Research Article

Evaluation of Quantitative and Qualitative Attributes of Forage Sorghum Irrigated with Saline Water

Aftab Ahmad Sheikh[1], Khalil Ahmed[1*], Belqees Akhter[1], Ghulam Qadir[1], Muhammad Qaisar Nawaz[1], Hafeezullah Rafa[1], Abdul Wakeel[1], Abdul Manan Saeed[2]

[1]Soil Salinity Research Institute Pindi Bhattian, Pakistan; [2]Soil and water testing laboratory for research Gujranwala, Pakistan.

Abstract | High population growth rates, shortage of fresh water, and threat of climatic change are major constrains for expansion of irrigated agriculture in the country. In this scenario, use of underground saline water for crop production with acceptable economic yield is a viable management strategy. Therefore, a lysimeter study was conducted to evaluate the effects of saline water on quality and quantity of forage sorghum (*Sorghum bicolor* L.). Forage sorghum was sown in cemented blocks and five increasing levels of saline water (0.30, 4, 6, 8 and 10 dS m^{-1}) were used to irrigate the crop. Data regarding the plant height, fresh/dry fodder yield, nitrogen free extracts (NFE), crude fat, crude protein, crude fiber, phosphorus, and calcium contents were envaulted at the physiological maturity of crop, four months after the sowing of crop. Results revealed that water salinity adversely affected the quantitative and qualitative attributes of sorghum crop and negative effects were more pronounced with higher level of salinity EC_{iw} (10 dS m^{-1}). Irrigation with higher level of salinity EC_{iw} (10 dS m^{-1}) decresed the plant height (9%), fresh fodder yield (16.21%), dry biomass yield (7.86%), crude fat (25.40%) and crude protein (17.94%) as compared to control. Results also showed that water salinity of 4 dS m^{-1} did not decreased most of the studied parameters as compared with control. Therefore. it was concluded that forage sorghum can grow successfully without any significant loss in yield and acceptable fodder quality with water salinity of 4 dS m^{-1}.

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***Correspondence** | Khalil Ahmed, Soil Salinity Research Institute Pindi Bhattian, Pakistan; **Email:** khalilahmeduaf@gmail.com
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Introduction

Due to continuous increase in world population and competition among industrial and agriculture sectors for fresh water, it is opined that after every 35 years, water requirement will be doubled to the present (Naeimi and Zehtabian, 2011). This situation is further expected to intensify in countries of water deficit regions like Pakistan where shortage and un reliable supply of fresh water is a major constraint for expansion of irrigated agriculture, economic growth and regional development. Hence, in foreseeable future, not only land but also supply of fresh water will determine the sustainability and expansion of agricultural productivity. In Pakistan, 1.2 million tube wells are workig and unchecked exploitation of underground water has has created severe environmental problems like soil salinity (Qureshi, 2020). Therefore, knowledge of salt tolerance potential of field crops against saline water irrigation is necessary to devise practicable and feasible strategy for enhancing the productivity of agriculture system. Sorghum also known as jawar in Pakistan, is grown on the area 0.34 million hectare with annual production of 0.21 million ton (Habib *et al*., 2013). Sorghum is identified as moderately tolerant to saline areas and showed intraspecific variability of yield and quality parameters for salinity tolerance (Shakeri and Emam, 2017). It could be cultivated in saline (Saberi, 2013; Dong, 2018) and dry environments (Yan *et al*., 2012) as dual-purpose crop for forage and grain yield with limited water demand and low nitrogen consumption (Olanite *et al*., 2010; Chen *et al*., 2018). These advantages of sorghum are very important, especially with increased return of unit value of water (Mahfouz *et al*., 2015) and offer the sorghum as a good alternative silage crop as compared to maize and other legumes crops in salt-affected soils (Qu *et al*., 2014; Sánchez-Duarte *et al*., 2018). In this perspective, cultivation of sorghum crop with brackish water is a strategic option to increase the productivity of forage during the summer season and wise use of available water resources.

In a field study, Joardar *et al*. (2018) irrigated the sorghum crop with saline water having the EC_{iw} (0.78, 4.19, 7.18, 10.79 and 14.04 dS m^{-1}). Results showed that number of leaves, stem diameter, and biomass yield of sorghum crop decreased linearly with increasing EC level of irrigation water. They concluded that when fresh water supply is limited, sorghum crop could be grown successfully with saline water of 10.79 dS m^{-1} in the coastal regions of Bangladesh. Igartua *et al*. (1995) investigated the response of one sorghum cultivar and eleven inbred lines irrigated with saline water. They observed significant genotypic responses to salinity and the traits most affected by salinized conditions were shoot dry weight, grain yield, Na, K, and Ca contents in leaves. Similarly, in a pot experiment, Guimaraes *et al*. (2019) evaluated the performance of six sorghum varieties viz. Ponta Negra, 2600-IPA, 1011-IPA, 2502-IPA, 2564-IPA, and Qualimax irrigated with brackish water of (0, 1.5, 3.0, 6.0, and 12.0 dS m^{-1}). They identified that 2502-IPA and 1011-IPA are the most salt tolerant varieties with maximum grain yield using brackish water of 6.0 dS m^{-1} while 2600-IPA was recognized as most sensitive variety to water salinity (2.75 dS m^{-1}) with 50% reduction in yield. Sun *et al*. (2014) evaluated the salinity tolerance of ten sorghum varieties (Tx7078, RTx430, BTx642, Tx2783, 1790E, Wheatland, Desert Maize, Schrock, Shallu, and Macia). All the varieties were irrigated with water salinity of 1.25, 5, 10 and 17 dS m^{-1}. On the basis of morphological traits (plant height, shoot dry weight, number of leaves, and number of tillers) and mineral nutrient contents of leaves (Na, K, Ca, and Cl), they categorized 1790E, Shallu and Desert Maize as the most salt tolerant, whereas RTx430 and Schrock proved as salt sensitive varieties. Niu *et al*. (2012) investigated the responses of sorghum varieties (KS585, NK7829, SS304 and Sordan 79) against water salinity of 8 dS m^{-1}. Water salinity reduced the net photosynthetic rate, leaf transpiration and stomatal conductance. They concluded that KS585 was the most salt sensitive genotype while Sordan79 was the most salt tolerant genotype. Irrigation with salinity level of 3.0 dS m^{-1} significantly reduced the biomass yield, plant height and number of plants m^2 in sorghum (Murtaza *et al*., 2020).

Under the above considerations, the present study was planned and conducted with the objective to evaluate the toxic effect of various levels of saline water on qualitative and quantitative attributes of forage sorghum and to determine the level of saline water which can be used to grow sorghum without any significant loss in yield and acceptable fodder quality.

Materials and Methods

A lysimeter experiment was conducted at the campus of Soil Salinity Research Institute Pindi Bhattian (altitude 184 m, latitude 31.8950° N and longitude 73.2706° E) from Kharif 2014 to 2015 to investigate the qualitative and quantitative attributes of sorghum fodder irrigated with saline water. Normal soil with EC_e (electrical conductivity of soil extract) = 1.69 dS m^{-1}, pH_s = (pH of soil saturated paste) 7.97, and SAR (sodium adsorption ratio) = 6.06 was filled in cemented lysimeters (6 x 4 x 3 ft). During the 3rd week of July 2014 and 2015, the forage sorghum (cv. Hegari) was sown in Completely Randomized Design (CRD) arrangement having three replications. Recommended dose of fertilizers at the rate of 60-60 NP kg ha^{-1} was applied in the form of urea and single super phosphate (SSP). The following treatments were tested i.e. T_1 Tap water (0.30 dS m^{-1}), T_2 EC_{iw} 4.0 dS m^{-1}, T_3 EC_{iw} 6.0 dS m^{-1}, T_4 EC_{iw} 8.0 dS m^{-1}, T_5 EC_{iw} 10.0 dS m^{-1}. The lysimeter were irrigated as per crop requirement and approximately 100 liters lysimeter $^{-1}$ irrigation^{-1} were given, a total of 5 irrigations were applied in each season. Weeds were control through manual hoeing. The data regarding plant height, fresh/dry fodder yield and moisture% in leaves was recorded at maturity during the 2nd week of October 2014 and

2015, four months after the sowing of crop. Quality parameters of sorghum fodder {nitrogen free extracts (NFE), crude fiber, crude protein and crude fat} were determined following the procedure of AOAC (2005), while phosphorus and calcium were estimated using the methods as per Tandon (2005). Composit soil samples were collected before the start of experiment and after the harvest of crop. Collected soil samples were air dried, passed through 2 mm sieve and analyzed by following the methods of U.S. Salinity Laboratory Staff (1954). All the data were subjected to analysis of variance using STATISTIX 8.1 package software following the method of Steel *et al.* (1997). Least significant difference (LSD) test at 5% probability level was employed to sort out significant differences among treatments means.

Results and Discussion

Effect of saline water on plant quantitave characteristics

Results of two years study showed that saline water of EC_{iw} above 6.0 dSm^{-1} irrigation adversely affected the growth and fodder yield of sorghum. Data about plant height (Table 1) revealed that maximum plant height (174.3 cm) was divulged by T_1 (0.30 dS m^{-1}) which was similar ($P < 0.05$) with (T_2) brackish water of 4 dS m^{-1}, however, further increase in water salinity exerted a noticeable negative effect on plant height. The minimum plant height of 158.6 cm was observed with the highest dose of salinity level (10.0 dS m^{-1}). Similarly, in the case of fresh fodder yield maximum fodder yield (58.48 t ha^{-1}) was observed in T_2 (4 dSm^{-1}) which remained non-significant with T_1 (tap water), however, further increment in water salinity adversely affected the fodder yield and highest level of salinity 10.0 dS m^{-1} (T_5) produced minimum fodder yield of 48.97 t ha^{-1} (Table 1). As far as dry biomass yield and moisture (%) are concerned, the maximum dry biomass yield (11.44 t ha^{-1}) and moisture content (80.49 %) were observed by tap water irrigation (control) which remained insignificant with T_2 (4 dS m^{-1}) (Table 1). While minimum dry biomass yield (10.54 t ha^{-1}) and moisture % (78.48) were documented by T_5 (10.0 dS m^{-1}). Data about dry matter% and ash% (Table 2) showed that saline water irrigation increased the values of these attributes and maximum values of dry matter (21.77%) and ash (11.45%) were achieved with the highest dose of salinity (EC_{iw} 10.0 dS m^{-1}). Whereas control (tap water) recorded the minimum values of dry matter (16.02%) and ash (8.59%). Data about minerals nutrient content (Table 2) showed that saline water negatively affected the phosphorus content of sorghum fodder and maximum phosphorus content (0.154%) was noted in control (T_1), which was non-significant from T_2 (4.0 dS m^{-1}). However, increasing levels of salinity decreased the phosphorus content and minimum value (0.110%) was observed at salinity treatment of 10.0 dS m^{-1}. Similarly, maximum calcium content (0.089%) was recorded in T_1 (0.23 dS m^{-1}) which remain non-significant ($P<0.05$) up to salinity level of 8.0 dS m^{-1} (T_4). While the highest dose of salinity (10.0 dS m^{-1}) significantly reduced the calcium content and recorded the minimum value of 0.076%.

Table 1: *Effect of saline irrigation water on plant height, fresh fodder yield, dry biomass yield and moisture contents of sorghum fodder (average of two season).*

Salinity levels of irrigation water (dS m^{-1})	Plant height (cm)	Fresh fodder Yield (t ha^{-1})	Dry biomass yield (t ha^{-1})	Moisture (%)
T_1 = 0.30	174.3 a	58.45 a	11.44 a	80.49 a
T_2= 4.0	173.9 a	58.48 a	11.41 ab	80.42 a
T_3= 6.0	170.8 b	56.78 b	11.24 b	80.20 b
T_4= 8.0	164.7 c	53.82 c	11.03 c	79.50 c
T_5= 10.0	158.6 d	48.97 d	10.54 d	78.48 d
LSD	2.4600	1.3975	0.1975	0.1908

Table 2: *Effect of saline irrigation water on dry matter, ash, phosphorus, and calcium contents of sorghum fodder (average of two season).*

Salinity levels of irrigation water (dS m^{-1})	Dry matter (%)	Ash (%)	Phosphorus (%)	Calcium (%)
T_1 = 0.30	16.02 c	8.59 b	0.154 a	0.089 a
T_2= 4.0	17.71 bc	8.43 b	0.146 a	0.085 a
T_3= 6.0	18.39 abc	8.88 b	0.118 b	0.081 ab
T_4= 8.0	20.42 ab	9.27 b	0.116 b	0.081 ab
T_5= 10.0	21.77 a	11.45 a	0.110 b	0.076 b
LSD	3.638	1.547	0.021	0.007

Effect of saline water on plant qualitative characteristics

Data regarding the forage quality (Table 3) indices revealed that salinity level of 4.0 dS m^{-1} did not influenced the crude fat and crude protein while further increase in water salinity negatively affected these forage qualities. Maximum value of crude fat (3.07%) and crude protein (9.92%) were observed in T_1 (0.23 dS m^{-1}) which remained non-significant with T_2 (4.0 dS m^{-1}). While increasing doses of water salinity diminished the values of these qualities and minimum values of 2.29% and 8.14% were recorded for crude fat and crude protein respectively for T_5 (10.0 dS m^{-1}). As far as crude fiber and NFE were concerned, saline water did not produce any significant effect in these quality parameters and all the treatments statistically (*P<0.05*) remained insignificant from each other.

Table 3: *Effect of saline irrigation water on crude fat, crude protein, crude fiber and NFE of sorghum fodder (average of two season).*

Salinity levels of irrigation water (dSm^{-1})	Crude fat (%)	Crude Protein (%)	Crude fiber (%)	NFE (%)
T_1 = 0.30	3.07 a	9.92 a	27.58 a	49.11 a
T_2= 4.0	3.05 a	9.86 a	28.34 a	49.41 a
T_3= 6.0	2.93 b	8.46 b	28.71 a	50.09 a
T_4= 8.0	2.36 b	8.37 b	28.73 a	50.67 a
T_5= 10.0	2.29 b	8.14 b	29.72 a	52.60 a
LSD	0.433	0.988	2.3411	5.0561

Effect of saline water on soil properties

Data regarding the soil chemical properties showed that saline water significantly increased the pH_s, SAR and EC_e of the soil (Table 4). At the end of study, maximum pH_s value of 8.11 was observed with higher level of salinity (EC_{iw} 10.0 dS m^{-1}) with an increased of 1.75% over its initial value. While minimum increase of 0.37% over its initial value in pH_s was noted in T_1 (EC_{iw} 0.30 dS m^{-1}). Irrigation with saline water had pronounced effect on final electrical conductivity of soil and increased linearly with increasing levels of water salinity. Maximum value of EC_e (6.26) with increase of 270.41% over its initial value was observed where saline water of 10.0 dS m^{-1} was used continuously for two years. On the other hand, minimum value of EC_e (1.71) with an increase of 1.18% over its initial value was documented in T_1. Likewise, in the case of soil SAR, T_5 (EC_{iw} 10.0 dS m^{-1}) recorded maximum value (7.28) of SAR with an increase of 20.13% as compare to initial value of SAR at the start of study. While minimum value (6.05) of SAR was divulged in T_1 (control) with an increase of 0.16% over its initial value.

The continuous expanding population, increasing demand of water for industrial, domestic use and agriculture sector are the major factors of water shortage and this situation is further exacerbated in developing countries like Pakistan which are also facing the threat of climatic change. For the sustainable irrigated agriculture, reliance on underground saline water seems inevitable. In this perspective, use of such agronomical crops that can produce the economic growth and yield with saline water irrigation is a very effective management practice. This approach could be the key to future agricultural and play a vital role in social wealth of the areas where underground water is saline and its disposal options are limited. In our study we used the sorghum crop which is reported as fairly tolerant to salinity (Sui *et al.*, 2015). The objective of the study was to evaluate the effect of different salinity levels of irrigation water on the yield and quality parameters of forage sorghum. Results reveled that increasing levels of water salinity significantly reduced the plant height that could be attributed to osmotic effect of salt stress which inhibits the uptake of essential mineral nutrients required for necessary plant growth and development (Rady *et al.*, 2015; Semida *et al.*, 2017). Data also indicated a negative correlation between fresh/dry fodder yield and higher salinity levels. It is well established fact that salt stress reduces the productivity of sorghum crop (Yang *et al.*, 2018). This reduction in biomass yield due to water salinity could be explained by toxic concentration of ions in leaves (Munns, 2002), inhibition of water uptake by the roots because of high osmotic pressure of brackish water resulting reduced plant growth and development and ultimately the final yield is decreased. It also reflects the reduced carbon gain and enhanced metabolic energy cost which could be corelated to adaptation to saline environment (Netondo *et al.*, 2004). Our results are also strengthen by earlier findings that saline water of 10 dS m^{-1} may reduce the production

Table 4: *Effect of saline irrigation on soil pH_s, EC_e, SAR of soil at the end of study.*

Salinity levels of irrigation water (dS m^{-1})	p_Hs	% increase over initial value	EC_e (dSm^{-1})	% increase over initial value	SAR	% increase over initial value
T_1 = 0.30	8.00	0.37	1.71	1.18	6.05	0.16
T_2= 4.0	8.03	0.75	2.69	59.17	6.36	4.95
T_3= 6.0	8.05	1.00	3.95	133.72	6.68	10.23
T_4= 8.0	8.10	1.63	4.90	189.94	7.09	16.99
T_5= 10.0	8.11	1.75	6.26	270.41	7.28	20.13

of sorghum crop up to 52% (Sun *et al*., 2014). Similarly, in another study, Shakeri and Emam (2017) reported a reduction of up to 66% in sorghum yield with saline water irrigation having EC of 12 dS m^{-1}. Our results are reinforced by the previous findings of Omer and Abdelwahab (2016) and Guimaraes *et al.* (2019) that saline water reduced the fodder yield of sorghum crop. Results also revealed that dry matter% and ash% increased with increasing the levels of salinity which may be attributed to low moisture contents in leaves (Table 1). Saline environment inhibits the uptake of water by roots due to more negative water potential of saline soils (Tigabu *et al*., 2013).

An inverse relationship between minerals content (P and Ca) and higher doses of saline water was also observed. This could be justified by the fact that salt stress damage the mechanisms that control the intracellular P concentration (Johnson, 1981). In addition, at higher salt concentration, mineral nutrients are not absorb effeciently by the roots and percentage of mineral nutrients will remain low (Devline *et al*., 1993). Reduced contents of minerals in sorghum leaves in saline environment was also reported by Netondo *et al*. (2004) and Al-amoudi and Afaf (2012) that supports the current findings.

Among the quality parameters of any forage crop, crude protein and fat have prime importance in evaluating the forage quality because they play direct role in improving the health of animals (Soni *et al*., 2016). In current study, results showed that saline water adversely affected the crude fat and protein contents. Possible reason of this low crude fat and protein with saline water irrigation may be that salt stress induced a nutritional imbalance in plants. Uptake of minerals nutrients like N, P and Ca reduced under the salt stress (Qadar, 2009; Irshad *et al*., 2009). As reported by Bavei *et al.* (2011) salt stress decreases the synthesis of amino acid which in turn reduces the protein contents. Phosphorus is integral constituent of ATP, the energy carrier involved in different metabolic processes and protein synthesis (Abd El-Lattief, 2011). Salt stress in rhizosphere render the conditions which reduced the uptake of nitrogen and phosphorus and it ultimately decreased the protein synthesis.

Fiber content in a forage is also an important quality index because high quality forage has low content of crude fiber which make it digestible (Keshavarz *et al*., 2012). In our finding crude fiber content and NFE% increased with saline water irrigation but statistically remain non-significant in all treatments. According to Ben-Ghedalia *et al.* (2001) fiber content responded positively with increasing level of saline water. Similarly, Keshavarz *et al.* (2012) stated that cell wall becomes more rigid and hard due to accumulation of salts that lowered the quality and digestibility of a forage crop. The deteriorated quantitative and qualitative attributes of sorghum crop with the use of saline water was also stated by different researchers (Abd El-Mageed *et al*., 2018; Guimaraes *et al*., 2019; Murtaza *et al*., 2020; Calone *et al*., 2020) which strengthen the findings of current study.

Soil analysis data after the harvest of 2nd sorghum crop revealed that saline water irrigation significantly increased the soil EC_e, SAR and pH_s. Concentration of soluble salts in soil (EC_e) increased linearly with increasing levels of salinity and the adverse impact was more pronounced with irrigation of saline water of 10.0 dS m^{-1}. A plausible reason for this increased electrical conductivity and soil reaction (pH_s) and SAR was the buildup of soluble salts in soil due to continous use of saline water (Murtaza *et al*., 2009; Iqbal *et al*., 2014). Comparable results are posited by Saqib *et al.* (2018) that soil salinity and sodicity increased progressively with saline water irrigation.

Conclusions and Recommendations

Constant supply of fresh water resources is expected to decrease in foreseen future due to climate changes and the situation may become more worse in countries of arid to semi-arid regions, including Pakistan. High population growth rates required the expansion in irrigated agriculture, therefore to fulfill the gap between increasing water demand and water availability, use of underground saline water with minimize side effects on crop growth and quality will be the effective and wiser management strategy. From the above results it can be concluded that forage sorghum can grow successfully without any significant loss in yield and quality in area having water salinity of 4 dS m^{-1}.

Novelty Statement

Forage sorghum can grow successfully without any significant loss in yield and quality in area having water salinity of 4 dS m^{-1}.

Author's Contribution

Aftab Ahmad Sheikh: Wrote the manuscript, review the literature and provided technical input at every step.
Khalil Ahmed and Ghulam Qadir: Conceived the idea and conducted the study for two years.
Belqees Akhter and Hafeezullah Rafa: Wrote the abstract and materials and methods.
Muhammad Qaisar Nawaz, Abdul Wakeel and Abdul Manan Saeed: Did the data collection and statistical analysis.

Conflict of interest
The authors have declared no conflict of interest.

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