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Original Article

Sustainable use of brackish water for cotton wheat rotation

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Abstract

The challenge of 21st century is to meet the food, fuel and fiber requirement of an increasing world population on a sustainable basis. Moreover, drought conditions, increasing demands of freshwater for agriculture and industrial sector has forced the farming community to pump more and more groundwater which is of marginal quality. This marginal quality water can be successfully used to increase agricultural productivity by preventing soil degradation if suitable management approaches are coupled with proper amendments. Therefore, a field study was conducted to manage the deleterious effects of brackish water for the sustainable production of cotton and wheat crops. The treatments tested were; T_1: Control [Brackish Water (BW)], T_2: BW + Gypsum application @ 100% on the basis of RSC of water, T_3: BW + H_2SO_4 @ 50% application on the basis of RSC of water, T_4: BW + Poultry manure @ 10 t. ha^{-1}, T_5: BW+ Press mud @ 10 t. ha^{-1}. A non-saline field (EC_e = 2.34 dS m^{-1}, pH_s = 8.15 and SAR = 8.58) was selected, leveled, and prepared. The experimental design was RCBD with four repeats. Cotton-wheat cropping system was followed. Brackish water was used {EC = 1.17 dS m^{-1}, SAR = 6.75 and RSC = 5.30 me L^{-1}} for irrigation. Data regarding different physiological and yield parameters were recorded at maturity. Pooled data analysis of three years showed that continuous use of brackish water significantly reduces the yield of cotton and wheat crops. However, the negative effects of brackish water were counteracted by all applied amendments while chemical amendments were more efficient in ameliorating the detrimental effects of brackish water. Maximum seed cotton yield (2.50 t. ha^{-1}) for cotton and grain yield (4.32 t. ha^{-1}) for wheat was recorded in T_2: BW + Gypsum application @ 100% on the basis of RSC of water followed by T_3: BW + H_2SO_4 @ 50% application on the basis of RSC of water. Soil analysis data showed that EC_e, pH_s and SAR were considerably improved with all the applied amendments as compared to control.

Keywords: Cotton, Wheat, Gypsum, Brackish water, Poultry manure

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Introduction

Due to prevailing drought conditions and limited available water resources, Pakistan is one of the most water-stressed countries of South Asia. Under the circumstances of imbalance in water supply and water demand, farmers are forced to pump the groundwater to meet crop requirements. Currently, approximately

60% of the irrigation water is being pumped (Chaudhry, 2010) and Pakistan is the third largest groundwater consumer country with more than 9% of the global groundwater withdrawal (Giordano, 2009). However, 70-75% of groundwater is brackish (Ghafoor et al., 1991) which may also result in secondary salinization of soil due to its misuse for crop production. Therefore, to utilize brackish water for sustainable agriculture and preventing salinization in the soil; special management practices e. g. conjunctive use of canal water and brackish water, amelioration of brackish water with amendments, and some other agronomic practices are needed (Minhas et al., 1995; Sharma and Minhas 2005). Many researchers developed various approaches by using different amendments like gypsum, sulfur, chemical fertilizers and organic amendments to avoid the risk of poor quality groundwater on crop growth (Gharaibeh et al., 2009; Ghafoor et al., 2010).

Qureshi et al. (2015) adopted three strategies to grow the cotton crop i) brackish water ii) canal water iii) mixing of canal water and marginal quality (1:1 ratio). They stated that maximum seed cotton yield was documented with canal water while marginal quality groundwater reduced the yield up to 53%. Avais et al. (2018) evaluated the effect of brackish water (EC_{iw}= 1.34 dS m^{-1}, SAR = 12.72 and RSC= 8.50 me L^{-1}) on Raya and Sunflower crops. They concluded that the gypsum @ 100% GR of water and poultry manure @ 10 t. ha^{-1} were the best strategies to counteract the detrimental effects of brackish water on crops and preventing secondary salinization in soil. Poor quality groundwater can be used for rehabilitation of sandy clay loam problematic soil and subsequent crop production if gypsum is increased by 25 % of soil gypsum requirement (Zaka et al., 2018). Gypsum @ of 100% gypsum requirement of soil is the most effective technology to combat irrigation-induced salinity (Abro et al., 2007). Brackish water can be safely used for the production of cotton and wheat crops without substantial loss to soil health if gypsum is applied @ 100% water gypsum requirement (Murtaza et al., 2002). Gypsum application, double to Na^+ contents of brackish water is the most effective strategy to improve the crop yield on a sustainable basis and to avoid water-induced salinity in soil due to its continuous and indiscriminate use (Hussain et al., 2000).

Organic material e.g. poultry manure, press mud and farmyard manure can be effectively use to counteract the hazardous effects of saline water with less risk of yield reduction in field crop and soil degradation (Ashraf et al., 2005). Organic materials can also be used in calcareous soils to alleviate the hazardous of saline water by mobilizing native $CaCO_3$ of soil (Choudhary et al. 2004). FYM application not only decreased the soil salinity indicators like pH and sodicity but also improved the yield of rice and wheat by 8% and 10% respectively when irrigated with brackish water of RSC = 5.6, meq/L, EC_{iw} = 3.2 dS m^{-1} and SAR =11.3 (Minhas et al. 1995). FYM and gypsum act synergistically in improving the sugarcane yield when brackish water is used for irrigation purposes (Choudhary et al., 2004). Gypsum and farmyard manure both are equally effective for decreasing EC_e, pH_s and SAR of soil even if saline water is used for the reclamation purpose and the highest net benefit for rice-wheat crop was observed for farmyard manure followed by gypsum (Kahlon et al., 2012). The addition of farmyard manure and potassium could be an effective strategy to exploit saline- irrigation water (Ashraf et al., 2017).

So the objective of this work was to facilitate the safe use of brackish groundwater for cotton-wheat cropping system by employing suitable strategies and practices which will not only alleviate the detrimental effects of brackish water on crop yield but also prevent the water-induced secondary salinity in the soil.

Material and Methods

A field study was conducted from 2013 to 2016 following cotton-wheat crop rotation on a permanent layout at Soil Salinity Research Institute, main campus, Pindi Bhattian, Punjab, Pakistan to manage the deleterious effects of saline water for sustainable production of cotton and wheat in normal soil (pH_s (pH of soil saturated paste) = 8.15, EC_e = 2.34 dS m^{-1} and SAR = 8.58, $CaCO_3$= 1.1%, texture = Loam). The treatments used were;

T_1: Control [Brackish Water (BW)],
T_2: BW + Gypsum application @ 100% on the basis of RSC of water,
T_3: BW + H_2SO_4 @ 50% application on the basis of RSC of water,
T_4: BW+ Poultry manure @ 10 t. ha^{-1},
T_5: BW + Press mud @ 10 t. ha^{-1}.

The experiment was laid out in RCBD with four repeats with a plot size of 6m x 4m. Chemical composition of used brackish water was {EC = 1.17

dS m^{-1}, RSC = 5.30 me L^{-1} and SAR = 6.75}. During Kharif 2013, land was prepared and cotton (cv. FH-942) was sown in 2nd week of June, keeping a distance of 75 cm between rows and 30 cm between plants on raised beds. The recommended dose for cotton was 150-60-50 NPK kg ha^{-1}, P as single super phosphate, K as sulfate of potash was applied at the time of sowing while the first dose of N as urea was applied at the time of sowing and the remaining balance in two splits with 2nd and 3rd irrigations. All amendments except H_2SO_4 were applied 15 days before sowing of the cotton crop once in each year. Sulfuric acid (95 % pure) was applied with each irrigation. Amendments rates were as: gypsum @ 100% on water RSC basis = 12.36 Kg 70% pure gypsum / plot / year, H_2SO_4 application @ 50 % of water RSC = 1.91 L / plot / year, poultry manure = 24 Kg / plot / year, press mud = 24 Kg / plot / year. Recommend cultural practices and plant protection measures were followed. The cotton crop was harvested in 2nd week of November and data regarding plant height, number of monopodial and sympodial branches per plant, number of bolls per plant, weight per boll and seed cotton yield was recorded. After the harvest of cotton, in the same layout wheat crop (cv. Faisalabad 2008) was sown in 3rd week of November with a spacing of 23cm between rows. The recommended dose of fertilizer @ 120-110-70 NPK kg ha^{-1} was used for wheat. P as single super phosphate, K as sulfate of potash were applied at the time of sowing while the first dose of N as urea was applied at the time of sowing and the remaining balance in two splits with 2nd and 3rd irrigations was applied. Standard cultural practices and plant protection measures were followed throughout the season uniformly. The crop was harvested in the last week of April and data regarding plant height, number of tillers m^{-2}, spike length, 1000 grain weight, grain and straw yield were recorded at maturity.

Statistical analysis

Data collected for three seasons were pooled up and analyzed statistically, treatment differences were evaluated by using the LSD test (Steel et al., 1997). Post-harvest soil samples were collected after harvesting of each crop and analyzed for EC_e, pH_s and SAR following the methods described by US Salinity Laboratory Staff (1954).

Results

Cotton crop

Pooled data analysis revealed that the use of brackish water without any amendment had detrimental effects on the cotton growth, on contrary, the addition of amendments mitigated the harmful effects of brackish water and significantly improved the growth and yield of the cotton crop. Data for plant height divulged that the highest plant height (113.73 cm) could be documented on gypsum application @ 100% gypsum requirement of water, followed by press mud @ 10 t. ha^{-1} while both treatments were statistically ($P < 0.05$) non-significant with each other (Table-1).

Table-1: Effect of different treatments on cotton growth irrigated with brackish water (average of three seasons)

Treatments	Plant height (cm)	No. of Monopodial branches/plant	No. of sympodial branches/plant
T_1: Control [Brackish Water (B W)]	106.65 C	1.33 B	18.66 D
T_2: BW + Gypsum application@ 100% on the basis of RSC of water	113.73 A	3.00 A	27.66 A
T_3: BW + H_2SO_4 @50% application on the basis of RSC of water	111.80 B	2.00 AB	26.00 AB
T_4: BW+ Poultry manure @10 t ha^{-1}	109.60 B	1.66 AB	22.33 C
T_5: BW+ Press mud @ 10 t ha^{-1}	112.45 AB	1.66 AB	25.33 B
LSD	2.8591	1.5564	2.0626

Conversely, the lowest plant height (106.65 cm) was observed where brackish water was used alone without any amendments (control). Data regarding the monopodial and sympodial branches unfolded that maximum number of monopodial (3.00) and sympodial (27.66) branches per plant was observed when gypsum @ 100% GR of RSC of water was applied as remedial strategy, however, statistically ($P < 0.05$) it was similar to H_2SO_4 @ 50% RSC of water. While the lowest number of monopodial (1.33) and sympodial (18.16) branches per plant were recorded where brackish water was used. As far as the number of bolls and weight of bolls was concerned, a maximum mean value for the number of bolls per plant (23.00) and weight of bolls (3.92 g) was achieved with gypsum application.

However, it was statistically ($P < 0.05$) alike with all other applied amendments (Table-2).

Data regarding seed cotton yield showed that continuous use of saline water, without any amendments, negatively affected the seed cotton yield, on contrary, all the remedial strategies counteracted the harmful effects of brackish water (Table-2). Gypsum @ 100% GR of RSC of water recorded maximum seed cotton yield (2.50 t. ha^{-1}), though, it was statistically similar with H_2SO_4 @ 50% RSC of water and poultry manure @ 10 t ha^{-1}. Whereas minimum seed cotton yield of 2.50 t. ha^{-1} was recorded where high RSC brackish water was used for irrigation without any amendments.

Table-2: Effect of different treatments on cotton growth irrigated with brackish water (average of three seasons)

Treatments	No. of bolls/ plant	Weight of boll (gm)	Seed Cotton (t. ha^{-1})
T_1: Control [Brackish Water (B W)]	20 A	3.74 B	2.19 C
T_2: BW + Gypsum application@ 100% on the basis of RSC of water	23 A	3.92 A	2.50A
T_3: BW + H_2SO_4 @50% application on the basis of RSC of water	22 A	3.86 A	2.43 AB
T_4: BW+ Poultry manure @10 t ha^{-1}	21 A	3.88 A	2.35 ABC
T_5: BW+ Press mud @ 10 t ha^{-1}	23 A	3.83 AB	2.31 BC
LSD	3.7316	0.1161	0.2028

Wheat crop

Mean average value (Table 3 and 4) depicted that brackish water irrigation produced significant drastic effects on wheat growth, yield, and yield attributes. Nevertheless, all applied amendments alleviated the harmful effect of brackish water and gypsum proved more superior over other treatments. The tallest plants (68.83 cm) were recorded by gypsum (@ 100% GR of RSC of water) but statistically, no significant difference was observed among all the applied amendments. Data for the number of tillers and spike length revealed that the maximum number of tillers and spike length of 222.33 and 9.60 cm respectively were produced by gypsum followed by H_2SO_4 @ 50% RSC of water and both treatments were alike ($P < 0.05$). Whereas the minimum number of tillers (160.33) and spike length (7.83 cm) were observed in control (brackish water). As far as 1000 grain weight was concerned, gypsum produced the highest 1000 grain weight of 31.83 g which was statistically similar to H_2SO_4 @ 50% RSC of water and poultry manure @10 t. ha^{-1}. At the same time, control treatment (brackish water) recorded the minimum 1000 grain weight of 25.20 g. With respect to grain and straw yield, gypsum showed its supremacy over all other amendments. Maximum grain (4.32 t. ha^{-1}) and straw (6.05 t. ha^{-1}) yield were noted where gypsum was applied as a remedial strategy followed by H_2SO_4 @ 50% RSC of water. Whereas irrigation with brackish water significantly reduced these yield attributes and produced the minimum grain and straw yield of 3.63 and 4.71 t. ha^{-1} respectively.

Table-3: Effect of different treatments on wheat growth irrigated with brackish water (average of three seasons)

Treatments	Plant height (cm)	Number of tillers m^{-2}	Spike length (cm)
T_1: Control [Brackish Water (B W)]	54.66 B	160.33 D	7.83 C
T_2: BW + Gypsum application@ 100% on the basis of RSC of water	68.83 A	222.33 A	9.60 A
T_3: BW + H_2SO_4 @50% application on the basis of RSC of water	68.00 AB	212.67 AB	9.13 AB
T_4: BW+ Poultry manure @10 t ha^{-1}	67.50 AB	202.67 B	9.16 AB
T_5: BW+ Press mud @ 10 t ha^{-1}	65.66 AB	184.33 C	8.86 B
LSD	13.393	16.436	0.5952

Soil properties

Soil data analysis at the end of the study revealed that continuous use of brackish tube well water, without any amendment, adversely affected the soil properties, while on contrary all the applied amendments counteracted the detrimental effect of brackish water (Table 5). With respect to control, maximum reduction (3.69 %) in soil pH_s was recorded by gypsum application at the rate of 100% GR of RSC of water followed by H_2SO_4 @ 50% RSC of water (3.45%) whereas, poultry manure and press mud reduced the pH_s value by 2.26 and 2.38 % respectively. A similar tendency was noted in the case of soil EC_e, maximum reduction (18.40 %) over control was observed with gypsum followed by H_2SO_4 (1.73 %). Similarly, gypsum and H_2SO_4 neutralized the effect of brackish water and reduced the SAR value by 46.28 and 42.56 % respectively.

Table-4: Effect of different treatments on wheat growth irrigated with brackish water (average of three seasons)

Treatments	1000 grain weight (g)	Grain yield	Straw yield
T_1: Control [Brackish Water (B W)]	25.20 C	3.63 D	4.71 E
T_2: BW + Gypsum @ 100% RSC of water	31.83 A	4.32 A	6.05 A
T_3: BW + H_2SO_4 @50% RSC of water	30.83 A	4.09 B	5.68 B
T_4: BW+ Poultry manure @10 t ha^{-1}	30.33 A	3.89 C	5.29 C
T_5: BW+ Press mud @ 10 t ha^{-1}	27.93 B	3.77 C	4.98 D
LSD	1.6237	0.1364	0.1853

Table-5: Effect of different amendments on soil chemical properties at the end of the study

Treatments	pH_s	% decrease over control	ECe (dS $^{m-1}$)	% decrease over control	SAR	% decrease over control
T_1: Control [Brackish Water (B W)]	8.39	------	2.88	------	15.88	-----
T_2: BW + Gypsum @ 100% RSC of water	8.08	3.69	2.35	18.40	8.53	46.28
T_3: BW + H_2SO_4 @50% RSC of water	8.10	3.45	2.40	16.66	9.12	42.56
T_4: BW+ Poultry manure @10 t ha^{-1}	8.20	2.26	2.42	15.97	11.53	27.39
T_5: BW+ Press mud @ 10 t ha^{-1}	8.19	2.38	2.47	14.23	11.76	25.94

Discussion

Results of the current study elaborated that the organic (poultry manure and press mud) and inorganic (gypsum and H_2SO_4) amendments effectively alleviated the ill effect of brackish water, however, gypsum proved more superior over other amendments. On the contrary, brackish water significantly decreased the growth, yield and yield characteristics in cotton and wheat crops. Brackish water, generally, contains different toxic cations (Na^+, Ca^{2+}) and anions (HCO_3^-, and CO_3^{2-}) which negatively affects the soil-water-plant relations and increases the root zone soil salinity and as a result, normal physiological activities of the crops are suppressed (De Pascale et al., 2013; Plaut et al., 2013). The results of the study showed that irrigation with brackish water induces a severe diminution in growth and yield characteristics of cotton and wheat crops. Poor quality groundwater may reduce the seed cotton yield by 53% in comparison to canal water (Qureshi et al., 2015). Saline water increases the salt concentration in soil (Singh et al., 2009), as it was observed in this study that soil salinity indicators e.g. EC_e and SAR increases with continuous use of brackish water in control treatment (Table 5). As a result, growth and yield attributes of cotton and wheat crops are adversely affected. Toxic salt concentration in root zone inhibits the uptake of macro and micronutrient, a phenomenon of hypersaline environment known as a nutritional imbalance which results in a stunted plant, less number of branches/tillers, reduced number/weight of bolls and consequently the final yield of cotton and wheat crop is reduced. Root zone salinity produced a stressful effect on flowering and boll formation in cotton (Anjum et al., 2005; Hu et al., 2013), while boll weight is directly proportional to the rate of photosynthesis (Anjum et al., 2005) which decreases under the saline environment.

According to Tekin et al. (2014), if wheat crop is continuously irrigated with brackish water during the growth, the grain filling will be negatively affected. So poor growth performance and reduced crop productivity with saline water irrigation in control treatment may be correlated to more negative osmotic potential (Tester and Davenport, 2003), nutritional imbalance, uptake of toxic ions (Na^+ and Cl^-), water deficit, alteration in certain hormonal activities, oxidative stress and retarding the mobilization rate of metabolites (Moosavi et al., 2013). Our results are inconsistent with earlier findings of many researchers who reported that saline water irrigation negatively affected the growth of cotton (Gandahi et al., 2017; Qureshi et al., 2015) and wheat crop (Mojid et al., 2013; Kumar et al., 2017).

On the other hand, all the amendments effectively mitigated the harmful effect of brackish water. Any substance which is a direct source of Ca^{2+} or mobilizes the native $CaCO_3$ of soil can be used successfully as an amendment to alleviate the detrimental effect of brackish water (Muhammad and Khattak, 2011). However, the feasibility of any amendments whether to use or not would be adjudged from their efficacy in improving soil health and crop growth, its accessibility, economics, and ease of handling (Abd El-Hady and Shaaban, 2010). As amendments application is a recurring need for brackish water, the effects of different amendments have been studied at large scale. Gypsum is the most economical and easily accessible source of soluble calcium (Feizi et al., 2010) which replaces the Na^+ from the exchange site and prevents its accumulation in soil (Ghafoor et al., 2008). According to Malik et al. (2015) application of gypsum, farmyard manure and growing of salt-tolerant crops is an effective strategy to manage the brackish water on salt-affected soil. Gypsum, as an amendment, improves the physical and chemical properties of salt-affected soil and increases the porosity of soil which in turn allows easier root penetration and healthier crop growth (Walia and Dick, 2016). Gypsum (25-50 %), with or without farmyard manure, must be used for the management of brackish water on calcareous saline-sodic soils (Saifullah et al., 2002). Gypsum and organic material, along with recommended doses of fertilizer, is a pre-requisite to improve the production of rice-wheat cropping system in areas where brackish groundwater is used for irrigation purposes (Yaduvanshi and Swarup, 2006). Gypsum and organic material improve the soil health and gypsum proved economical amendment for reclamation (Qadir et al., 2017). Singh et al. (2002) reported an increase of 221 kg ha^{-1} over canal water when gypsum and farmyard manure were applied to mitigate hazardous of brackish water. Gypsum precludes the development of water-induced secondary salinity in soil by neutralizing the adverse effects of high sodium (Hamza and Anderson, 2003) and act as soil modifier by preventing the build of salt, because the minimum value of EC_e and SAR in our study were documented where gypsum was used as an amendment (Table 5). So the better yield of cotton and wheat crop in treatment receiving gypsum may be explained by the fact that gypsum provides the soluble Ca^{2+} which mitigate the toxic effect of sodium, furthermore, crops also took the advantages of the improved soil chemical and physical properties resulting in more crop growth and yield in this treatment (Mohamed et al., 2012; Ahmed et al., 2015) and thereafter, higher number of branches/tillers, and number and weight of bolls resulted from a maximum grain yield of wheat and seed cotton yield in this treatment.

Similarly, a research study revealed that the application of organic material is also an effective strategy for the amelioration of saline soil (Pang et al., 2010). Addition of organic material help to promote the sustainability of the agricultural system by improving the quantity and quality of agricultural produce (Liu et al. 2008) and the biological, chemical, and physical characteristics of soil (Ould-Ahmed et al., 2010). Organic matter acts as soil conditioner (Garg et al., 2005), it not only prevents the build of toxic salts but also conserves the fertility status of soil on a long term basis (Yu et al., 2010). However, the determination of the optimal dose of organic amendments is very critical to avoid toxicity and deficiency of mineral nutrients (Oustani et al., 2015). After decomposition, organic material provides N, P, and K (Urselmans et al., 2009; Moler and Stinner, 2009) and enhanced the microbial activities in soil that results more nutrients uptake and root proliferation (Fageria and Baligar, 2005) which in turn had more yield attributing factors of cotton and wheat crop in treatments receiving poultry manure or press mud as compared to control (without any amendment). Among organic amendments, poultry manure showed its superiority over press mud in increasing growth characteristics and final yield of cotton and wheat crop which might be ascribed to rapid decomposition, more solubility and release of nutrients from poultry manure (Avais et al., 2018). Results of this study are inconsistent with previous findings (Abro et al., 2007; Avais et al., 2018; Zaka et al., 2018) who reported that gypsum, poultry manure and press mud application are very effective strategies to prevent the build of toxic salts in soil due to brackish water irrigation and had positive effects on soil health by improving the soil porosity, allow the easier root penetration and more nutrient uptake which results in improved crop growth and yield.

Indiscriminate use of saline waters without any suitable management approach poses grave risks to the environment and soil health (Minhas and Samra, 2003). Similarly, in current study soil analysis data revealed that continuous use of brackish water resulted in an increased in soil salinity indicators like EC_e, pH_s and SAR. A slight increase in pH_s and EC_e was observed but at the same time, SAR was significantly increased over its initial value. This increased in soil chemical properties (EC_e, pH_s and SAR) may be attributed to an accumulation of Na^+ due to the high RSC of brackish water (Avais et al., 2018). Similar findings were reported by (Cucci and Lacolla, 2013; Iqbal et al., 2014) that irrigation with saline water resulted in progressive salinization and sodification of soil.

However, at the same time, all the remedial strategies used counteracted the detrimental effects of saline water and had positive effects on the soil chemical properties when compared with control (Table 5). Positive effects of amendments on soil chemical characteristics may be explained by the fact that higher concentration of ions like Ca^{2+}, K^{+}, etc. released from these amendments which reduced the detrimental effect of saline water due to leaching of Na^+ from the cation exchange complex (Kahlon et al., 2012). Likewise, the addition of organic material to the soil increased the chelation ability of Ca^{2+}, Mg^{2+}, and K^+ in the soil solution to replace Na^+ from the soil complex, leading to declining in SAR (Ashraf et al., 2015). Present results are in agreement with earlier findings (Izhar-ul-Haq, 2009; Zaka et al., 2018) reporting that gypsum and organic material were effective strategies to reduce the ill effects of brackish water.

Conclusion

Continuous use of brackish water without any amendments resulted in secondary salinization in soil with the significant increase of soil salinity indicators i.e. EC_e, pH_s and SAR. However, the application of organic and inorganic amendment prevents the buildup of toxic Na^+ in soil and improve the soil chemical properties, leading to a significant increase in growth and yield of cotton and wheat crops.
Gypsum @ 100 RSC of water showed its supremacy over other treatments and is recommended as the best management practice at the field level which prevents the build of salinity/sodicity in soil and provides the most favorable soil conditions for crop production.

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Ghulam Q: Conceived idea, analyzed the data, wrote the article and did overall management of the article.
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Saqib AI: Wrote abstract.
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