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RESEARCH PAPER

Maintenance of nutrients' concentration in sorghum (*Sorghum bicolor* L.) using brackish water through leaching fraction strategy

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Key Message: In this study brackish water irrigation impaired the nutrients concentration in sorghum due to negative impact of brackish water on soil properties. This negative impact of saline water irrigation has been minimized successfully using a leaching fraction technique.

ABSTRACT: Brackish ground water is a major factor of secondary salinity in Pakistan and practice of leaching fraction (LF) may help to keep the salt contents within the desired levels in the root zone. In this study, three types of water (canal water, water with EC = 2 dSm^{-1} and water with EC = 3 dSm^{-1}) was used as such and with leaching fraction of 10 and 20 %. Randomized complete block design (RCBD) was applied to make layout of the experiment. The experiment comprised of 9 treatments replicated four times; T1 = EC 0.23 dS m^{-1} (canal water), T2 = EC 2.0 water, T3 = EC 3.0 water, T4 = T1 + 10 % LF, T5 = T2 + 10 % LF, T6 = T3 + 10 % LF, T7 = T1 + 20 % LF, T8 = T2 + 20 % LF and T9 = T3 + 20 % LF. Sorghum was used as a test crop. Sorghum plants samples were collected from all plots for laboratory analysis. The maximum nitrogen, phosphorous, potassium, calcium and magnesium contents were noted in the sorghum plants that were harvested from the plots having T1 + 20 % LF (T7). However, the minimum nitrogen, phosphorous and magnesium contents were observed in the plots of treatment T3 getting water with EC 3.0 dSm^{-1}. However, T3 resulted the highest sodium contents (0.35%) in sorghum plants. In short, technique of leaching fraction proved to be useful to overcome the bad effects of saline water on the concentration/content of various elements present in sorghum plants.

Keywords: Brackish and canal water, Leaching fraction, Sorghum, Electrical conductivity

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INTRODUCTION

Water stress is a key component which has negative effect on crop productivity. In major agricultural countries various techniques are used to save water for increasing a sustainable crop production (Shahid et al., 2012). In low rainfall regions, water shortage is taken into consideration as the most forbidding factor because of low rainfall. Deficiency of water is the major issue of climatic regions having less rainfall. Consequently, water of poor quality has to be applied for growing crops in these areas (Minhas et al., 2007). In Pakistan, water shortage is noticeable stress which has adverse impact on the yield of various crops. The shortage of fresh water resource limits the crop production. So, improving the wise use of available resources of irrigation water is excellent way to enhance the water use efficiency in low rainfall areas (Pawlowski et al., 2009).

Sorghum (*Sorghum bicolor* L.) is locally recognized as "Jowar" in Pakistan and India and in Africa and China as "durra" and "kaffir corn" (Iqbal, 2015). Sorghum is extensively adopted as fodder and forage crop and has a primary function in cattle farming and has grown extensively throughout the summer season (Amandeep, 2012). Sorghum is one of the most important cereal crops widely grown for food, feed, fodder/forage, and fuel in the semi-arid tropics of Asia, Africa, Americas and Australia. The global sorghum areas remained static as the increased area in Africa compensated the area loss in Asia (Kumar et al., 2011). In developing countries, economic improvement is based upon processing of domestically grown sorghum to valuable products and beverages (Ratnavathi et al., 2016). For human intake, more than 35% of sorghum is grown, while remaining is used in the animal feed industry (Taylor & Belton, 2004). It is the cheapest source of energy and provides 50% of micronutrients and vitamins specifically in rural India where people do no longer have easy access to nutrient-wealthy foods (Kumar et al., 2011). It is the second cheapest source of power and micronutrients after millet. A majority of human beings in Africa and India rely on it to fulfill energy requirements and micronutrients (Vietmeyer, 1996). It is efficient in water use and is suitably perfect to semi-arid regions, whereas in saline environment it could be the most important economic plants especially when groundwater is a source of irrigation. Sorghum is an annual C_4 herb and produces high biomass feed consistent with unit of land (Parthasarathy et al., 2006).

Soil salinity is the main factor that restricts the productivity of agricultural crops affecting 5-10% of arable land, approximately 75 to 100 million hectares internationally (Munns, 2005). Globally, soil salinity and/or sodicity represent extra risks to sustainable agriculture. Keeping in view with a report by (Food and Agriculture Organization [FAO], 2000) that within the world greater than 8×10^8 ha lands are affected either with sodicity (4.34×10^8 ha) or salinity (3.97×10^8 ha), each of which constitute about 6% of the total area in the world. It is known that sorghum is relatively extra salt tolerant than that of corn or legumes, and has the capacity to be grown as replacement of corn in saline soils (Igartua et al., 1994). Gill et al. (2003) found that at 37 ºC, the seeds of sorghum showed reduction in the germination due to salt stress in saline soils. Many researches on sorghum had evaluated its tolerance at the germination stage. But it showed a little tolerance at later stages (Munns & Tester, 2008).

Sorghum is characterized by way of being moderately tolerant to salinity. However, salinity reduces its production and biomass (Almodares & Sharif, 2007). It was known that growth of sorghum was considerably reduced at all salinity stages from 50 to 150 mm. The growth of sorghum is significantly reduced by salinity and this reduction is greater at 250 mm than at a 125 mm NaCl (Ibrahim, 2004). Percentage of germinated seeds is reduced by the burden of salt pressure; although at maximum salt concentration the greatest decrease in germination occurred. However, the first choice to increase productivity in saline soils can be possible by improving high yield salinity tolerant sorghum genotypes (Igartua et al., 1994). Therefore, this research study aimed to investigate the impact of irrigation of saline water on contents of different nutrients/elements in sorghum plants and to evaluate the impact of leaching fraction to mitigate ill effects of irrigation of saline water on concentration of different nutrients/elements in sorghum plants.

MATERIALS AND METHODS

This research was done to examine the leaching fraction; an efficient soil management strategy for the use of brackish water on maintenance of nutrients' concentration of sorghum under field conditions during summer season, 2018. This study was performed in RCBD with 9 treatments that were replicated four times. The plot size was 3.5m × 3.5m. The treatments of the experiments were as under:

T1 = EC 0.23 dS m^{-1} (canal water); T2 = EC 2.0 water; T3 = EC 3.0 water; T4 = T1 + 10 % LF; T5 = T2 + 10 % LF
T6 = T3 + 10 % LF; T7 = T1 + 20 % LF; T8 = T2 + 20 % LF; T9 = T3 + 20 % LF

Before sowing, the seed beds were prepared by cultivating the field for 2-3 times with tractor-installed cultivar. Sorghum cultivar "Hegari" was sown @ 40 kg $acre^{-1}$. To keep plant to plant distance 25 cm thinning was done. The hoeing was done two times in the whole growing season to reduce weed-crop competition. The first irrigation was applied after 10 days of germination, while other irrigations were applied to the crop according to water requirement of the crop. Fertilizers like SOP (Sulphate of Potash), SSP (Single Super Phosphate) and Urea were the N, P, K sources used in the experiment. Maturity of sorghum was achieved in 75 days after sowing. Sorghum seeds were sown on March 15, 2018 and harvested on June 01, 2018. At maturity, the crop was harvested and plant samples were collected to analyze different parameters.

Data analysis

The analysis was made according to the methods written in Hand Book 60 of U.S Laboratory Staff 1969 (United States Salinity Laboratory Staff, 1969). Plant samples dried in oven were used for all determinations. Statistics 8.1 software was used to analyze the data.

Table 1 Laboratory analysis of soil used for experiments

Parameters	Unit	Value
pH_s (Soil reaction)	-	8.1
EC_e (Electrical conductivity)	dSm^{-1} (Deci siemen/meter)	0.89
SAR (Sodium adsorption ratio)	-	3.62
Soil textural class	-	Clay loam

RESULTS

Nitrogen (%) in sorghum plants

Nitrogen is a component of chlorophyll and therefore essential for photosynthesis. Data regarding the nitrogen (%) in sorghum is presented in Fig. 1 which indicated that canal and saline water significantly affected the nitrogen (%) in sorghum plant. The maximum nitrogen contents in the sorghum plants were obtained from the plots which were under the canal water irrigation followed by the plots irrigated with the water of EC 2.0 dSm^{-1} and EC 3.0 dSm^{-1}. Similar effect of leaching fraction was observed within the treatments. Nitrogen contents in the sorghum plants of the plots having 20% leaching fraction was noted to be higher than those of having 10 and 0% leaching fraction (Fig. 1). The treatment T_7 demonstrated dominance over all the other treatments because of canal water with 20% leaching fraction. As the EC of irrigation water increased and the leaching fraction decreased, nitrogen contents in the sorghum plants were reduced. The minimum nitrogen was observed in the plots of treatment T_3 which were irrigated with water of EC 3.0 dSm^{-1} followed by T_6 (T3 + 10 % LF) and T_9 (T3 + 20 % LF), respectively (Fig. 1.). The treatments, T_6 and T_9 were statistically similar with each other in term of nitrogen contents in the sorghum plants.

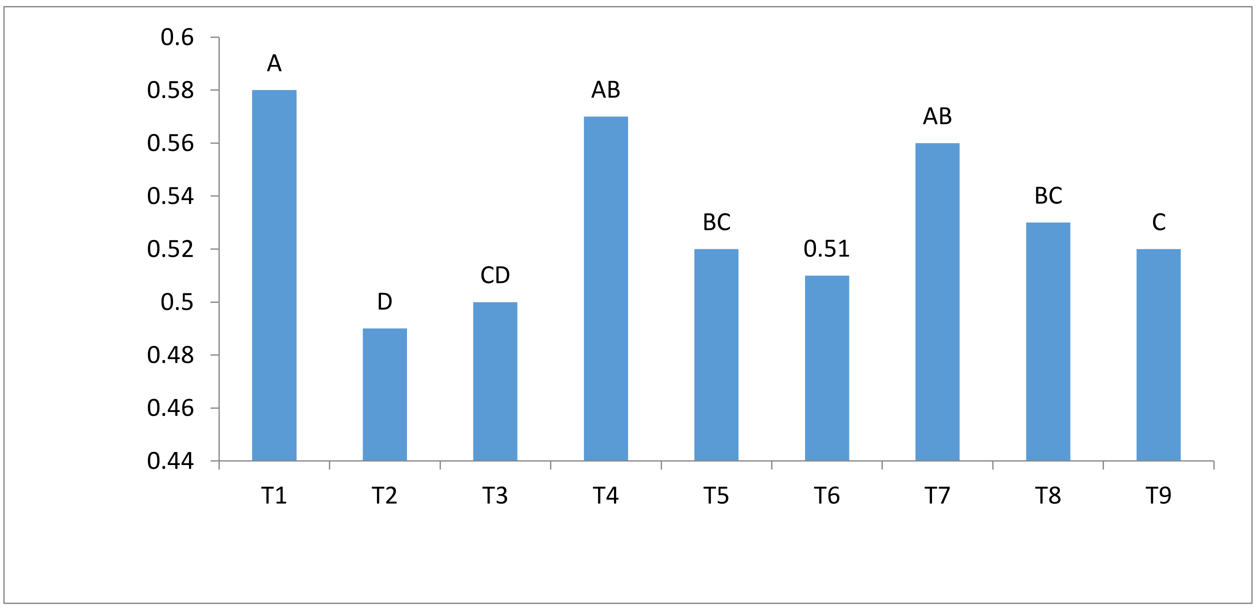

Fig. 1 Impact of canal and saline water with and without leaching fraction on N (%) in sorghum plants

Phosphorous (%) in sorghum plants

Phosphorous is one of the most essential nutrients for plants (Sarwar, 2005). It plays an important role in photosynthesis, energy storage, respiration, cell enlargement, cell division and various other processes in plants. Data showed that the use of canal and saline water with and without leaching fraction affected phosphorous (%) in sorghum significantly. Among all the treatments, maximum phosphorous (0.18%) in sorghum was gained where irrigation with canal water was applied with 20% leaching fraction (T_7). The treatments, T_4 (T1 + 10 % LF) and T_1 (EC 0.23 dSm^{-1}) produced similar fresh weight of sorghum 0.17% (Fig. 2). The T_1 and T_4 were statistically non-significant with each other for phosphorous (%) in sorghum. However, T_8 (T2 + 20 % LF) recorded 0.15% which was followed by T_2 (EC 2.0 dSm^{-1} water) and T_5 (T2 + 10 % LF) that produced 0.14% nitrogen in sorghum (Fig. 2). The minimum phosphorous (0.12%) in sorghum was noted for T_3 (EC 3.0 dSm^{-1} water) which was followed by T_6 (T3 + 10 % LF) that recorded 0.13% nitrogen in sorghum plants.

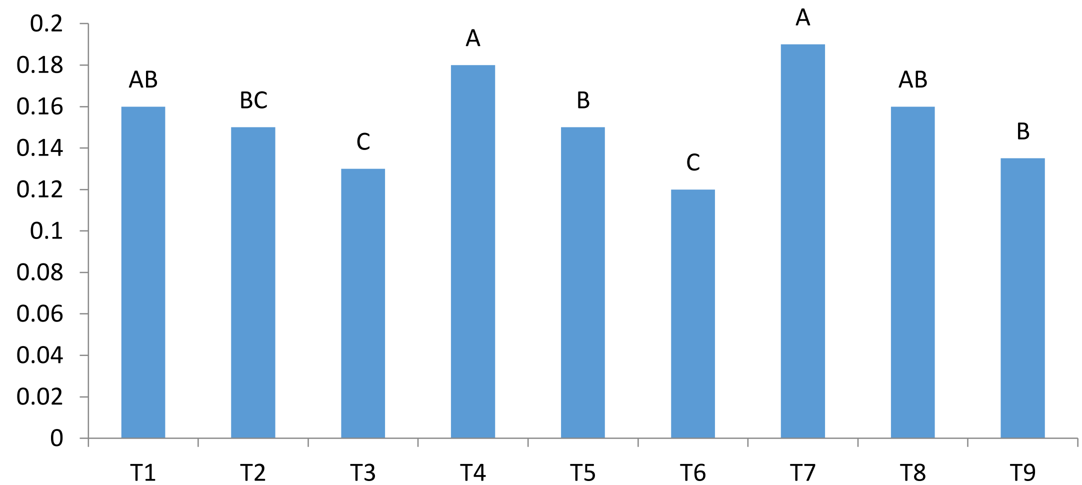

Fig. 2 Impact of canal and saline water with and without leaching fraction on P (%) in sorghum plants

Potassium (%) in sorghum plants

In plants, potassium is important for water uptake and for synthesizing plant sugars for use as food (Sarwar, 2005). Potassium concentration in sorghum plant showed substantial response to canal and saline water. Data about potassium (%) in sorghum plant is presented in Fig. 3. That reveals that saline water had significant effect on potassium (%) in sorghum. The maximum potassium contents of the sorghum plants were obtained from the plots which were under the canal water irrigation followed by the plots getting water of EC 2.0 dSm^{-1} and 3.0 dSm^{-1} (Fig. 3). Similar effect of leaching fraction was observed within the treatments and sub treatments. Potassium contents of the plots having 20% leaching fraction was noted to be higher than those of having 10 and 0% leaching fraction. The treatment T_7 demonstrated dominance over all the other treatments because of canal water with 20% leaching fraction. As the EC of irrigation water increased and the leaching fraction decreased potassium contents were reduced. The minimum potassium contents were observed in the plots of treatment T_3 which were irrigated with the water of EC 3.0 dSm^{-1} followed by T_6 (T3 + 10% LF) and T_9 (T3 + 20 % LF), respectively (Fig. 3.).

Calcium (%) in sorghum plants

Calcium is responsible for holding together the cell walls of plants (Sarwar, 2005). When calcium is deficient, new tissue such as root tips, young leaves, and shoot tips often exhibit distorted growth from improper cell wall formation. Data regarding calcium (%) in sorghum is presented in Fig. 4 which reveals that by the use of canal and saline water, calcium (%) in sorghum plant responded significantly. The maximum Ca contents in the sorghum plants were obtained from the plots which were under the canal water irrigation followed by the plots irrigated with water of EC 2.0 dSm^{-1} and 3.0 dSm^{-1} (Fig. 4). Similar effect of leaching fraction was observed within the treatments. Ca contents in sorghum plants of the plots having 20% leaching fraction was noted to be higher than those of having 10 and 0% leaching fraction. The treatment T_7 demonstrated dominance over all the other treatments because of canal water with 20% leaching fraction. As the EC of irrigation water increased and the leaching fraction decreased Ca contents were reduced. The minimum Ca contents were observed in the plots of treatment T_3 which were irrigated with the water of EC 3.0 dSm^{-1} followed by T_6 (T3 + 10 % LF) and T_9 (T3 + 20 % LF), respectively (Fig. 4.). The treatments, T_6 and T_9 were statistically similar with each other in term of Ca contents in sorghum plants.

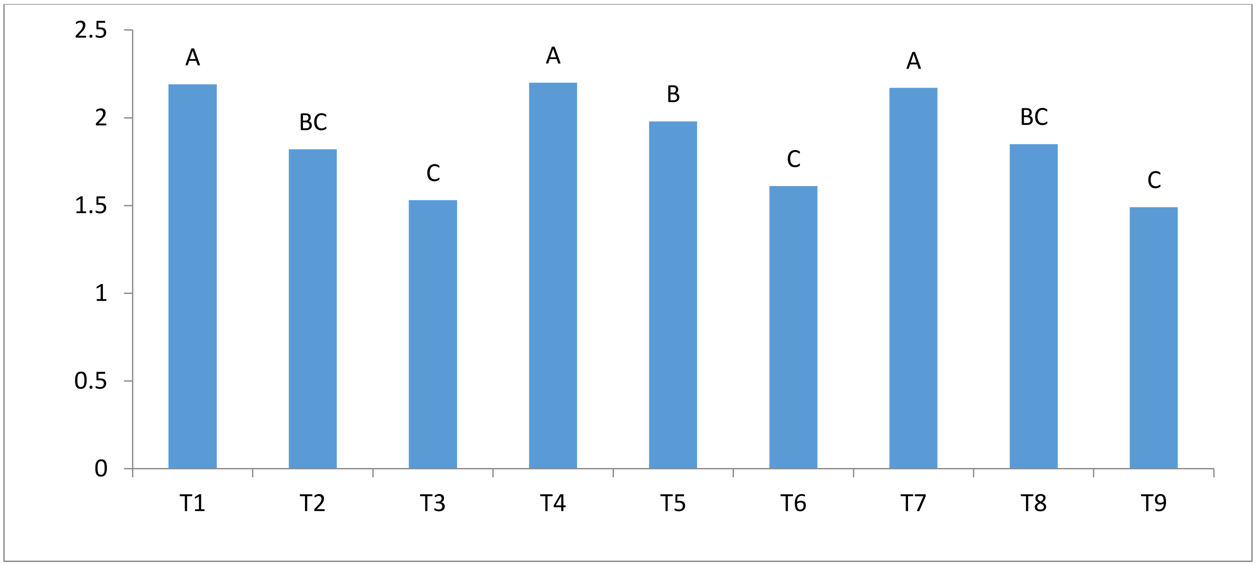

Fig. 3 Impact of canal and saline water with and without leaching fraction on K (%) in sorghum plants

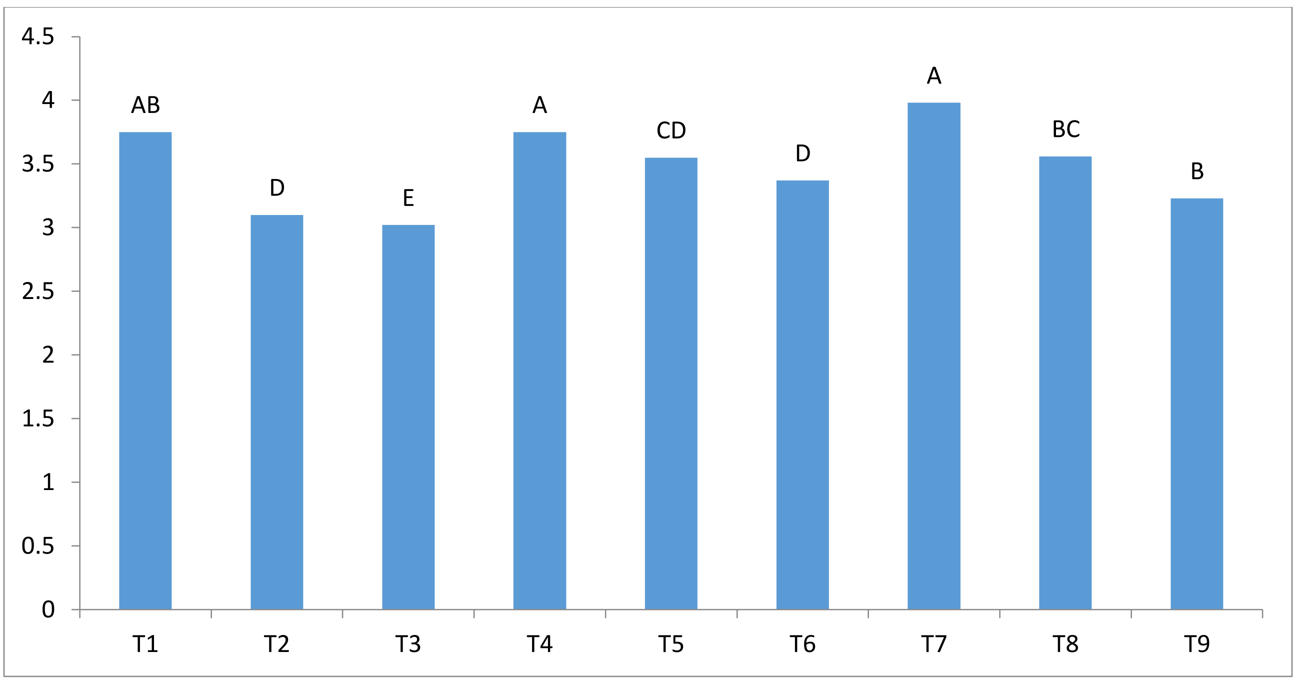

Fig. 4 Impact of canal and saline water with and without leaching fraction on Ca (%) in sorghum plants

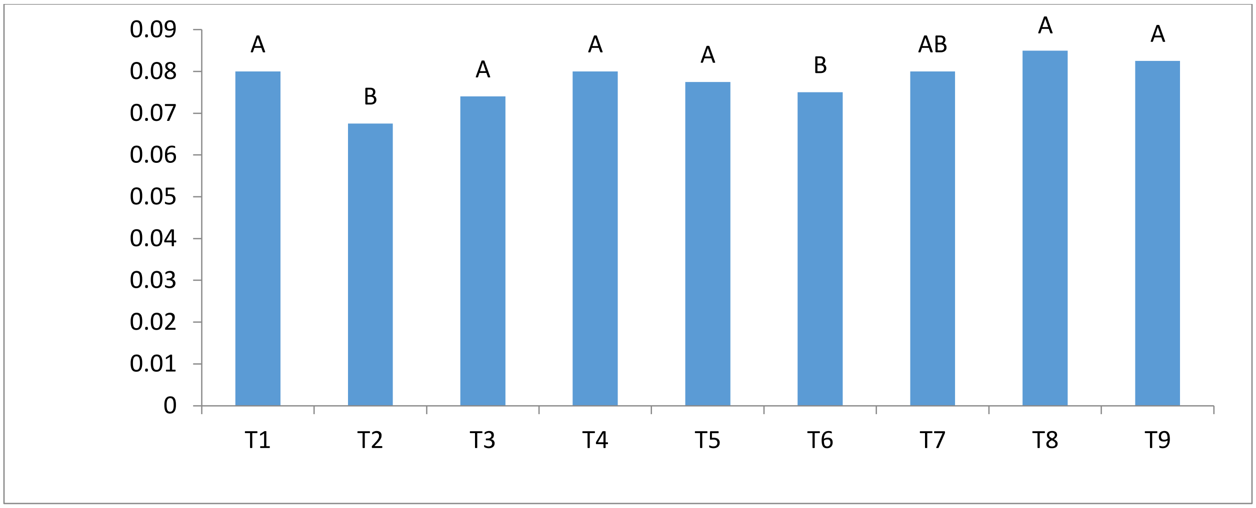

Fig. 5 Impact of canal and saline water with and without leaching fraction on Mg (%) in sorghum plants

Magnesium (%) in sorghum plants

Magnesium plays an important role in plant photosynthesis. In absence of magnesium, chlorophyll in the plants are unable to capture the sun energy that was necessary for photosynthesis (Sarwar, 2005). Data revealed that irrigation with canal and saline water had a significant impact on the magnesium contents (%) in sorghum. Data exhibited in Fig. 5 indicated that use of canal water was better than that of irrigation with water of EC = 2.0 dSm^{-1} and 3.0 dSm^{-1} alone and with leaching fraction. The maximum magnesium contents of the sorghum plants were obtained from the plots which were under the canal water irrigation followed by the plots irrigated with the water of EC 2.0 dSm^{-1} and 3.0 dSm^{-1}. Similar effect of leaching fraction was observed within the treatments and sub treatments. Magnesium contents in the sorghum plants of the plots having 20% leaching fraction was noted to be higher than those of having 10 and 0% leaching fraction. The treatment T_7 demonstrated dominance over all the other treatments because of canal water with 20% leaching fraction. As the EC of irrigation water increased and the leaching fraction decreased, magnesium contents were reduced. The minimum magnesium contents were observed in the plots of treatment T3 which were irrigated with EC 3.0 dSm^{-1} water followed by T_6 (T3 + 10 % LF) and T_9 (T3 + 20 % LF), respectively (Fig. 5.). The treatments, T_6 and T_9 were statistically similar with each other in term of magnesium content.

Sodium (%) in sorghum plants

Sodium is a mineral that is required in small amount for plants. The irrigation with saline water promoted the salt concentration in plants that causes reduction in growth and development due to high toxic levels. The irrigation with canal and saline water significantly affected the sodium contents in sorghum plant. Among all the treatments, irrigation with water of EC 3.0 dSm^{-1} (T_3) produced the highest sodium contents (0.35%) in sorghum which were followed by T_6 (T3 + 10 % LF) and T_9 (T3 + 20 % LF) that recoded 0.33% of sodium contents (Fig. 6.). The treatments T_6 and T_9 were non-significant with each other. The sodium contents 0.31, 0.30 and 0.29% in sorghum were noted for T_2 (EC 2.0 water), T_5 (T2 + 10 % LF) and T_8 (T2 + 20 % LF), respectively. However, these treatments (T_2, T_5 and T_8) were proved statistically to be non-significant with each other. The treatments T_7 (canal water with 20% leaching fraction) recorded the lowest sodium contents (0.24%) in sorghum which was followed by T_4 (canal water with 10% leaching fraction) and T_1 (T1 + 20 % LF) that recorded 0.25 and 0.26% sodium contents in sorghum, respectively (Fig. 6.).

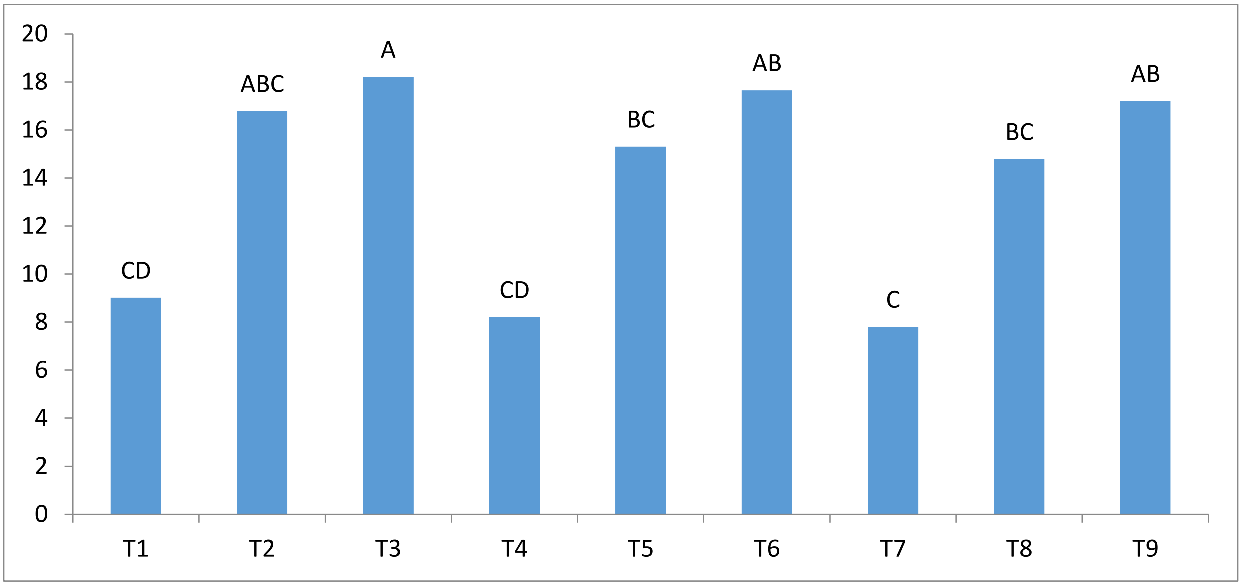

Fig. 6 Impact of canal and saline water with and without leaching fraction on Na (%) of sorghum plants

DISCUSSION

The concentration of various elements in plant tissues is known as chemical composition of plants. Hence, plants chemical composition depicts the soil and other climatic conditions under whose umbrella plants start or finally complete their life cycle. It can be said that plants chemical composition is the indicator of all positive or negative changes that are faced and challenged to a plant during its life cycle. In the same way, there are many internal and external factors such as soil properties, climatic conditions, water availability and its concentration, root development process and stage, concentration and availability of nutrients and aeration etc. that affect the uptake of various nutrients from the soil in one or the other way. In addition to all these things, the most important and basic point is the type and concentration of a particular element in available form that plays a key role in its uptake (Sarwar, 2005). Due to arid climate, there is high salt content in Pakistani soils that is one reason of poor soil fertility. Availability of all types of nutrients can be increased by the supply of quickly available form of specific elements/nutrients to the soil. But unfortunately, all such nutrients also neither taken up by the plants nor permanently present in available form in the soil due to high pH and salt stress environment. Consequently, significant part of applied nutrients is readily changed into unavailable forms due to natural dynamic process that is continuously operating and remains in action. Under brackish water irrigation, some fraction of it is fixed permanently in the soil.

The present study was investigated to evaluate the possibilities of leaching fraction when coupled with brackish water irrigation. It was noted in the present study that under brackish water irrigation, uptake of nutrients by sorghum plants was affected in a negative way (Sarwar, et al., 2009). In this regard, uptake and quantity of nutrients like nitrogen, phosphorus, potassium, calcium and magnesium was affected in a significant way when saline water was used as a source of irrigation. Maximum concentration of these nutrients was recorded when canal water was used as a source of irrigation in contrast to the application of saline water having EC = 3.0 dS m^{-1}. The application of this saline water when coupled with leaching fraction @ 20% proved to be useful in improving the concentration of these nutrients in sorghum plants. However, under such conditions, the concentration of Na was comparatively high under saline water irrigation. As a result of more uptakes of Ca & Mg, the uptake of Na ultimately decreased and vice versa. This was due to the reason that technique of leaching fraction makes the root zone of the soil salt free by removing salts down the profile. In this way, enhanced availability of nutrients caused their more uptakes by the plants. Due to the technique of leaching fraction, excessive salts are leached down the soil profile that lead to more solubility and availability of nutrients causing more uptakes. As a result of these improvements, soil physical properties (hydraulic conductivity, bulk density, porosity, water holding capacity, infiltration rate and many others become favorable for plant growth. Thus, root growth is promoted which in turn leads to more uptakes of nutrients from the soil (Sarwar, et al., 2002).

Our findings are supported by many researchers who revealed that in various crops including sunflower, cabbage and canola, salt stress can reduce the accumulation and transfer of important nutrients like Ca^{+2}, K^{+} and N^{+} in plants (Akram et al., 2007; Jamil et al., 2007; Ulfat et al., 2007). El-Nour et al. (2005) reported that uptake of nitrogen, phosphorous, potassium and magnesium from soil significantly reduced by the application of saline water. The present results are in line with the findings of Carden et al. (2003) who claimed that by using leaching fraction technique under saline condition maintained the potassium contents in the plant cells. According to Akram et al. (2007) who indicated that salt stress significantly reduced the calcium, nitrogen and potassium contents in plants. Carter et al. (2005) also reported findings similar to our results who revealed that higher salt concentrations in the soil reduced Ca^{2+} activity in the external environment, which also reduced the availability of calcium in plants. Our results are supported by El-Nour et al. (2005) who stated that under saline conditions, plant cannot uptake nutrients such as phosphorous, nitrogen, potassium, calcium and magnesium from the soil. Similar results were reported by Acosta-Motos et al. (2017) who stated that sodium contents in plants increased significantly due to irrigation with saline water that enhanced the salinity in the soil.

CONCLUSION

From this study it was concluded that use of leaching fraction (a modern management technique) proved to be beneficial in minimizing the negative effects of brackish water irrigation. It was noted that concentrations/contents of various elements/nutrients like N, P, K, Ca and Mg were improved in sorghum when leaching fraction was coupled with saline water of various levels. In this study, use of canal water proved to be superior to all other treatments. But sole application of saline water proved to be inferior to all other treatments.

Author Contribution Statement: Muhammad Zeeshan Manzoor conducted and carried out this research study. Ghulam Sarwar planned, designed and supervised this research study. Ghulam Sarwar is the program leader and provided the research facilities. Ayesha Zafar helped in conducting the research project and wrote the manuscript. Fakhar Mujeeb contributed in the plant analysis of the parameters prescribed in the manuscript. Faheem Khadija contributed in data analysis, description and edited the manuscript. All the authors read and approved the manuscript to be published in Journal of Pure and Applied Agriculture.

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

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