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EXTENUATING THE DETRIMENTAL EFFECTS OF SODIC WATER ON AGRONOMIC, IONIC, AND QUALITY ATTRIBUTES OF FODDERS

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SUMMARY

Brackish water used for irrigation in shortage of appropriate soil-water-crop practices often constitutes salinity in the soil profile. Canal irrigation water is scarce to aid agriculture; thus, a supplementary water supply requires accessibility from drainage water. In Pakistan, groundwater is brackish because of elevated levels of electrical conductivity (EC), residual sodium carbonates (RSC), and sodium adsorption ratio (SAR). But these waters can benefit well for irrigation during the primary phase of saline-sodic soil's reclamation, if employing appropriate management practices, such as, chemical and organic amendments. A pot trial procedure ran under environmental conditions at the research area of the Department of Soil and Environmental Sciences, College of Agriculture, University of Sargodha, to assess the effect of sodic water with various amendments on sorghum and berseem fodder crops. The pot experiment comprised seven treatments, including T_1 = Control having canal water with SAR 0.1 and EC 0.2 dS m^{-1}; T_2 = Sodic water with SAR 15; T_3 = Sodic water (SAR 15) + Gypsum; T_4 = Sodic water (SAR 15) + H_2SO_4; T_5 = Sodic water (SAR 15) + compost; T_6 = Sodic water (SAR 15) + FYM; T_7 = Sodic water (SAR 15) + poultry manure, with three replicates under complete randomized design (CRD) by sowing sorghum "JS-88" and berseem "Hisar Berseem 1" cultivars taken from the Fodder Research Institute (FRI), Sargodha. The agronomic and fodder quality attributes were maximum in T_3 treatment in sorghum compared with other concentrations and berseem. In both crops, mineral nutrients were variable, and nitrogen, phosphorus, and potassium were maximum in T5, compared with others.

Keywords: Fodder crops, berseem, sorghum, chemical and organic amendments, brackish water, canal water, gypsum

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Key findings: The application of sodic water alone as irrigation impaired the properties of soil, agronomic, and mineral nutrients, and quality parameters of fodder crops. The safe determination that sodic water usage with gypsum amendment proved superior to all other alterations being the most extensively used amendment due to its less cost, general obtainability, and more supply of calcium (Ca^{2+}) for an extended period, tailed by leaching of salts by improving sodic soils.

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INTRODUCTION

Pakistan is present between latitudes 24°−37° North and longitudes 61°−76° East in the Northern Hemisphere. In Pakistan, groundwater extraction is about 9.25×10^6 MAF (million acre-feet) (Economic Survey of Pakistan, 2022). Yet, these types of water can serve efficient use for irrigation during the early phase of saline-sodic soil reclamation by following accurate management procedures (Murtaza *et al.,* 2020). The problem of soil affected by salts is non-innovative, but its strength has since risen because of unsuitable amelioration techniques. Pakistan's population surged at a rate of 1.83% (Economic Survey of Pakistan, 2022), which causes massive stress on water and land reserves for more food for human beings and forage for livestock.

The quality condition of irrigation water plays a crucial part in crop yield. In many arid and semi-arid regions, sodic water usage negatively impacts soil productivity by manipulating nutrient uptake and numerous soil properties (Bennett *et al.,* 2009). Such waters usually have sodium carbonate as a leading salt. Farming relies on good quality irrigation water, depending on irrigation time and quantity. Canal water inundation amount is limited to boost agriculture in the Indus plains. Hence, an additional water resource requires access from an underground pool of water and drainage for agriculture expansion. Salinity and sodicity of soil are a universal dilemma affecting >8 × 108 ha of earth, either by sodicity (4.34 ha × 108 ha) or by salinity (3.97 ha × 108 ha), constituting more than 10%–12% of the globe's irrigated soil (Wang *et al.,* 2021).

Soils are becoming salt-affected due to the use of brackish water, and there are several methodologies to reclaim the affected ground encompassing amendment addition, salt leaching, ripping of salt-affected soil, halophytes usage for revegetation, and salt's scrapping. Shaygan and Baumgartl (2022) disclosed that detecting an applicable reclamation approach for salt-affected soil by brackish water requires knowledge of climate, plant, and soil interaction. Supportable reclamation and implementable method must be a concern, as many reclamation techniques are time-bound. Leaching of salts is a valuable method among the above-said techniques, but its efficacy depends on soil physio-chemical conditions. As a good example, saline-sodic soil retrievable could be through replantation using halophytes. Supplement of amendments becomes crucial to enhance physical properties of soil environment; thus, increase leaching of rain and lessen ascending solutes progress in expanded dried up situations. Soluble salt leaching occurs in that soil, which has the potential for deep drainage in the natural condition when rainfall (Halwatura *et al.,* 2015).

Organic matter usage, having a high specific surface area with colloidal characteristics as an organic amendment, is one crucial factor in a soil pore system, structure, and chemistry. Various authors have reported improvements in salt leaching with organic amendments' addition (Mahmoodabadi *et al.,* 2013). An example, Miller *et al.* (2005) determined that a 3% organic amendment addition helped lessen pH and EC in saline-sodic soils. But, in a few cases, mucks and composts resulted in an upsurge in soil sodicity and salinity by providing more salt (Miller *et al.,* 2005). It recommends that not all compost and manure may suit the retrieval of soils affected by saline water.

Similarly, saline-sodic lands' reclamation can use chemical alterations. The distinctive chemical amendments include gypsum, lime, sulfuric acid, nitric acid, and hydrochloric acid. Sulfuric acid, being a chemical amendment (Sadiq *et al.,* 2007), and hydrochloric acid (González, 2016) have aided calcite dissolution by activating calcium (Ca^{2+}) for replacement with sodium (Na^{+}) in calcareous saline-sodic soils. As an illustration, adding sulfuric acid was of utmost efficiency in salt leaching and diminishing salinity in contrast with gypsum alterations. But acidic modification application can lessen soil pH; consequently, some considerations for this application are necessary.

Gypsum, a widespread soluble calcium (Ca^{2+}) source, can aid alteration in sodium-rich soils (Sundha *et al.,* 2020; Gunal, 2021). Lime and gypsum comprising calcium (Ca^{2+}) can alter sodium ions during leaching at exchange sites of cations. This procedure can lead to cleansing sodium (Na^{+}) from the region of roots. The advantageous use of lime and gypsum for salinity lessening and enhancing soil structure has been visible in various experiments (Gonçalo *et al.,* 2019). One example, Gonçalo *et al.* (2019) determined that saline-sodic soil (EC: >4 dSm^{-1}; pH: >8.5; ESP: >22.2%) situated in semi-arid areas of northern Brazil can substitute 20% of the ESP by gypsum application of 38.7 t ha^{-1}. Thus, gypsum is the utmost widely beneficial amendment for saline-sodic soils reclamation due to its little cost, universal obtainability, and high supply of Ca^{2+} followed by leaching, which can revolutionize the soils affected by salts (Murtaza *et al.,* 2020).

Furthermore, forage crops act as bioremediator in salt-affected soils resulting from saline-sodic irrigation water. The halophytes merger into agricultural approaches may also have additional compensations, such as, lessening water tables triggering lesser salinity (Bennett *et al.,* 2009). The sorghum is more a salt-accepting crop with high fodder harvests than Sudan grass and maize (Chang and Leghari, 1995; Widyawan *et al*., 2018). Formerly, many efforts have taken place on salt-affected soil reclamation by growing diverse crops (Lang *et al*., 2018), but partial research existed on fodder crops. Small and poor farmers in Pakistan hope to cultivate forage crops on those soils affected by salts using saline-sodic water due to the non-accessibility of good-quality water (Nazeer *et al.,* 2023). Considering these aspects, this research aimed to a) evaluate the negative impact of sodic irrigation on the growth of berseem and sorghum fodder crops and b) access the efficacy of organic and inorganic amendments in lowering the negative impact of saline water on fodder crops.

MATERIALS AND METHODS

Study area

The study took place at the outer research area of the Department of Soil and Environmental Sciences, College of Agriculture, University of Sargodha, Sargodha, Punjab, Pakistan, positioned at 32.0740° N and 72.6861° E (Siddiqui *et al.,* 2021). Its elevation is 193 meters above sea level.

Research design and treatments

The pot trial setup was in a complete randomized design (CRD) with three replicates and seven treatments by sowing sorghum cultivar "JS-88" and berseem cultivar "Hisar Berseem 1." The experiment's treatments were as below:

- T_1 = Control having canal water with SAR 0.1 $(mmol\ L^{-1})^{1/2}$ and EC 0.2 dS m^{-1}
- T_2 = Sodic water with SAR 15 ($NaHCO_3$ @ 4.29 gL^{-1})
- T_3 = Sodic water (SAR 15) + gypsum (calculated by Eaton formula on gypsum requirement based on water used)
- T_4 = Sodic water (SAR 15) + H_2SO_4 (added to the soil [with each irrigation] equivalent to neutralize CO_3^{2-} and HCO_3^{1-} of water used

Table 1. Physio-chemical properties of the soil used for research trials.

Soil properties	Pot	References
Physical properties		
Textural class	Clay loam	Bouyoucos (1962)
Chemical properties		
pH	7.79 ± 0.05	U.S. Salinity Laboratory Staff (1954)
Electrical conductivity (μS cm ^{1})	1128 ± 18.52	
Total organic-C (g kg^{-1})	5.79 ± 0.14	Walkley and Black (1934)
Total nitrogen (mg kg $^{-1}$)	262.07 ± 9.39	Jackson (1958)
Available P (mg kg $^{-1}$)	6.89 ± 0.59	Watanabe and Olsen (1965)
Extractable K (mg kg $^{-1}$)	179.91 ± 9.34	U.S. Salinity Laboratory Staff (1954)

Values are mean of three replicates followed by (±) standard error of means.

- T_5 = Sodic water (SAR 15) + compost (10 t ha^{-1})
- T_6 = Sodic water (SAR 15) + FYM (10 t ha^{-1})
- T_7 = Sodic water (SAR 15) + poultry manure (10 t ha^{-1})

Sampling of soil and investigation

A composite soil sample preparation collected numerous samples from the University research farm, air-dried, passed through a 2 mm sieve and then observed for soil physicochemical properties. The study ensued using the Handbook 60 of the U.S. Laboratory Staff (1954). Clay loam was the soil texture, having a pH = 7.79 and EC = 11.28 dSm^{-1} (Table 1).

Seed germination

Each even-sized pot had a filling with 12 kg of field soil. All pots establishment used CRD and replicated three times. Sterilizing seeds of berseem and sorghum for 30 sec utilized a 5% sodium hypochlorite solution followed by 96% ethanol. In each pot, 10 seeds of berseem and sorghum sown at 2-3 cm depth gained thinning to five after seedling appearance. The sown sorghum and berseem seeds in pots attained daily watering. Distilled water for irrigation maintained ideal moisture for the development and seedling growth.

Poor-quality water level preparation

The salt requisite for preparing poor-quality or brackish water levels proceeded with mixing in distilled water using a quadratic equation (Abid, 2002). The $NaHCO_3$ salt @ 4.29 gL^{-1} for sodic water level production continued in the laboratory. This poor-quality sodic water irrigated the pot experiment as the plant growth medium for all treatments except control at the 2–3 leaves' seedling stage.

Use of fertilizers

Recommended dosages of NPK (80-40-40 kg ha^{-1}) application for sorghum and berseem (60-40-40 kg ha^{-1}) transpired in this trial. Urea, Single Superphosphate (SSP), and Sulfate of Potash (SOP) comprised nitrogen (N), phosphorus (P), and potassium (K) supply. Half nitrogen and all phosphorus and potassium consumption occurred at the stage of sowing, while the remaining nitrogen (half) was at the booting phase in sorghum, and for berseem forage, applying the other nitrogen half was after sprouting in 30 days.

Measurements of agronomic attributes

Plants of berseem mowing ensued after 60 days, while sorghum plants harvested after 90 days. The data recording included growth and yield and agronomic parameters. Whole fresh plant samples of both crops received distilled water rinsing before splitting into shoots and roots. The plant height, fresh weights, and lengths of each plant's shoots had verification. Afterward, sorghum and berseem plant samples underwent oven drying at 70 °C till they achieved a constant weight, with the dry weights of both crops' shoots recorded and then ground (Table 2).

Table 2. Effect of different amendments on agronomic growth attributes of berseem and sorghum under the canal and sodic water stress.

Treatments	Fodder crops	Plant height	Plant fresh biomass	Plant dry biomass
T1	Berseem	47.3 ± 3.06	116.5 ± 3.96	65.0 ± 2.30
	Sorghum	339.3 ± 4.18	57.5 ± 1.09	38.2 ± 1.16
T2	Berseem	26.6± 2.52	63.9 ± 3.40	26.4 ± 0.76
	Sorghum	304.6 ± 4.14	26.7 ± 3.59	17.9 ± 1.29
T3	Berseem	44.0 ± 3.61	95.8 ±3.56	48.5 ±0.78
	Sorghum	335.4 ± 3.58	53.7 ± 5.83	33.1 ± 1.41
T4	Berseem	42.3 ± 1.53	87.6 ±0.69	43.6 ±0.95
	Sorghum	330.2 ± 7.07	48.1 ± 0.25	24.7 ± 2.00
T5	Berseem	40.0 ± 1.00	78.1 ± 1.44	42.1 ±0.51
	Sorghum	332.9 ± 5.92	47.5 ± 2.01	23.0 ± 1.40
T6	Berseem	38.0 ± 1.00	74.7 ± 2.62	35.2 ± 1.56
	Sorghum	322.7 ± 5.43	44.0 ± 1.33	16.8 ± 1.25
T7	Berseem	36.0 ± 2.65	72.0 ± 1.70	31.0 ± 1.54
	Sorghum	317.0 ± 2.83	47.0 ± 0.44	17.6 ± 1.00

Values are mean of three replicates followed by (±) standard error of means.

Table 3. Effect of different amendments on minerals nutrients of berseem and sorghum under canal and sodic water stress.

Treatments	Fodder crops	Nitrogen (%)	Phosphorus (%)	Potassium (%)
T1	Berseem	2.92 ± 0.14	0.41 ± 0.02	3.25 ± 0.14
	Sorghum	2.68 ± 0.05	0.31 ± 0.01	7.44 ± 0.06
T2	Berseem	2.32 ± 0.07	0.21 ± 0.03	2.91 ± 0.03
	Sorghum	2.33 ± 0.06	0.18 ± 0.01	6.74 ± 0.03
T3	Berseem	2.94 ± 0.14	0.43 ± 0.01	3.34 ± 0.03
	Sorghum	2.73 ± 0.05	0.32 ± 0.01	7.57 ± 0.02
T4	Berseem	3.01 ± 0.14	0.44 ± 0.02	3.35 ± 0.04
	Sorghum	2.68 ± 0.05	0.39 ± 0.01	7.64 ± 0.05
T5	Berseem	3.69 ± 0.10	0.58 ± 0.02	3.48 ± 0.10
	Sorghum	2.89 ± 0.60	0.61 ± 0.05	8.75 ± 0.06
T6	Berseem	3.07 ± 0.15	0.47 ± 0.02	3.39 ± 0.03
	Sorghum	2.79 ± 0.61	0.48 ± 0.01	8.29 ± 0.06
T7	Berseem	3.09 ± 0.15	0.49 ± 0.02	3.41 ± 0.09
	Sorghum	2.85 ± 0.06	0.53 ± 0.04	8.42 ± 0.40

Values are mean of three replicates followed by (±) standard error of means.

Measurements of ionic attributes

Sorghum and berseem leaf samples were dried at 70 °C in an oven and continued with grinding. For the mineral nutrients' analysis, placing the dried-up ground plant material of 0.5 g into digestion tubes received acid digestion. Nitrogen and phosphorus determination used the Jackson method (1958). Potassium concentrations testing in plant samples employed a flame photometer (Table 3).

Measurement of fodder quality attributes

Quality parameters checked followed the steps endorsed by AOAC (1990), including crude protein (CP), crude fiber (CF), and ash contents (Table 4). Mineral nitrogen multiplied by 6.25 attained crude protein. The Kjeldahl method helped calculate the mineral nitrogen value. As a result, crude protein content (%) = N content. Crude fiber identification consisted of the fraction that remained after digestion with standard sulfuric acid and sodium

Table 4. Effect of different amendments on quality parameters of berseem and sorghum under the canal and sodic water stress.

Treatments	Fodder crops	Crude Protein (%)	Crude Fiber (%)	Ash (%)
T1	Berseem	16.77 ± 0.02	24.76 ± 0.04	9.51 ± 0.01
	Sorghum	8.55 ± 0.04	1.86 ± 0.02	1.96 ± 0.07
T2	Berseem	15.13 ± 0.09	19.21 ± 0.02	6.33 ± 0.02
	Sorghum	7.31 ± 0.03	1.12 ± 0.02	1.74 ± 0.03
T3	Berseem	15.85 ± 0.03	24.13 ± 0.03	8.45 ± 0.04
	Sorghum	8.46 ± 0.16	1.77 ± 0.02	1.90 ± 0.05
T4	Berseem	15.52 ± 0.02	23.83 ± 0.03	8.37 ± 0.02
	Sorghum	8.35 ± 0.03	1.65 ± 0.04	1.84 ± 0.03
T5	Berseem	15.42 ± 0.02	23.64 ± 0.02	7.23 ± 0.02
	Sorghum	7.72 ± 0.04	1.45 ± 0.02	1.82 ± 0.02
T6	Berseem	15.34 ± 0.04	23.27 ± 0.02	7.10 ± 0.02
	Sorghum	7.54 ± 0.06	1.36 ± 0.02	1.81 ± 0.02
T7	Berseem	15.25 ± 0.04	22.74 ± 0.03	6.86 ± 0.02
	Sorghum	7.41 ± 0.08	1.27 ± 0.01	1.78 ± 0.03

Values are mean of three replicates followed by (±) standard error of means.

hydroxide solutions under strict conditions. Its calculation employed the following formula:

Crude fiber (% of fat free DM) = (weight of crucible + dried residue) - (weight crucible + ashed residues)/sample weight.

The ash weight divided by the original sample weight multiplied by 100 percent equals the total content of ash. Typical sample size is 6 g, which represents the crucibles, each of which contains 2 g samples. For this purpose, the following method ran:

Weighing 2 g sample into a dry tared porcelain dish then placing at 600 °C for 6 h in a muffle furnace. Cooling in a desiccator and weighing followed. Computation used the formula below:

Ash (%) = weight of ash/weight of sample × 100

Weather-related data

The weather-related data during the tested fodder crops' growth period came from the meteorological department of Pakistan (Table 5).

Statistical analysis

As per complete randomized design (CRD), the composed data statistically analyzed engaged Fisher's study of variance, with the significance of treatments observed using CRD (Steel *et al.,* 1997). Statistical evaluation and correlations among variables' assessment ran the Statistic 8.1 package.

RESULTS

Agronomic attributes

Data indicated that the plant height had significant effects using the canal and sodic water with different amendments. The data (Table 2) showed that the maximum plant height in the berseem (47.33 cm) and sorghum (339.31 cm) resulted in the treatment T_1, followed by T_3 and T_4, producing 44.00 and 42.33 cm, respectively. However, T_3 and T_4 were significant with each other in terms of statistics. The lowest value of plant height appeared in treatment T_2 in the berseem and sorghum (26.67 and 304.69 cm, respectively) (Table 2). Data showed that the

Table 5. Weather-related data of mean temperature, humidity, and rainfall collected during the growth period of sorghum from the month of March to August and berseem from September to February during 2019–2020.

Month	Temp			RH	Rainfall	Pan Evaporation	Sunshine	ETo	Wind speed
	Max	Min	Ave						
	°C	°C	°C	%	Mm	Mm	Hrs	mm	km h^{-1}
Sorghum									
March	27.23	22.24	24.73	55.24	22.29	3.97	10.32	3.46	8.79
April	28.77	23.01	25.89	51.09	20.09	4.49	11.31	4.13	10.01
May	31.35	25.47	28.41	43.45	20.55	5.25	12.29	4.89	11.33
June	39.45	31.44	35.44	34.08	19.97	6.99	13.11	5.77	15.47
July	44.47	36.08	40.27	35.54	28.57	6.77	12.95	5.79	17.88
August	41.59	34.22	37.90	55.56	36.38	6.01	12.75	5.97	19.78
Berseem									
September	38.37	30.00	34.18	69.23	49.08	7.88	11.44	6.68	8.98
October	36.21	28.68	32.44	57.67	32.67	6.13	10.97	5.89	7.76
November	34.72	24.37	29.54	56.52	22.20	5.76	10.40	4.45	672
December	33.45	20.86	27.15	66.30	18.90	4.18	9.38	3.23	6.19
January	24.97	18.58	21.77	68.55	15.30	3.62	8.65	2.54	5.35
February	25.35	19.54	22.44	60.46	17.21	3.45	9.48	2.04	6.76

ETo: Evapotranspiration, RH: Relative humidity, Max: Maximum, Min: Minimum, Ave: Average, hrs: Hours.

canal and sodic water with different amendments affected the fresh plant biomass significantly.

Table 2 data indicated that maximum plant fresh biomass in the berseem (116.54 g) and sorghum (57.59 g) were available in the treatment T_1, followed by T_3 and T_4 at 95.82 and 87.66 g, respectively. However, T_3 and T_4 were statistically significant with each other. In the berseem plant, fresh biomass of 78.11, 74.75, and 72.05 g was notable in the treatment T_5, T_6, and T_7, respectively, while in sorghum, the fresh plant biomass was at 47.56, 44.06, and 47.08 g. The lowest value of fresh plant biomass emerged in treatment T_2 in the berseem and sorghum, 63.90 and 26.75, respectively (Table 2).

Data specified that the plant oven-dry biomass acquired substantial influences from the canal and sodic water with different amendments. The data available in Table 2 signified the maximum plant oven-dry biomass in the berseem (65.04) and sorghum (38.24) resulted in the treatment T_1, followed by T_3 and T_4 (48.53 and 43.66, respectively). However, T_3 and T_4 revealed statistically significant with each other. In the berseem, plant dry biomasses of 42.14, 35.28, and 31.04 were noteworthy in the treatments T_5, T_6, and T_7, and in sorghum, the plant dry biomass was 23.05, 16.81, and 17.67. The lowest value of dry plant biomass surfaced from treatment T_2 in the berseem (26.40, Table 2).

Plant ionic attributes

Data disclosed the nitrogen percentage being affected significantly by the canal and sodic water with different amendments. The figures in Table 3 showed that the maximum nitrogen percentage in the berseem (3.69) and sorghum (2.89) occurred in the treatment T_5, followed by T_7 and T_6, produced 3.09% and 3.07% in the berseem and 2.85% and 2.79% in sorghum, respectively. However, T_7 and T_6 were significant to each other based on statistics. In the berseem, nitrogen percentages (3.01%, 2.94%, and 2.92%) emanated from the treatments T_4, $T_{3,}$ and T_1. Although, in sorghum, the nitrogen was remarkably similar for earlier mentioned treatments (2.68%, 2.73%, and 2.68%). The lowest value of percent nitrogen came from treatment T_2 in the berseem and sorghum, 2.32% and 2.33%, respectively (Table 3).

Data revealed that a canal and sodic water with different amendments significantly affected the phosphorus percentage. Details in Table 3 showed that the maximum phosphorus percentage in the berseem (0.58%) and sorghum (0.61%) emerged in the treatment T_5, followed by T_7 and T_6 with 0.49% and 0.47% in the berseem and 0.53% and 0.48% sorghum, respectively. However, T_7 and T_6 were statistically significant to each other. In the berseem, percent phosphorus of 0.44%, 0.43%, and 0.41% came from the treatment T_4, T_3, and T_1, accordingly, while in sorghum, it was considerably similar for the said treatments (0.39%, 0.32%, and 0.31%). Treatment T_2 gave the lowest value of phosphorus percentages in the berseem and sorghum, 0.21% and 0.18%, respectively (Table 3).

Using canal and sodic water with different amendments substantially influenced the potassium percentages. Data displayed in Table 3 showed that the maximum potassium percentage in the berseem (3.48%) and sorghum (8.75%) manifested in the treatment T_5, followed by T_7 and T_6 at 3.41% and 3.39% in the berseem and 8.43% and 8.29% sorghum, respectively. However, T_7 and T_6 were significant to each other in terms of statistics. In the berseem, percent potassium, 3.35%, 3.34%, and 3.25% occurred in the treatment T_4, T_3, and T_1. For sorghum, the potassium was notably alike for the said treatments, at 7.64%, 7.57%, and 7.44%, correspondingly. The lowest value of potassium percentage turned up in treatment T_2 in the berseem and sorghum, 2.91% and 6.74%, respectively (Table 3).

Crop quality parameters

Data on crude protein revealed varying with different amendments coupled with sodic water in berseem and sorghum fodders. More significant results are in sodic water (SAR15) with amendments like gypsum, sulfuric acid, and other organic amendments, i.e., compost, FYM, and poultry manure (Table 4). The maximum crude protein content value in berseem appeared in the canal water (16.77%), followed by SAR15 + gypsum (15.85%), SAR15 + sulfuric acid (15.53%), SAR15 + compost (15.42%), SAR15 + FYM (15.34%), and SAR15 + poultry manure (15.25%), whereas in the treatment of sodic water without any amendments exhibited minimum crude protein content (15.13%). The highest crude protein value in sorghum resulted in the canal water (8.55%), followed by SAR15 + gypsum (8.46%), SAR15 + sulfuric acid (8.35%), SAR15 + compost (7.73%), SAR15 + FYM (7.54%), and SAR15 + poultry manure (7.42%). In treatment where sodic water was without any amendments, a 7.31% minimum crude protein content showed (Table 4).

Irrigation of sodic water alone and with different amendments showed much variation among treatments regarding crude fiber of berseem and sorghum fodders. More significant results are in the treatment of SAR15 with gypsum application. Irrigation with sodic water disclosed a considerable difference in crude protein with different amendments. More noteworthy results are in treatments of sodic water SAR15 with amendments like gypsum, sulfuric acid, and other organic amendments (Table 4). The maximum crude fiber content value in berseem emerged in canal water (8.55%), followed by SAR15 + gypsum (8.46%), SAR15 + sulfuric acid (8.35%), SAR15 + compost (7.73%), SAR15 + FYM (7.54%), and SAR15 + poultry manure (7.42%); however, in treatment where sodic water is without any amendments exhibited the minimum crude fiber content (7.31%). The supreme crude fiber value in sorghum came from the canal water (24.76%), followed by SAR15 + gypsum (24.13%), SAR15 + sulfuric acid (23.83%), SAR15 + compost (23.65%), SAR15 + FYM (23.27%), and SAR15 + poultry manure (22.74%), while in sodic water dose without any amendments gave the lowest crude fiber content (19.21%), as shown in Table 4.

Data for total ash content revealed that ash content varied with different amendments with sodic water in berseem and sorghum fodders. More significant results are in concentration of sodic water SAR15 with modifications, namely, gypsum, sulfuric acid, and other organic amendments (compost, FYM, and poultry manure) (Table 4). Canal water gave a maximum ash content value in berseem (9.52%), followed by sodic water SAR15 + gypsum (8.45%), SAR15 + sulfuric acid (8.37%), SAR15 + compost (7.23%), SAR15 + FYM (7.11%), and SAR15 + poultry manure (6.87%), whereas in treatment without any amendments to sodic water exhibited the least ash content (6.33%). Likewise, total ash content value in sorghum occurred in canal water (1.96%), followed by sodic water SAR15 + gypsum (1.91%), SAR15 + sulfuric acid (1.84%), SAR15 + compost (1.82%), SAR15 + FYM (1.81%), and SAR15 + poultry manure (1.78%), but in treatment where sodic water had no amendments provided the minimum total ash content (1.75%), as shown in Table 4.

DISCUSSION

Crops irrigated with saline-sodic water are in direct association with increasing harm to soil health and damage to crop production. Soil sodicity is much more detrimental than salinity for quinoa (Abbas *et al.,* 2021). Constant use of brackish water worsens the soil's physical and chemical features, with a consequent decay in yields and development of crops (Singh, 2020). Therefore, efforts progress to attain sustainable agricultural development goals by handling sodic water use and its impact on the soil excellence.

Agronomic attributes

Data about plant growth parameters of berseem and sorghum after irrigation with canal water and sodic water with different amendments varied. There was a substantial effect on the height of plants with canal water and sodic water use with various adjustments. The sodic water used alone for exaggerated farming is the leading reason for soil particle disintegration continuing in a poor soil structure. A previous study disclosed similar results in wheat (Arshad *et al.,* 2022) and sorghum (Manzoor, 2019). A significant impact on the fresh biomass weight resulted in using the canal and brackish water with diverse alterations. The fresh biomass weight was better in canal water than in brackish water in the sorghum and berseem. These findings are similar to the previous study reported on sorghum. The dry biomass weight of the sorghum and berseem was higher in the canal water than in the other brackish water amendments. Analogous results also showed in the mustard and sorghum (Murtaza *et al.,* 2020).

Plant ionic attributes

Nitrogen is an essential component of plant tissues. Compost substantially upgraded the N % in the sorghum and berseem plants, aligning with a previous study description by Litardo *et al.* (2022). Phosphorus is part of the nuclei acid structure of plants, liable for regulating protein synthesis. It is vital in new tissue growth and cell division. Findings reflected that the P% of berseem and sorghum plants had positive improvements by combining brackish water with compost application. The Potassium (K) contributes to plant tissue nutrients, water, and carbohydrate movement. The saline water with different amendments demonstrated that compost manure improves the potassium percentage in the berseem and sorghum plants. Outcomes of many earlier researchers also suggested similar findings that combined brackish water with compost manures upgraded the mineral composition in plants (Tahir *et al.,* 2020).

Crop quality attributes

Crop quality attributes of fodder material like crude protein (CP), crude fiber (CF), and ash contents gained a checking via steps approved by AOAC (1990). General crude protein is at medium level in all genotypes, fiber is comparable to good class grasses, and ash is within the suitable levels even at 15 dS m^{-1}. The chief quality traits of forage crops are CP and CF, and assessing them under water and salt stress is crucial to produce high-quality sorghum and berseem (Capstaff and Miller, 2018). The CP contents in dry matter are essential in fodder crops as it examines the palatability and digestibility of fodder crops.

The crude fiber in forage material has an adversative effect on forage quality as it affects digestibility. The irrigation with canal and brackish waters significantly impacted berseem and sorghum's CP and CF contents. A similar study came from Daru and Mayulu (2020). They noted a damaging parabolic affiliation between relative alfalfa CP (CP) and comparative soil electrical conductivity with an EC $_r$ threshold (EC_{rth}) for maximum CP_r (Hu *et al.,* 2021).

Another study by Oktem*,* Yucel, and Oktem (2021) stated that salinity substantially reduced CP and CF in tomato and sweet sorghum shoots and roots. Overall, the maximum ash values were present in plants under the control treatment (mean ~13.3% DM), with the lowest in the 5.0, 7.5, and 10.0 dS m^{-1} treatments (mean ~12.6% DM). Elder plants had meaningfully low ash content, declining from an average of 14.4% DM in the first period to 12.4% DM in the last (Diaz *et al.,* 2018). The enhanced water stress reduced ash content. The nutrients are less reachable to the plant's root in a water-stress situation. Mostly, ash content can be a pointer to the total minerals in a plant. Other studies also stated ash contents in three forage crops, including sorghum, corn, and millet, declined sharply due to water stress. The ash content in sorghum-Sudan grass hybrids decreased due to water stress compared with the control treatment. Water stress dramatically diminished the ash percentage in two maize crop hybrids (Shoaei and Rafiei, 2014). The product prepared from the cabbage sown under sodic soil treated with farmyard manure (FYM) and gypsum revealed higher ash, protein, fat, sugars, and dietary fiber when than to cabbage grown using canal water. Ash content reduction with enhanced brackish water irrigation has descriptions from other researchers for diverse fodders below greenhouse environments (Rani *et al.,* 2013).

CONCLUSIONS

The study concludes that canal water use is ideal and accepted universally. But if canal water is scarce, the only alternative for farmers to use is brackish groundwater for irrigation purposes, but sensibly using certified scientific techniques. From this study, sodic water can be a source of irrigation for berseem and sorghum fodder crops production when coupled with different inorganic (gypsum and sulfuric acid) and organic (compost, farmyard, and poultry manure) amendments. A safe determination also revealed that agronomic and fodder quality attributes showed a maximum in T_3 treatment in sorghum compared with other concentrations and the berseem crop. The gypsum amendment (T_3) proved superior to all others, being the most extensively used amendment due to its less cost, general obtainability, and more supply of Ca^{2+} for extended periods tailed by salt leaching by improving sodic soils. In both crops, mineral nutrients were variable, with nitrogen, phosphorus, and potassium being maximum in T_5 versus other treatments. Another conclusion is that sorghum, being the halophyte, is the better crop for cultivation using brackish water as an irrigation source. Further investigation is necessary at the field level and in other field crops due to less or non-availability of good quality irrigation water.

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