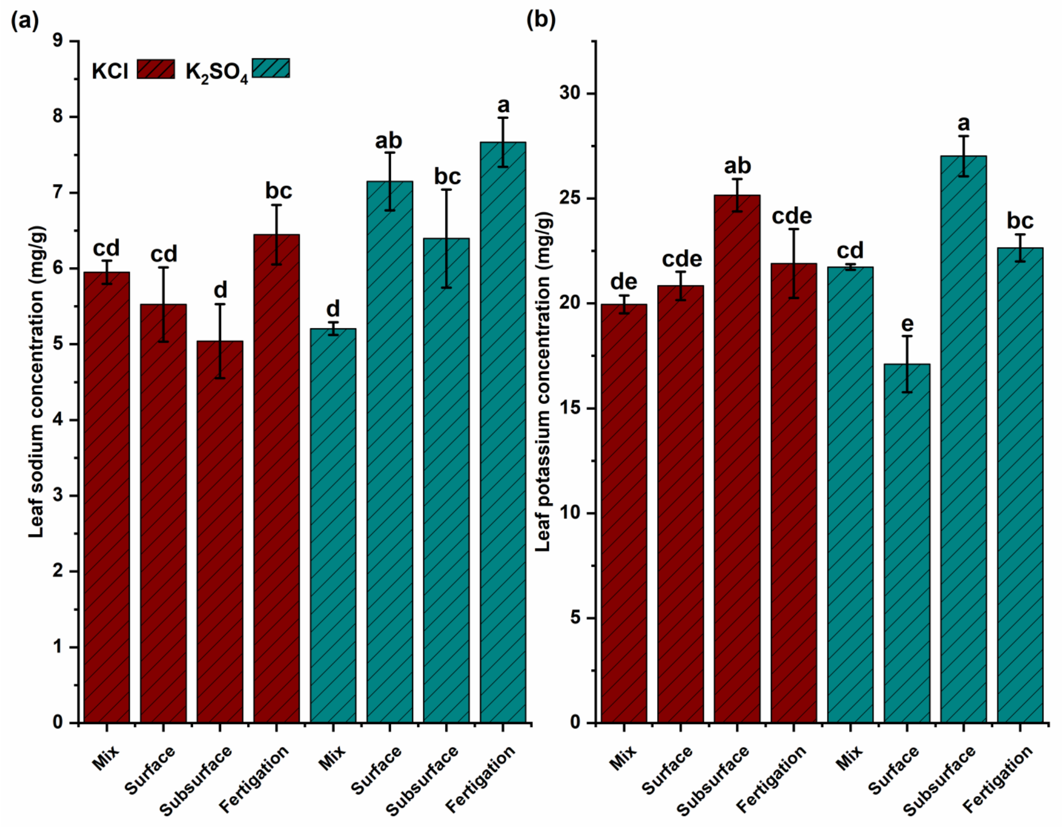

Fig. 5. The effect of K application methods and their sources (KCl and K_2SO_4) on leaf Na^+ and K^+ contents. Different lowercase letters indicate the significant differences at $P < 0.05$ among different treatments (means ± standard deviation).

Conclusion

This research trial was conducted on saline-sodic soil at the Agricultural Farm of Bahauddin Zakariya University, Multan, Punjab, Pakistan. In this experiment, the influence of K on maize crop growth was investigated under different K application methods and various sources like KCl and K_2SO_4 in saline-sodic soil. It was evident that SFW was significantly increased in the subsurface application for KCl as well as for K_2SO_4. Similarly, for RFW, the surface, and mix application methods gave the incredibly best results for both sources of K. Relative Water Content and electrolyte showed significant effects in maize with various sources and different application methods of K. In the case of electrolyte leakage, the mix, and surface application methods gave the significant and satisfactory results for KCl and K_2SO_4 respectively than subsurface and fertigation. While, for RWC, subsurface showed the significant results for both sources of K. The trend of K concentration showed the significantly decreased K^+ contents in the mix and significantly best results in subsurface method from the application of KCl than mixing, surface, and fertigation. However, K concentration decreased in surface method of application, and significant results were recorded for subsurface under K_2SO_4.-Hence, there is a robust requirement for proper K application to get the maximum benefits and the yield response. The key problems regarding the K application still unsolved. Hence the current research recognizes which application method and source of K could provide the maximum benefits to maize crop.

Authors Contribution: Z.U.N. and N.A.S. conducted and carried out this research study. S.A. and A.H. planned, designed, and supervised this research study. M.I.U, Z.U.Z, and B.A. helped in conducting the research project. Z.U.N., N.A.S., Z.A. and A.H. edited the manuscript. All the authors read and approved the manuscript to be published.

Conflict of Interest: The authors declare that they have no conflict of interest.

References

Abbas, G., Fatima, Z., Hussain, M., Hussain, S., Sarwar, N., Ahmed, M., & Ahmad, S. (2020). Nitrogen rate and hybrid selection matters productivity of maize–maize cropping system under irrigated arid environment of Southern Punjab, Pakistan. *International Journal of Plant Production, 14*(2), 309-320.

Abbaszadeh, B., Sharifi, A. E., Lebaschi, M. H., Naderi, H. B. M., & Moghadami, F. (2008). The effect of drought stress on proline contents, soluble sugars, chlorophyll and relative water contents of balm (*Melissa officinalis* L.), *Iranian Journal of Medicinal and Aromatic Plants, 4*(38), 504-513.

AbdElgawad, H., Zinta, G., Hegab, M. M., Pandey, R., Asard, H., & Abuelsoud, W. (2016). High salinity induces different oxidative stress and antioxidant responses in maize seedlings organs. *Frontiers in Plant Science, 7*, 276. https://doi.org/10.3389/fpls.2016.00276

Ahmad, S., Atique-ur-Rehman, E., Fatima, Z., Kan, M., & Ahmed, M. (2018). Agricultural land-use change of major field crops in Pakistan (1961–2014). *Science, Technology and Development, 37*(3), 113-121.

Ashraf, M. Y., Akhtar, K., Sarwar, G., & Ashraf, M. (2002). Evaluation of arid and semi-arid ecotypes of guar (Cyamopsis tetragonoloba L.) for salinity (NaCl) tolerance. *Journal of Arid Environments, 52*(4), 473-482.

Ashraf, M. Y., Wahed, R. A., Bhatti, A. S., Sarwar, G., & Aslam, Z. (1999). Salt tolerance potential in different Brassica species, Growth studies. *Halophyte Uses in Different Climates II (Hamdy A, Leith H, Todorovic M and Moscheuko M, eds.). Backhuys Pubs, Leiden*, 119-125.

Bänziger, M., & Araus, J.-L. (2007). Recent advances in breeding maize for drought and salinity stress tolerance. *Advances in molecular breeding toward drought and salt tolerant crops*, Springer, Dordrecht 587-601. https://doi.org/10.1007/978-1-4020-5578-2_23

Belcher, C. R., & Ragland, J. (1972). Phosphorus absorption by sod-planted corn (Zea mays L.) from surface-applied phosphorus. *Agronomy Journal, 64*(6), 754-756.

Blaylock, A. D. (1994). *Soil salinity, salt tolerance, and growth potential of horticultural and landscape plants*: University of Wyoming, Cooperative Extension Service, Department of Plant.

Borkiewicz, L., Polkowska-Kowalczyk, L., Cieśla, J., Sowiński, P., Jończyk, M., Rymaszewski, W., Szymańska, K. P., Jaźwiec, R., Muszyńska, G., & Szczegielniak. J. (2020). Expression of maize calcium-dependent protein kinase (ZmCPK11) improves salt tolerance in transgenic Arabidopsis plants by regulating sodium and potassium homeostasis and stabilizing photosystem II. *Physiologia plantarum, 168*(1), 38-57.

Corwin, D. L. (2020). Climate change impacts on soil salinity in agricultural areas. *European Journal of Soil Science*, *72*(2), 842-862.

Cramer, G. R., Epstein, E., & Läuchli, A. (1988). Kinetics of root elongation of maize in response to short-term exposure to NaCl and elevated calcium concentration. *Journal of Experimental Botany*, *39*(11), 1513-1522.

Cuin, T. A., Betts, S. A., Chalmandrier, R., & Shabala, S. (2008). A root's ability to retain K+ correlates with salt tolerance in wheat. *Journal of Experimental Botany, 59*(10), 2697-2706.

Cuin, T. A., Miller, A. J., Laurie, S. A., & Leigh, R. A. (2003). Potassium activities in cell compartments of salt-grown barley leaves. *Journal of Experimental Botany, 54*(383), 657-661.

Cuin, T. A., & Shabala, S. (2005). Exogenously supplied compatible solutes rapidly ameliorate NaCl-induced potassium efflux from barley roots. *Plant and Cell Physiology*, *46*(12), 1924-1933.

Degl’Innocenti, E., Hafsi, C., Guidi, L., & Navari-Izzo, F. (2009). The effect of salinity on photosynthetic activity in potassium-deficient barley species. *Journal of Plant Physiology, 166*(18), 1968-1981.

Demidchik, V., Davenport, R. J., & Tester, M. (2002). Nonselective cation channels in plants. *Annual Review of Plant Biology, 53*(1), 67-107.

Drazic, M., Gligorevic, K., Pajic, M., Zlatanovic, I., Spalevic, V., Sestras, P., Skataric, G., Dudic, B. (2020). The Influence of the Application Technique and Amount of Liquid Starter Fertilizer on Corn Yield. *Agriculture, 10*(8),347. doi: 10.3390/agriculture10080347

Egilla, J., Davies, F., & Boutton, T. (2005). Drought stress influences leaf water content, photosynthesis, and water-use efficiency of Hibiscus rosa-sinensis at three potassium concentrations. *Photosynthetica, 43*(1), 135-140.

Farooq, M., Hussain, M., Wakeel, A., & Siddique, K. H. (2015). Salt stress in maize: effects, resistance mechanisms, and management. A review. *Agronomy for Sustainable Development, 35*(2), 461-481.

Folberth, C., Khabarov, N., Balkovič, J., Skalský, R., Visconti, P., Ciais, P., Janssens, I., Peñuelas, J., Obersteiner, M. (2020). The global cropland-sparing potential of high-yield farming. *Nature Sustainability*, *3*(4), 281-289.

Goulding, K., Jarvis, S., & Whitmore, A. (2008). Optimizing nutrient management for farm systems. *Philosophical Transactions of the Royal Society of London B: Biological Sciences, 363*(1491), 667-680.

Griffith, D. R., Mannering, J. V., & Moldenhauer, W. C. (1977). Conservation tillage in eastern corn belt. *Journal of Soil and Water Conservation, 32*(1), 20-28.

Hamza, M., & Anderson, W. (2003). Responses of soil properties and grain yields to deep ripping and gypsum application in a compacted loamy sand soil contrasted with a sandy clay loam soil in Western Australia. *Australian Journal of Agricultural Research, 54*(3), 273-282.

Hickman, M. V. (2002). Long term tillage and crop rotation effects on soil chemical and mineral properties. *Journal of Plant Nutrition*, *25*, 1457-1470.

Husain, A., Muneer, M. A., Fan, W., Gao-Fei, Y., Shi-Zhou, S., Feng, W., Gao-Fei, Y., Shi-Zhou, S., Yuan, L., Ke-Qiang, Z. (2019). Application of Optimum N Through Different Fertilizers Alleviate NH4+-N, NO3–N and Total Nitrogen Losses in the Surface Runoff and Leached Water and Improve Nitrogen Use Efficiency of Rice Crop in Erhai Lake Basin, China. *Communications in Soil Science and Plant Analysis*, *50*(6), 716-738.

Jungklang, J., Saengnil, K., & Uthaibutra, J. (2017). Effects of water-deficit stress and paclobutrazol on growth, relative water content, electrolyte leakage, proline content and some antioxidant changes in Curcuma alismatifolia Gagnep. cv. Chiang Mai Pink. *Saudi Journal of Biological Sciences, 24*(7), 1505-1512.

Kamran, M., Parveen, A., Ahmar, S., Malik, Z., Hussain, S., Chattha, M. S., Saleem, M.H., Adil, M., Heidari, P., Chen, J.-T. (2020). An overview of hazardous impacts of soil salinity in crops, tolerance mechanisms, and amelioration through selenium supplementation. *International Journal of Molecular Sciences, 21*(1), 148.

Karathanasis, A., & Wells, K. (1990). Conservation tillage effects on the potassium status of some Kentucky soils. *Soil Science Society of America Journal, 54*(3), 800-806.

Karlen, D. L., Berry, E. C., Colvin, T. S., & Kanwar, R. S. (1991). Twelve-year tillage and crop rotation effects on yields and soil chemical properties in northeast Iowa 1. *Communications in Soil Science & Plant Analysis, 22*(19-20), 1985-2003.

Ketcheson, J. (1980). Effect of tillage on fertilizer requirements for corn on a silt loam soil. *Agronomy Journal, 72*(3), 540-542.

Latković, D., Jaćimović, G., Marinković, B., Malešević, M., & Crnobarac, J. (2009). Fertilizing system in function of corn yield in monoculture and two crop field. *Letopis naučnih radova Poljoprivrednog fakulteta, 33*(1), 77-84.

Läuchli, A., & Epstein, E. (1990). Plant responses to saline and sodic conditions. *Agricultural Salinity Assessment and Management, 71*, 113-137.

Li, Y., Guan, K., Schnitkey, G. D., DeLucia, E., & Peng, B. (2019). Excessive rainfall leads to maize yield loss of a comparable magnitude to extreme drought in the United States. *Global Change Biology*, *25*(7), 2325-2337.

Maathuis, F. J., & Amtmann, A. (1999). K+ nutrition and Na+ toxicity: the basis of cellular K+/Na+ ratios. *Annals of Botany, 84*(2), 123-133.

Mackay, A., Kladivko, E., Barber, S., & Griffith, D. (1987). Phosphorus and potassium uptake by corn in conservation tillage systems. *Soil Science Society of America Journal, 51*(4), 970-974.

Marschner, H. (1995). The soil root interface (rhizosphere) in relation to mineral nutrition. *Mineral nutrition of higher plants*. Balaban Publishers, Philadelphia/Rehovot, *Symbiosis*, *9*(1), 19-27.

McDaniel, M. D., Walters, D., Bundy, L., Li, X., Drijber, R., Sawyer, J. E., Castellano, M.J., Laboski, C., Scharf, P.C., Horwath, W. (2020). Combination of biological and chemical soil tests best predict maize nitrogen response. *Agronomy Journal, 112*(2), 1263-1278.

Mengel, D., Hawkins, S., & Walker, P. (1988). Phosphorus and potassium placement for no-till and spring plowed corn. *Journal of Fertilizer Issues, 5*(1), 31-36.

Mengel, K., & Dou, H. (1998). Release of potassium from the silt and sand fraction of loess-derived soils. *Soil Science, 163*(10), 805-813.

Mesterházy, Á., Oláh, J., & Popp, J. (2020). Losses in the grain supply chain: Causes and solutions. *Sustainability, 12*(6), 2342. https://doi.org/10.3390/su12062342.

Minhas, P., Ramos, T. B., Ben-Gal, A., & Pereira, L. S. (2020). Coping with salinity in irrigated agriculture: Crop evapotranspiration and water management issues. *Agricultural Water Management, 227*, 105832.

Mmbaga, G. W., Mtei, K. M., & Ndakidemi, P. A. (2014). Extrapolations on the use of rhizobium inoculants supplemented with phosphorus (P) and potassium (K) on growth and nutrition of legumes. *Agricultural Sciences, 5*(12), 1207.

Muneer, M. A., Wang, P., Lin, C., & Ji, B. (2020a). Potential role of common mycorrhizal networks in improving plant growth and soil physicochemical properties under varying nitrogen levels in a grassland ecosystem. *Global Ecology and Conservation, 24*, e01352.

Muneer, M. A., Wang, P., Zhang, J., Li, Y., Munir, M. Z., & Ji, B. (2020b). Formation of common mycorrhizal networks significantly affect plant biomass and soil properties of the neighboring plants under various nitrogen levels. *Microorganisms, 8*(2), 230. doi: 10.3390/microorganisms8020230.

Munns, R. (2002). Comparative physiology of salt and water stress. *Plant, Cell & Environment, 25*(2), 239-250.

Nawaz, A., Shahbaz, M., Asadullah, A. I., Marghoob, M. U., Imtiaz, M., & Mubeen, F. (2020). Potential of salt tolerant PGPR in growth and yield augmentation of wheat (Triticum aestivum L.) under saline conditions. *Frontiers in Microbiology, 11*. doi: 10.3389/fmicb.2020.02019

Parida, A. K., & Das, A. B. (2005). Salt tolerance and salinity effects on plants: a review. *Ecotoxicology and Environmental Safety*, *60*(3), 324-349.

Pitman, M. G., & Läuchli, A. (2002). Global impact of salinity and agricultural ecosystems *Salinity: environment-plants-molecules* (pp. 3-20): Springer.

Saeed, R., & Ahmad, R. (2013). Effect of partial decomposed organic mulch in reducing salinity in rhizosphere to improve overall plant growth. *FUUAST Journal of Biology*, *3*(1), 79-86.

Shabala, S., & Cuin, T. A. (2008). Potassium transport and plant salt tolerance. *Physiologia Plantarum*, *133*(4), 651-669.

Shahbaz, M., & Ashraf, M. (2013). Improving salinity tolerance in cereals. *Critical Reviews in Plant Sciences*, *32*(4), 237-249.

Shahzad, A. N., Fatima, A., Sarwar, N., Bashir, S., Rizwan, M., Qayyum, M. F., Qureshi, M.K., Javaid, M.H., & Ahmad, S. (2017). Foliar Application of Potassium Sulfate Partially Alleviates Pre-anthesis Drought-induced Kernel Abortion in Maize. *International Journal of Agriculture & Biology*, *19*(3), 495-501.

Shear, G., & Moschler, W. (1969). Continuous corn by the no-tillage and conventional tillage methods: A six-year comparison. *Agronomy Journal*, *61*(4), 524-526.

Shrivastava, P., & Kumar, R. (2015). Soil salinity: A serious environmental issue and plant growth promoting bacteria as one of the tools for its alleviation. *Saudi Journal of Biological Sciences*, *22*(2), 123-131.

Sindhu, S., Dahiya, A., Gera, R., & Sindhu, S. S. (2020). Mitigation of abiotic stress in legume-nodulating Rhizobia for sustainable crop production. *Agricultural Research*, *9*, 444–459. https://doi.org/10.1007/s40003-020-00474-3

Singh, S., Singh, U. B., Trivedi, M., Sahu, P. K., Paul, S., Paul, D., & Saxena, A. K. (2020). Seed biopriming with salt-tolerant endophytic Pseudomonas geniculata-modulated biochemical responses provide ecological fitness in maize (Zea mays L.) grown in saline sodic soil. *International Journal of Environmental Research and Public Health*, *17*(1), 253. doi: 10.3390/ijerph17010253

Tahjib-Ul-Arif, M., Siddiqui, M. N., Sohag, A. A. M., Sakil, M. A., Rahman, M. M., Polash, M. A. S., Mostofa, M. G., & Tran, L.-S. P. (2018). Salicylic acid-mediated enhancement of photosynthesis attributes and antioxidant capacity contributes to yield improvement of maize plants under salt stress. *Journal of Plant Growth Regulation*, *37*(4), 1318-1330.

Tester, M., & Davenport, R. (2003). Na+ tolerance and Na+ transport in higher plants. *Annals of Botany*, *91*(5), 503-527.

Wakeel, A. (2013). Potassium–sodium interactions in soil and plant under saline sodic conditions. *Journal of Plant Nutrition and Soil Science*, *176*(3), 344-354.

Wang, M., Zheng, Q., Shen, Q., & Guo, S. (2013). The critical role of potassium in plant stress response. *International Journal of Molecular Sciences*, *14*(4), 7370-7390.

White, P. J. (1999). The molecular mechanism of sodium influx to root cells. *Trends in Plant Science*, *4*(7), 245-246.

Xu, G., Zhang, Y., Sun, J., & Shao, H. (2016). Negative interactive effects between biochar and phosphorus fertilization on phosphorus availability and plant yield in saline sodic soil. *Science of The Total Environment*, *568*, 910-915.

Zörb, C., Geilfus, C. M., & Dietz, K. J. (2019). Salinity and crop yield. *Plant Biology*, *21*, 31-38.