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Managing Salt Ratios in Saline Water Irrigated Cotton-Wheat Cropping System by Farm Yard Manure and Sewage Sludge

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Abstract

A field experiment was conducted during 2021–22 at Hisar using two irrigation treatments, *viz.* canal water (I_1: 0.30 dS m^{-1}) and saline water (I_2: 8 dS m^{-1}) and eight fertilizer/manure treatments, *viz.* T_1: control, T_2: farm yard manure (FYM) 10 Mg ha^{-1}, T_3: sewage sludge (SS) 5 Mg ha^{-1}, T_4: 100% recommended dose of fertilizer (RDF), T_5: 75% RDF+10 Mg ha^{-1} FYM+ST-3 (*Azotobacter*), T_6: 75% RDF+5 Mg ha^{-1} SS+ST-3, T_7: 100% recommended dose of nitrogen (RDN)+75% P&K+10 Mg ha^{-1} FYM+ST-3, T_8: 100% RDN+75% P & K+5 Mg ha^{-1} SS+ST-3. The aim of this investigation was to evaluate the impact of integrated nutrient management and saline water irrigation on salt ratios in cotton-wheat crop rotation. The FYM and SS were applied in the *Kharif* season only. Na^+/K^+ and Cl^-/SO_4^{2-} ratio were significantly increased with increased irrigation water salinity in cotton and wheat crops. However, RDF, organic manures and integrated nutrient management treatments resulted in lower Na^+/K^+ and Cl^-/SO_4^{2-} ratio in cotton and wheat as compared with control. The Na^+/K^+ ratio was reported lowest with T_7 in seed and stalk of cotton, while it was lowest with T_4 in wheat grain and straw as compared to control. Similarly, the Cl^-/SO_4^{2-} ratio was reported lowest with T_7 in cotton seed, stalk and wheat straw compared to control. It may be concluded that combined application of FYM, SS and inorganic fertilizers increases the potential of agricultural crops to withstand salt stress by decreasing Na^+ and Cl^- besides increasing the K^+ and SO_4^{2-} in the plants.

Key words: Na^+/K^+ and Cl^-/SO_4^{2-} ratio, Cotton-wheat cropping system, Saline water, Sewage sludge

Introduction

Due to limited supply of freshwater, there is a growing need to use poor quality water for agriculture irrigation. Both primary (natural) and secondary (anthropogenic) salinization give rise to the saline groundwater (Mirzavand *et al.,* 2020). The amount of salt in irrigation water varies greatly and is mostly determined by the soil and water properties. Farmers in Haryana have little choice but to utilize the poor-quality groundwater for irrigation due to the limited canal water supply and low, irregular and uneven rainfall. In Haryana state 62% area has poor quality groundwater (Anonymous, 2019), whose irrigation leads to problem of soil salinity and poor soil health and ultimately reducing crop production. Many nations have embraced the use of poor quality irrigation water as a solution to the problem of water shortage (Abou-Shady *et al.,* 2023). Salinity negatively impacts the availability of nutrients as well as plant growth, including cell division, leaf elongation, evapotranspiration rate, root growth, nutrient and water absorption and ultimately reduce yield, which may be caused by a shift in the osmotic potential of the soil-water phase (Soni *et al.,* 2023). Saline water irrigation may lead to increased production of various reactive oxygen species (ROS) in plants and a higher accumulation of sodium and chloride in plant tissue. Nevertheless, it depends on plant species, how the sensitive or tolerant genotype responds to the salt stress.

Both cotton and wheat are very nutrient-exhaustive crops that can withstand salt to a reasonable extent. To achieve higher output, it is therefore necessary to regularly apply a balanced nutrient amount using chemical fertilizers integrated with various organic sources like sewage sludge and farm yard manure. Globally, the researchers have conducted experiments to evaluate the effect of various nutrients on crop salt tolerance (Hopmans *et al.,* 2021, Dey *et al.,* 2021). Sustainable agricultural development is receiving more attention in accordance with the United Nations Sustainable Development Goals. The degree of salt stress in the root zone determines how a plant would react to fertilizers. Some researchers reported that plant's salt tolerance may decrease or remain the same with application of inorganic fertilizers + organic manures in salt-affected soils (Shaddad, 2010, Mehdi *et al.,* 2018), while other reported an increase in plant salt stress tolerance with fertilizers and manures (Hamoud *et al.,* 2024). The decomposed combination of litter, leftover materials from roughages or cow feed, farm animal excrement and urine are all referred to as farmyard manure (FYM). Sewage sludge (SS) is the by-product of municipal solid waste treatment plants which has potential use in the field to address waste disposal issues. Nutrients, microbes, and metals are present in it in varying concentrations. Applying SS and FYM to the soil enhances its physio-chemical and biological properties while also recycling nutrients (Rodrigues *et al.,* 2024). The present investigation evaluated the effects of FYM, SS application and saline water irrigation on the ratios of Na^+/K^+ and Cl^-/SO_4^{2-} in cotton and wheat crops. There is also limited data available on the use of sewage sludge as an amendment to reduce salinity stress.

Material and Methods

Location of the experiment and soil characteristics

The experiment was carried out at Soil Science research farm of Chaudhary Charan Singh Haryana Agricultural University, Hisar during 2021-22. The farm is located at 29°8′N latitude, 75°70′E longitude, at an elevation of 215.2 meters (mean sea level) in the semi-arid subtropics. The sandy loam texture of the experimental soil had low levels of organic carbon (0.37%) and available nitrogen (102.25 kg ha^{-1}), medium available phosphorus (14.14 kg ha^{-1}), high soil potassium (283.57 kg ha^{-1}) and sulfur (78.41 ppm). The soil was alkaline with $pH_{(1:2)}$ 7.98 and $EC_{(1:2)}$ 0.52 dS m^{-1} (Table 1). Factorial randomized block design with three replications was used for the investigation.

Details of treatments

The study comprised two salinity levels: 0.30 dS m^{-1} canal water and 8 dS m^{-1} EC saline water and eight fertilizer/manure treatments: T_1: control, T_2: farm yard manure (FYM) 10 Mg ha^{-1}, T_3: sewage sludge (SS) 5 Mg ha^{-1}, T_4: 100% RDF, T_5: 75% RDF+10 Mg ha^{-1} FYM+ST-3 (*Azotobacter*), T_6: 75% RDF+5 Mg ha^{-1} SS+ST-3, T_7: 100% RDN+75% P & K+10 Mg ha^{-1} FYM+ST-3, T_8: 100% RDN+75% P & K+5 Mg ha^{-1} SS+ST-3, where FYM and SS were applied as a basal dose prior to the final plough in *Kharif* season only. The properties of water used are shown in Table 2. The FYM had $EC_{(1:5)}$ (0.61 dS m^{-1}), organic carbon (35.41%), total NPKS (0.82, 0.75, 1.68 and 0.32%, respectively), and alkaline pH (7.29) (Table 3); while SS had $EC_{(1:5)}$ (2.1 dS m^{-1}), organic carbon (23.39%), total NPKS (1.17, 0.89, 1.23 and 0.65%, respectively), alkaline pH (7.54) (Table 4).

Crop variety and management practices

Cotton H 1098 improved and wheat WH 1105 varieties were taken for experimentation. An agricultural hand plough was used to assist in crop sowing. The crops were irrigated in accordance with the CCSHAU, Hisar package of practices for crop production and the required electrical conductivity level (8 dS m^{-1}) was achieved by blending canal water with saline water (Table 2).

Sample analysis of soil, FYM and SS

The standard procedures described by Antil *et al.* (2002) were used to determine the chemical characteristics of soil, FYM and SS. Dried plant samples were ground by mixer grinder for plant salt ratio analysis. The digestion of plant samples for sodium, potassium and sulphate was done with diacid mixture of HNO_3 and $HClO_4$ in a ratio of

Table 1. Soil properties before sowing

Soil								DTPA Ext. Metals (mg kg^{-1})						Soluble Cations/Anions (me l^{-1})							
Before sowing	pH (1:2)	EC (1:2) (dS m^{-1})	OC (%)	Avl. N (kg ha^{-1})	Avl. P (kg ha^{-1})	Avl. K (kg ha^{-1})	Avl. S (kg ha^{-1})	Fe	Zn	Cu	Mn	Cd	Cr	Ni	Co	Na^+	K^+	Ca^{2+}	Mg^{2+}	CO_3^{2-}	HCO_3^-
Mean	7.98	0.52	0.37	102.25	14.14	283.57	78.41	3.66	0.87	0.96	5.32	0.08	0.24	0.36	0.12	1.54	0.35	0.45	1.12	Nil	0.34

4:1 (Antil *et al.,* 2002), while for chloride the grounded tissues of plant were subjected to extraction by incubation in test tubes with screw caps, containing 25 ml of distilled water and boiled in a water bath at 100 °C for 1 hour. Using a flame photometer, the concentration of K^+ and Na^+ in the plant samples were ascertained (Richards, 1954). The sulfate concentration was determined using the method described by Chesnin and Yien (1950). The chloride was analyzed using the potassium dichromate indicator with the silver nitrate titration method (Richards, 1954).

Statistical analysis

The data were statistically analyzed by using R software (4.2.3 (2023-03-15 ucrt), RStudio version 2023.06.2, R core team 2023). The test for the effect of irrigation water and fertilizer treatments on cotton and wheat salt ratios were conducted using two factor Anova test. Post-hoc Tukey comparison was conducted using agricolae package. The graphs were prepared using the ggplot2 package.

Results and Discussion

Na^+/K^+ ratio in seed/grain

Irrigation with saline water significantly increased the sodium/potassium ratio in cotton seed and wheat grain (Fig. 1a). The lowest Na^+/K^+ ratio in cotton seed (0.11) and wheat grain (0.19) was reported with canal water irrigation as compared with saline water irrigation. Na^+/K^+ ratio was 64.16 and 41.27 percent lower in cotton seed and wheat grain with canal water irrigation compared to saline water irrigation, respectively. The results are in accordance with the findings of several research workers (Kalhoro *et al.,* 2016; Akter and Oue, 2018). Among various fertilizer/manure treatments (Fig. 1b), the data revealed that FYM and SS application with inorganic fertilizer significantly reduced Na^+/K^+ ratio in cotton seed and wheat grain compared with control. Significantly lowest Na^+/K^+ ratio in cotton seed (0.15) was reported with application of 100% RDN + 75% P & K + 10 Mg ha^{-1} FYM + ST-3 (T_7) compared to absolute control (T_1). Application of 100% RDN + 75% P & K + 10 Mg ha^{-1} FYM + ST-3 (T_7) also resulted in

Table 2. Chemical composition of irrigation waters

Irrigation water	pH	EC (dS m^{-1})	Na^+	K^+	Ca^{2+}	Mg^{2+} (me l^{-1})	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}
Canal	7.34	0.30	0.66	0.07	0.72	1.84	Nil	0.68	2.34	1.4
Saline water of EC 8 dS m^{-1}	7.82	8.0	46.43	0.81	6.5	17.28	Nil	1.54	58.45	18.32

Table 3. Properties of farm yard manure used in the experiment

FYM								DTPA Ext. Metals (mg kg^{-1})									
	pH (1:5)	EC (1:5) (dS m^{-1})	OC (%)	N (%)	P (%)	K (%)	S (%)	Fe	Zn	Cu	Mn	Pb	Cd	Cr	Ni	Co
Mean	7.29	0.61	35.41	0.82	0.75	1.68	0.32	286.29	61.57	16.49	100.34	4.47	0.16	0.52	3.21	0.25

Table 4. Properties of domestic sewage sludge used in the experiment

SS								DTPA Ext. Metals (mg kg^{-1})									
	pH (1:5)	EC (1:5) (dS m^{-1})	OC (%)	N (%)	P (%)	K (%)	S (%)	Fe	Zn	Cu	Mn	Pb	Cd	Cr	Ni	Co
Mean	7.54	2.1	23.39	1.17	0.89	1.23	0.65	234.06	38.41	9.79	90.56	35.49	1.83	7.68	21.46	0.97

significantly lower Na^+/K^+ ratio in cotton seed compared to 100% RDF (T_4). Significantly lower Na^+/K^+ ratio (14.16%) was also reported with application of 100% RDN + 75% P & K + 5 Mg ha^{-1} SS + ST-3 (T_8) compared to absolute control (T_1). While in wheat grain, significantly lowest Na^+/K^+ ratio (0.18) was reported with RDF (T_4) compared with control (T_1). Integrated application of FYM + inorganic fertilizer and SS + inorganic fertilizer *viz.* T_7 and T_8 also resulted in significantly lower Na^+/K^+ ratio (36.39%, 25.08%) in wheat grain compared to control (T_1), respectively. The decrease in Na^+/K^+ ratio with 100% RDN + 75% P & K + 5 Mg ha^{-1} SS + ST-3 (T_8) was statistically at par with 75% RDF + 5 Mg ha^{-1} SS + ST-3 (T_6) in wheat grain. It has been demonstrated that cultivars with higher K ion flow and lower Na^+/K^+ ratios in the leaves may have a higher chance of survival (Akter and Oue, 2018). Agricultural crop salt tolerance is basically dependent on the Na^+/K^+ ratio. Since potassium (K) is the third essential element and is needed for physiological and metabolic processes that help the plant achieve resistance to stress by preserving ion homeostasis and osmotic balance, a lower ratio generally enhances the tolerance capacity of the plant. According to Merwad (2016) the K application could have a positive effect on *B. vulgaris* cultivars under salinity stress. The results of this study are in line with Fayez and Bazaid (2014) who reported decreased Na^+/K^+ ratio with fertilizer application in *H. vulgare*. The FYM + inorganic fertilizer and SS + inorganic fertilizer was applied to cotton and they interacted with Na^+, limiting its uptake and accumulation, increasing K^+ concentration and lowering the Na^+/K^+ ratio in cotton seed. As a result, the plants were more tolerant to high salt concentrations. According to Akram *et al.* (2009), higher concentrations of Na^+ in the presence of high salts in the rooting medium easily displaced K^+ from membrane binding sites, as a result, maintaining higher levels of endogenous K^+ with the application of organic manure which may be a viable strategy to maintain crop productivity when using brackish/saline water irrigation. Similarly, the higher K^+ concentration and lower Na^+/K^+ ratio in wheat grains had been reported by Ashraf *et al.* (2011) with combined application of organic manures and inorganic fertilizers.

Na^+/K^+ ratio in stalk/straw

The data (Fig. 1a) revealed that the Na^+/K^+ salt ratio in both crops was significantly increased under saline water irrigation. There was 60.0% and 49.83% lower Na^+/K^+ ratio in cotton stalk and wheat straw with canal water irrigation compared to saline water irrigation, respectively. Plants receiving saline water irrigation tend to collect more sodium, which can lead to symptoms of nutritional deficiencies, specific-ion effects, and ionic imbalance. An increasing ratio with salinity levels was the consequence of salinity causing a drop in potassium and an increase in sodium (Kalhoro *et al.,* 2016). The application of sodium salt dominated water resulted in 7.17% higher sodium in rice Shaydri-3 seedlings as compared to control which led to higher Na^+/K^+ in leaf (non-saline water, Khare *et al.,* 2015). Conversely, the salt ratio in wheat straw and cotton stalk was reduced by the application of FYM and sewage sludge. In cotton stalk, a significantly lowest Na^+/K^+ ratio (0.19) was reported with 100% RDN + 75% P & K + 10 Mg ha^{-1} FYM + ST-3 (T_7) compared to control (T_1). It was statistically at par with RDF (T_4). Application of 100% RDN + 75% P & K + 5 Mg ha^{-1} SS + ST-3 (T_8) also resulted in significantly lower Na^+/K^+ ratio (6.71%) in cotton stalk compared with control (T_1). However, in the case of wheat straw, the significantly lowest Na^+/K^+ ratio (0.75) was reported with 100% RDF (T_4) compared to control (T_1). The application of 100% RDN + 75% P & K + 10 Mg ha^{-1} FYM + ST-3 (T_7) resulted in a significantly lower Naz /Kz ratio in wheat straw compared to the control, and it was statistically at par with 75% RDF + 10 Mg ha^{-1} FYM + ST-3 (T_5). Similarly, the application of 100% RDN + 75% P & K + 5 Mg ha^{-1} SS + ST-3 (T_8) significantly reduced the Naz /Kz ratio compared to the control group (T_1), and this reduction was statistically at par to that observed with 75% RDF + 5 Mg ha^{-1} SS + ST-3 (T_6). It has been suggested that a balanced Naz /Kz ratio characterizes the plant stress tolerance response, ion homeostasis and this ratio may be utilized to predict tolerance/sensitivity in crops like cotton and wheat varieties (Hussain *et al.,* 2021). A plant's capacity to keep the Na^+/K^+ ratio low in its tissues is often associated with better growth performance. As with other salt-tolerant agricultural plants, acquiring K^+ ions has always been essential for maintaining a low Na^+/K^+ ratio. The addition of organic manures like FYM and SS decreases Na^+/K^+ ratio in plants owing to the fact that organic manure stores Na^+ in the form of Na-organic compounds. The reduction in Na^+ ions uptake favors an increase in K^+ accumulation under salinity stress thus reducing Na^+/K^+ ratio in plants. Similarly, Ashraf *et al.* (2017) observed

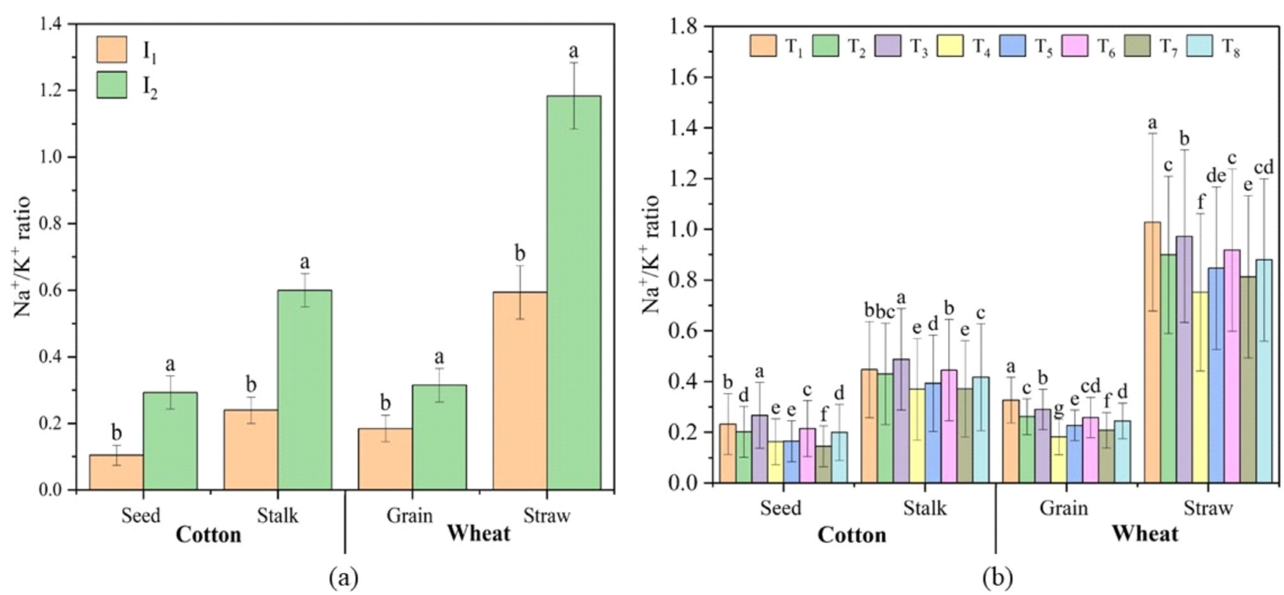

Fig. 1 Effect of **a).** irrigation water and **b).** FYM, SS and inorganic fertilizer application on Na^+/K^+ ratio in cotton and wheat cropping system. Data is represented as means with standard deviation and the different letters above error bars shows the statistical difference between various treatments. I_1: canal water (0.30 dS m^{-1} EC), I_2: saline water (8 dS m^{-1} EC), T_1: control (no fertilizer), T_2: FYM (10 Mg ha^{-1}), T_3: SS (5 Mg ha^{-1}), T_4: 100% RDF, T_5: 75% RDF+ 10 Mg ha^{-1} FYM + ST-3 (*Azotobacter*), T_6: 75% RDF+ 5 Mg ha^{-1} SS + ST-3, T_7: 100% RDN+ 75% P&K + 10 Mg ha^{-1} FYM + ST-3, T_8: 100% RDN + 75% P&K + 5 Mg ha^{-1} SS + ST-3

that application of FYM with inorganic manure decreased Na^+/K^+ ratio (500%) in shoot of sunflower.

Cl^-/SO_4^{2-} ratio in seed/grain

Similar to the Na^+/K^+ ratio the Cl^-/SO_4^{2-} ratio also was reported significantly higher with saline water irrigation in cotton seed and wheat grain compared to canal water irrigation (Fig. 2a). The Cl^-/SO_4^{2-} ratio was 63.96 and 57.84 percent lower with canal water irrigation in cotton seed and wheat grain compared with saline water irrigation, respectively. Similar to Na^+/K^+ ratio, the Cl^-/SO_4^{2-} ratio is essential for crops to be able to withstand salt stress. Previous research has shown that plants with higher salinity have higher chloride and lower sulfate contents (Yadav *et al.,* 2015). However, significantly lowest Cl^-/SO_4^{2-} ratio (5.32) in cotton seed was reported with application of 100% RDN + 75% P & K + 10 Mg ha^{-1} FYM + ST-3 (T_7) compared with control (T_1, Fig. 2b). However, it was statistically at par with 100% RDN + 75% P & K + 5 Mg ha^{-1} SS + ST-3 (T_8), 75% RDF+ 10 Mg ha^{-1} FYM + ST-3 (T_5), 100% RDF (T_4) and 10 Mg ha^{-1} FYM (T_2). While in wheat grain, the Cl^-/SO_4^{2-} ratio was non-significant among fertilizer/manure treatments. Mansour and Soliman (2022) reported higher leaching of Cl^- ions with FYM addition and decreased accumulation in soils under saline water application. The lower Cl^-/SO_4^{2-} ratio with organic manures like FYM and SS application might be due to lower uptake of Cl^- and its transport in the grain, thus balancing and reducing the Cl^-/SO_4^{2-} ratio in seed and grains (Ankush *et al.,* 2021).

Cl^-/SO_4^{2-} ratio in stalk/straw

The data revealed that Cl^-/SO_4^{2-} ratio in stalk/straw of cotton and wheat was significantly higher with saline water irrigation (Fig. 2a). The Cl^-/SO_4^{2-} ratio was found 63.27% and 68.94% lower with canal water irrigation in cotton stalk and wheat straw compared with saline water irrigation, respectively. The water used for saline irrigation was chloride dominated. It was also reported earlier that chloride dominant salinity has a more negative effect on physiological parameters of wheat than sulphate salinity due to high chloride uptake. The higher Cl^-/SO_4^{2-} ratio may be due to the higher mobility of Cl^- ion than SO_4^{2-} ion, therefore the uptake of chloride was also more than the sulphate ion (Asad *et al.,* 2022). Chloride also has an antagonistic effect with many plant nutrients (nitrogen, phosphorus and sulphate). The Cl^-/SO_4^{2-} ratio was reported significantly

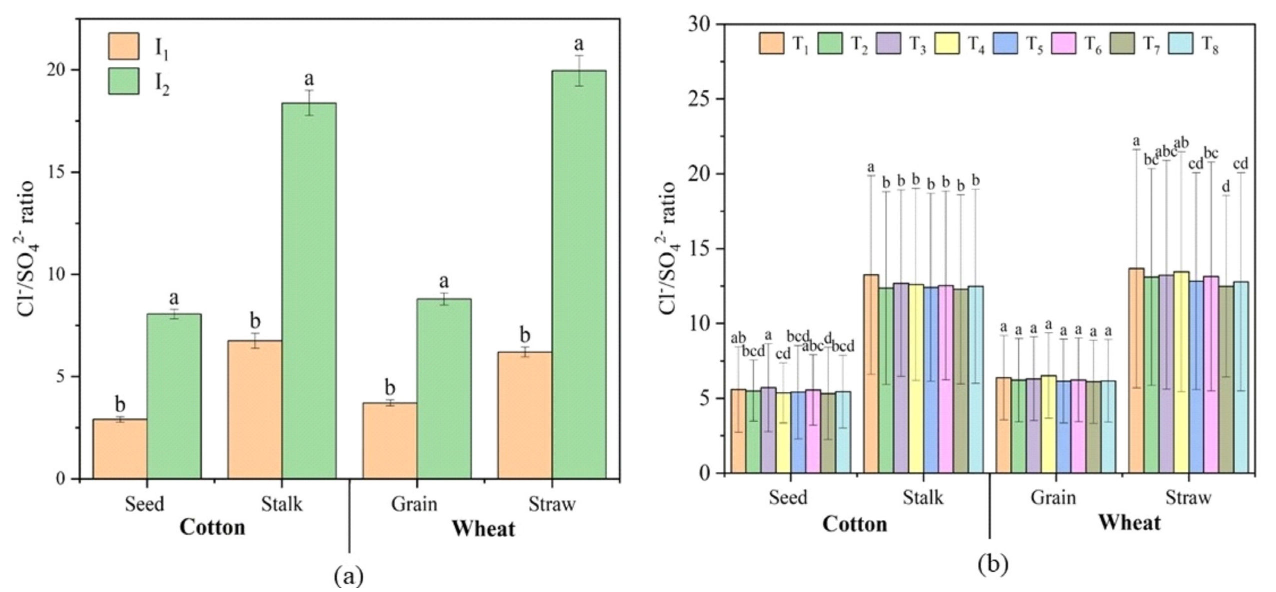

Fig. 2 Effect of **a).** irrigation water and **b).** FYM, SS and inorganic fertilizer application on Cl^-/SO_4^{2-} ratio in cotton and wheat cropping system. Data is represented as means with standard deviation and the different letters above error bars shows the statistical difference between various treatments. I_1: canal water (0.30 dS m^{-1} EC), I_2: saline water (8 dS m^{-1} EC), T_1: control (no fertilizer), T_2: FYM (10 Mg ha^{-1}), T_3: SS (5 Mg ha^{-1}), T_4: 100% RDF, T_5: 75% RDF+ 10 Mg ha^{-1} FYM + ST-3 (*Azotobacter*), T_6: 75% RDF+ 5 Mg ha^{-1} SS + ST-3, T_7: 100% RDN+ 75% P&K + 10 Mg ha^{-1} FYM + ST-3, T_8: 100% RDN + 75% P&K + 5 Mg ha^{-1} SS + ST-3

lower with all fertilizer and manure treatment in cotton stalk compared to control, however, it was non-significant among fertilizer and manure treatments (Fig. 2b). Similar trend was reported for Cl^-/SO_4^{2-} ratio among fertilizer/manure treatments in wheat straw as the Cl^-/SO_4^{2-} ratio was reported significantly lowest (7.05) with 100% RDN + 75% P & K + 10 Mg ha^{-1} FYM + ST-3 (T_7) compared with control (T_1). It was statistically at par with 100% RDN + 75% P & K + 5 Mg ha^{-1} SS + ST-3 (T_8) and 75% RDF + 10 ha^{-1} FYM + ST-3 (T_5). Since chloride dominated the water used to irrigate the crops, the lower Cl^-/SO_4^{2-} ratio in our experiment may have resulted from competition between Cl^- and SO_4^{2-} ions, where an overabundance of chloride ions prevented the plants from absorbing sulphate. When comparing fertilizer treatments, the Cl^-/SO_4^{2-} ratio in wheat straw and cotton stalk was lowered by applying FYM and sewage sludge. The composition of the FYM and SS added to crops may be the cause of the lowered Cl^-/SO_4^{2-} ratio. A unified strategy to salinity through sulfur metabolism is not known, but it is thought that the transition of S metabolism in plants will assist to mitigate the negative impacts of salinity as its metabolites affect different plant activities (Khan *et al.,* 2014).

Conclusion

It was concluded that salty irrigation water significantly increased the salt ratios (Na^+/K^+ and Cl^-/SO_4^{2-}) in wheat and cotton crops. The integrated FYM + mineral fertilizers + ST-3 (*Azotobacter*) and SS + mineral fertilizers + ST-3 (*Azotobacter*) application, on the other hand, showed noticeably reduction in salt ratios across various fertilizer treatments.

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