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COMPARATIVE RECLAMATION EFFICIENCY OF GYPSUM AND SULFUR FOR IMPROVEMENT OF SALT AFFECTED

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Abstract

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Salinization of soils or water is among the salient environmental stresses which impair productivity of all the arable crops. Damages induced by such stresses could be decreased by the application of certain soil amendments. Hence, a four-year field study was conducted to investigate comparative reclamation efficiency and economic feasibility of two sulfur sources i.e elemental sulfur and gypsum. Rice wheat crop rotation was adopted in a saline-sodic field (electrical conductivity of soil extract = 6.10 dS m^{-1}, pH of soil saturated paste = 9.21, sodium absorption ratio = 41.67 (mmol $L^{-1})^{1/2}$, SO_4-S = 16.0 (mg kg^{-1}) and soil gypsum requirement of 9.10 t ha^{-1} for 0-15 cm soil depth). The treatments included were: control, gypsum application @ 100% of soil gypsum requirement, sulfur application @ 25, 50, 75, 100 & 125% of soil gypsum requirement. Analysis of four-year pooled data indicated that varying levels of sulfur and gypsum significantly improved soil chemical properties and rice-wheat yield. Results showed that sulfur @ 125 & 100% of soil gypsum requirement gave similar results as that of gypsum @ 100% of soil gypsum requirement in terms of growth and yield of both tested crops and reducing pH, electrical conductivity and sodium absorption ratio of soil. However economic analysis proved the supremacy of gypsum @ 100% of soil gypsum requirement with second best treatment of sulfur @ 100% of soil gypsum requirement which could also use an alternative but slightly expensive amendment for improving the different qualities of salt affected soils and rice-wheat yield.

Key words: amendments, economics, rice, wheat, crop rotation, salinity
Abbreviations: EC_e (electrical conductivity of soil extract); pH_s (pH of soil saturated past); SAR (sodium absorption ratio); SGR (soil gypsum requirement); S (sulfur); BCR (benefit*:* cost ratio)

Introduction

Among environmental stresses, salinization is the leading widespread threat to sustainable crop production around the globe (Katerji et al., 2009); as about approximately 800 million hectares of land on this globe is subjected to salinity (Munns, 2005). Soil salinity considerably limits crop production especially in arid to semi-arid areas due to low rainfall and high evaporative demand and the consequences are damaging in both socioeconomic and environmental terms. Pakistan is situated in semiarid region of the world and more than 6.67 m ha land is exposed to salinity problem which is nearly 1/3rd of total cultivated area (Khan, 1998). Salt affected soils, are usually reclaimed by chemical methods (Qadir et al., 2007; Feizi et al., 2010) and may be used after reclamation (Chaudhary et al., 2004). Leaching of Na^+ from root zone is the most familiar and useful methods for lowering its buildup in salt affected soils (Ghafoor et al., 2008).

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Several products have been used as soil amendments for reclamation and improvement of saline and alkaline soils such as $CaCl_2$, H_2SO_4 and $CaSO_4$ and elemental sulphur (S) (Hilal and Abd-Elfattah, 1987). Calcium amendments can act as soil modifiers which improve various soil properties and prevent the development of salinity/sodicity hazards which is directly related to plant growth, crop productivity and crop yields (Muhammad and Khattak, 2011). Gypsum is typical source of calcium which replaces the Na^+ from exchange site and because of its low cost, availability and ease of handling (Amezketa et al., 2005) it is extensively used as amendment to counteract the injurious effects of high sodium leading to substantial decrease in soil electrical conductivity (EC) and sodium adsorption ration (SAR) (Hamza and Anderson, 2003).

Sulfur (S) is one of the essential nutrients for plant growth. Plants need sulfur in similar amount as that of phosphorus (De Kok et al., 2002; Ali et al., 2008). Sulfur is involved in synthesis of cystine, cysteine, methionine, chlorophyll, vitamins (B, biotin and thiamine) and helps in metabolism of carbohydrates, especially by its effect on the protolytic enzymes (Mengel and Kirkby, 2001; Marschnar 1995; Najar et al., 2011). Its fertilization in salt affected soils has definite impact on plant establishment as it increased nutrient use efficiency N, P, K and Zn in the plant due to its synergistic effect as well as it improves K^+/Na^+ selectivity and helps Na^+ exclusion of plant roots exposed to saline conditions (Ali et al., 2003; Aslam et al., 2001; Mahmood et al., 2009; Badr et al., 2002).

Elemental sulfur as soil amendment is recommended when soil pH exceeds 6.6 for the purpose of reducing pH and changes in soil pH can mobilize nutrients from unavailable phases to available pools therefore increasing P and micronutrient availability (Schueneman, 2001; Wei et al., 2006; Rice et al., 2006). On calcareous soils, added S under the effect of autotrophic bacteria slowly is oxidized: $S° \rightarrow S_2O_3^{2-} \rightarrow S_4O_6^{2-} \rightarrow S_3O_6^{2-} \rightarrow SO_3^{2-} \rightarrow SO_4^{2-}$ (Orlov et al., 2005). This SO_4 is further oxidized to H_2SO_4, which reacts with native Ca_2CO_3 to form $CaSO_4$ (gypsum) (El-Hady and Shaaban, 2010). Nevertheless $CaCO_3$ transformation into $CaSO_4$ with added sulfur increased Ca^{2+} in the soil phase which probably replaced the sodium in the colloidal complex consequently improving the soil EC_e, pH_s and SAR (Abdelhamid et al., 2013).

Sulfur inoculated with thiobacillus increased the yield of cowpea and yam bean and produced the favorable soil conditions by reducing pH from 8.2 to 4.7 and EC_e from 15.3 to 1.7 dS m^{-1} (Stamford et al., 2002). Sulfur application alleviated the detrimental effects of brackish water in *Dalbergia sissoo* (Azza et al., 2006). Root zone application of sulfur in sunflower increased the level of tolerance against salinity in terms of increased fresh and dry weight of plant (All et al., 2002). In saline conditions sulfur fertilization increased seed yield and yield components of canola (Al-Solimani et al., 2010). Kubenkulov et al., 2013 studied the reclamation efficiency of elemental sulfur of refinery and considered it the most comprehensible amendment for the soda-saline soils.

So keeping the above facts in viewed, a study was planned to evaluate the comparative reclamation efficiency and economic feasibility of varying levels of sulfur against gypsum for rice-wheat crop rotation in salt affected soils.

Materials and Methods

Description of Experimental Site

A field experiment was conducted for four consecutive years (2011 to 2014) following rice-wheat crop rotation i.e starting in July 2011 (rice) and ending in April 2014 (wheat) at Soil Salinity Research Institute, Pindi Bhattian, Pakistan to investigate the effect of varying levels of S through two sources (gypsum and elemental S) on chemical soil properties and productivity of rice wheat crop in terms of growth and yield parameters grown under salt affected conditions. The experimental site was fairly uniform and saline- sodic in nature. Before the first sowing of first crop, the soil had EC_e = 6.10 (dS m^{-1}), pH_s = 9.21, SO_4-S = 16.0 (mg kg^{-1}) and SAR = 41.67 $(mmol\ L^{-1})^{1/2}$ with soil gypsum requirement (SGR) of 9.10 t ha^{-1} for 0-15 cm soil depths.

Treatment Details

The experiment was laid out in randomized complete block design (RCBD) with three replications. The experiment was conducted in the same field with following seven treatments:

T_1 = Control
T_2 = S @ 25% of SGR
T_3 = S @ 50 % of SGR
T_4 = S @ 75 % of SGR
T_5 = S @ 100% of SGR
T_6 = S @ 125 % of SGR
T_7 = Gypsum @ 100% SGR

Elemental granular sulfur (90%) and gypsum (80% pure, 30 mesh size) were applied 30 days before sowing in respective treatment plots, followed by leaching with canal water at soil surface and maintaining a 7.5 cm water depth for 13 days. No amendment was added in the control plots. The treatments were replicated on plots with size 6 × 4 m^2. Twenty five days old rice seedlings of Shaheen Basmati were transplanted in July and were fertilized at the rate of 110, 90 and 60 kg ha^{-1} of nitrogen (N), phosphorus (P) and potassium

(K) as urea, single super phosphate and sulphate of potash. All P and K fertilizers and 50% N were applied at the time of transplanting whereas; remaining 50% N was applied after thirty days of transplanting. Chemical herbicides were used to control weeds. The $ZnSO_4$ (33%) at 12.5 kg ha^{-1} was also applied 10 days after rice transplanting. Crop was harvested at maturity. After harvesting of rice crop, wheat crop (Inqulab 91) was sown in Rabi season (November) within same layout. Recommended dose of fertilizer for wheat (120-110-70 NPK kg ha^{-1}) were applied. All cultural and management practices were performed uniformly as and when required.

Observations Recorded

The data regarding plant height, number of tillers, panicle/spikelet length, 1000-grain weight, paddy/grain and straw yield for both the crops (wheat and rice) were recorded at maturity. Before the start of experiment, and after the harvest of each crop in each season, composite soil samples from each experimental plot were collected and were analyzed for determination of soil pHs, ECe and SAR by following the methods as described by the US Salinity Lab. Staff (1954).

Statistical and Economic Analysis

The data collected during four years was pooled up and statistically analyzed following analysis of variance (ANOVA) technique under randomized complete block design while the least significance difference (LSD) test was used to compare the differences among treatment means (Steel et al., 1997). In order to appraise the economic feasibility of sulfur and gypsum used, an economic analysis was conducted (Shah et al., 2013).

Results

Effect of sulfur and gypsum on rice growth

Pooled data (average of four seasons) of rice crop showed that that varying levels of sulfur and gypsum had significant effect on the vegetative growth of rice crop. Data regarding plant height (Table 1) depicted that treatment using gypsum @ 100% SGR recorded the statistically ($P \leq 0.05$) maximum plant height (109.67 cm) which was followed by S @ 125 % of SGR (108.33 cm) and S @ 100 % of SGR (106.67 cm) however statistically all the treatments were at par. Whereas shortest plants (87.67 cm) were recorded in control where no amendment was used followed by S @ 25% of SGR. As far as No. of tillers are concerned pooled data of four consecutive seasons showed that maximum No. of tillers (151.00) were with application of gypsum @ 100% SGR followed by S @ 125 % of SGR and S @ 100 % of SGR with No. of tillers of (149.67) and (148.00) respectively and difference among these treatment was not large enough to reach level of significant ($P \leq 0.05$). While minimum No. of tillers (124.67) were recorded in control. Similar trend was observed in panicle length, gypsum @ 100% SGR produced maximium panicle length of 24.00 cm which was at par with S @ 125 % of SGR (23.70 cm) and S @ 100 % of SGR (23.80 cm) and minimum panicle length of 21.50 cm was produced in control.

Table 1

Comparative effect of gypsum and varying levels of sulfur on rice growth (Average of four years)

Treatments	Plant height, cm	No of tiller, m^{-2}	Panicle length, cm
Control	87.67 E	124.67 E	21.50 D
S @ 25% of SGR	92.67 D	130.00 D	22.56 C
S @ 50 % of SGR	96.67 C	137.33 C	22.80 BC
S @ 75 % of SGR	100.33 B	142.67 B	23.43 AB
S @ 100% of SGR	106.67 A	148.00 A	23.80 A
S @ 125 % of SGR	108.33 A	149.67 A	23.70 A
Gypsum @ 100% SGR	109.67 A	151.00 A	24.00 A
LSD	3.09	2.14	0.63

Means sharing the same small letters are statistically similar at *$P \leq 0.05$*

Yield attributes of rice crop were also proved superior (Table 2) with application of varying levels of sulfur and gypsum as compare to treatment where no amendment was applied (control). An obvious increased ($P < 0.05$) in paddy yield (4.18 Mg ha^{-1}) was observed where gypsum @ 100% SGR was applied over rest of treatments, followed by S @ 125 % of SGR (4.16 Mg ha^{-1}) and S @ 100 % of SGR (4.08 Mg ha^{-1}) nevertheless, these three treatments were statistically ($P< 0.05$) alike and lowest paddy yield at 1.81 Mg ha^{-1} was recorded in T_1 (control). Same trend was evidenced in pooled data of straw yield, peak value of 9.87 Mg ha^{-1} was obvious to be at gypsum @ 100% SGR followed by S @

Table 2

Comparative effect of gypsum and varying levels of sulfur on rice growth (Average of four years)

Treatments	Straw yield, Mg ha^{-1}	Paddy yield, Mg ha^{-1}	1000-grain weight, g
Control	4.27 E	1.81 E	18.25 D
S @ 25% of SGR	5.54 D	2.35 D	19.19 C
S @ 50 % of SGR	6.63 C	2.81 C	21.28 B
S @ 75 % of SGR	8.79 B	3.72 B	21.62 B
S @ 100% of SGR	9.63 A	4.08 A	23.35 A
S @ 125 % of SGR	9.81 A	4.16 A	23.37 A
Gypsum @ 100% SGR	9.87 A	4.18 A	23.38 A
LSD	0.30	0.12	0.61

Means sharing the same small letters are statistically similar at *$P \leq 0.05$*

125 % of SGR (9.81 Mg ha^{-1}) and S @ 100 % of SGR (9.63 Mg ha^{-1}) however statistically (P< 0.05) there were alike but significantly (P< 0.05) better over control with straw yield of (4.27 Mg ha^{-1}).

Thousand grain weights showed statistically (P< 0.05) significant differences with use of amendments over control (Table 2). Highest value (23.38 g) was ensue in treatment with application of gypsum @ 100% SGR which was at par with S @ 125% of SGR and S @ 100% of SGR while minimum thousand grain weight (18.25 g) was observed in control followed by S @ 25% of SGR.

Effect of sulfur and gypsum on wheat growth

Amendments application significantly enhanced the wheat growth than control (no amendment) (Table 3). Overall mean values for plant height (86.85 cm) and No. of tillers (398.00) were highest in gypsum @ 100% SGR followed S @ 125 % of SGR and S @ 100 % of SGR which were statistically alike. While T_1 (control) led to minimum plant height and No. of tillers of 71.36 cm and 360.00 respectively. In case of spike length, on an average maximum spike length (9.29 cm) were computed in gypsum @ 100% SGR followed S @ 125 % of SGR which were, however statistically at par among themselves. Lowest spike length (8.39 cm) was given by T_1 (control).

Table 3
Comparative effect of gypsum and varying levels of sulfur on wheat growth (average, four years)

Treatments	Plant height, cm	No. of tillers, m^{-2}	Spike length, cm
Control	71.36 E	360.00 E	8.39 F
S @ 25% of SGR	74.53 D	368.00 D	8.65 E
S @ 50 % of SGR	76.70 C	378.00 C	8.83 D
S @ 75 % of SGR	80.25 B	387.00 B	8.97 C
S @ 100% of SGR	86.30 A	396.00 A	9.16 B
S @ 125 % of SGR	86.75 A	397.00 A	9.26 AB
Gypsum @ 100% SGR	86.85 A	398.00 A	9.29 A
LSD	0.94	2.51	0.10

Means sharing the same small letters are statistically similar at $P \leq 0.05$

Use of amendments had pronounced effect on yield characteristics of wheat crop and magnitude of increase was more noticeable in amended field than field with no amendment used (Table 4). A progressive increase in grain and straw yield of 3.42 and 4.76 Mg ha^{-1} respectively was achieved with gypsum application @ 100% SGR which was statistically similar with S @ 125 % of SGR and S @ 100 % of SGR. While minimum grain and straw yield (2.00 and 2.76 Mg ha^{-1}) was exhibited in control.

With respect to thousand grain weight similar trend was observed, statistically (P< 0.05) maximum thousand grain weight (30.44 g) was accounted in gypsum @ 100% SGR followed by S @ 125 % of SGR (30.26 g) and S @ 100 % of SGR (30.05 g) however statistically there were alike in average thousand grain weight of four seasons.

Control (no amendment used) resulted statistically less value of 23.59 g for thousand grain weight.

Effect of sulfur and gypsum on soil properties

Results from our study revealed that regardless of the amendments used, soil chemical properties were substantially improved by all the treatments after four years of experimentation (Table 5). Varying levels of sulfur and gypsum @ 100% SGR considerably improved the soil chemical properties i.e pH_s, EC_e, SAR and SO_4-S contents. Among all the treatments S @ 125% of SGR dropped pH_s value by 6.94 % followed by gypsum @ 100% SGR lowering pH_s value by 6.84%, whereas with control decreased in pH_s was only 3.36% of their respective initial values. Similarly gypsum @ 100% SGR appreciably lowered the EC_e and SAR by 44.26% and 48.64% respectively and S @ 125% of SGR and S @ 100% of SGR lowered the EC_e and SAR by 44.59%, 43.44% and 49.60%, 45.83% respectively at the end of study. Soil S contents were also augmented with varying levels of sulfur and gypsum. Maximum addition in soil S contents (90.14 mg kg^{-1}) were noted in S @ 125% of SGR followed by S @ 100% of SGR (80.91 mg kg^{-1}) and gypsum @ 100% SGR (76.25 mg kg^{-1}) whereas, in control (no amendment used) sulfur content decreased to (14.6 mg kg^{-1})

Table 4
Comparative effect of gypsum and varying levels of sulfur on wheat growth (Average of four years)

Treatments	Straw yield, Mg ha^{-1}	Grain yield, Mg ha^{-1}	1000-grain weight, g
Control	2.76 D	2.00 D	23.59 E
S @ 25% of SGR	3.25 C	2.36 C	25.48 D
S @ 50 % of SGR	3.53 BC	2.57 C	27.06 C
S @ 75 % of SGR	3.71 B	2.87 B	28.70 B
S @ 100% of SGR	4.55 A	3.24 A	30.05 A
S @ 125 % of SGR	4.72 A	3.41 A	30.26 A
Gypsum @ 100% GR	4.76 A	3.42 A	30.44 A
LSD	0.41	0.25	0.71

Means sharing the same small letters are statistically similar at $P \leq 0.05$

Economic analysis

Economic feasibility in financial terms of any innovation or technique has primary importance in deciding its wider adoption among farming community.

Table 5
Soil analyses at the end of study

Treatments	pH_s	EC_e (dS m^{-1})	SAR (mmol L^{-1})$^{1/2}$	SO_4-S (ppm)
Control	8.90 (-3.36)	4.90 (-19.67)	33.57 (-19.43)	14.6 (-8.75)
S @ 25% of GR	8.79 (-4.56)	3.78 (-38.03)	27.00 (-35.20)	25.87 (+61.68)
S @ 50 % of GR	8.74 (-5.10)	3.57 (-41.47)	26.41 (-36.62)	25.01 (+56.31)
S @ 75 % of GR	8.70 (-5.53)	3.52 (-42.29)	24.00 (-42.40)	35.6 (+122.5)
S @ 100% of GR	8.60 (-6.62)	3.45 (-43.44)	22.57 (-45.83)	80.91 (+405.68)
S @ 125 % of SGR	8.57 (-6.94)	3.38 (-44.59)	21.00 (-49.60)	90.14 (+463.37)
Gypsum @ 100% GR	8.58 (-6.84)	3.40 (-44.26)	21.40 (-48.64)	76.25 (+376.56)

The values in parenthesis represent the percent decrease (-)/increase (+) in the respective soil properties

Table 6
Effect of varying levels of sulfur and gypsums on net income and benefit: cost ratio (BCR) of rice-wheat crop (Average of four years)

Treatments	Cost of production (Rs. ha^{-1})	Gross income (Rs. ha^{-1})	Net income (Rs. ha^{-1})	Benefit: cost ratio (BCR)
Control	33000	121302	88302	3.67
S @ 25% of SGR	34128	150106	115978	4.39
S @ 50 % of SGR	36257	171624	135367	4.73
S @ 75 % of SGR	40386	209663	169277	5.19
S @ 100% of SGR	42515	234372	191857	5.51
S @ 125 % of SGR	45651	241982	196331	5.30
Gypsum @ 100% GR	35560	243066	207506	6.83

note: 1 euro =135.2481 Rs

Economic analysis was carried out at the end of study to evaluate the best and economical sulfur level to be used as amendment for the amelioration of salt affected soils. Different sulfur levels and gypsum had significant effect on gross income, net income and benefit: cost ratio (BCR) of rice and wheat crops grown under saline-sodic conditions (Table 6).

However maximum BCR was recorded with gypsum @ 100% SGR followed by S @ 100% of SGR as compare to other treatments which may be due to more economic yield.

Discussion

Salt affected soils are usually reclaimed by chemical methods (Qadir et al., 2007; Feizi et al., 2010) and leaching of Na^+ from root zone is the most familiar and useful methods for lowering its buildup in salt-affected soils (Ghafoor et al., 2008). Recently several amendments are being used for reclamation and improvement of saline and alkaline soil such as $CaCl_2$, elemental sulfur (S), H_2SO_4 and $CaSO_4$ (Hilal and Abd-Elfattah, 1987). Gypsum is the most commonly used amendment for sodic soil reclamation because of its solubility, low cost, availability and ease of handling (Amezketa et al., 2005; El-Hady and Shaaban, 2010) but on calcareous soils with pH more than 6.6, sulfur may also be added which is microbiologically oxidized to sulfuric acid, which reacts with the native calcium carbonate to form gypsum (Balbaa, 1995; Wei et al., 2006). Results of our study revealed that varying levels of sulfur and gypsum significantly increased vegetative growth and yield attributes of rice and wheat crop than non-amended soil (control). Pooled data showed gypsum @ 100% SGR and S @ 100 & 125% of SGR basis proved best to improve the vegetative growth of rice and wheat crops in term of plant height, No. of tillers, panicle/spike length. Increased vegetative growth of rice and wheat with treatments receiving the gypsum and sulfur than untreated soils can be explained by the ameliorative role of these amendments in alleviating the harmful effects of salinity and sodicity by replacing the Na^+ from exchange site. After leaching of Na^+ from root zone, crop might also benefited by the improved physical properties of soil leading to more vegetative growth in these treatments (Hussain et al., 2001; Tzanakakis et al., 2011; Mohamed et al., 2012). Previously sulfur have been reported to have a definite impact on plant establishment under saline sodic environment in maize (Manesh et al., 2013; Badr et al., 2002) Dalbergia sissoo (Azza et al., 2006) and wheat (Ali and Aslam, 2005; Ali et al., 2012) which support the findings of this study.

Sulfur (S) is one of the essential nutrients for plant growth. It is required in similar amount as that of phosphorus (De Kok et al., 2002; Ali et al., 2008). It is a building block of protein and a key ingredient in the formation of chlorophyll (Kacar and Katkat, 2007; Scherer et al., 2008). Crops cannot reach their full potential regarding yield or protein content (McGrath, 2003; Gyori, 2005; Zhao et al., 1999; Blake-Kalff et al., 2000; Saini et al., 2005). Furthermore under salt stress, sulfur and calcium improve K^+/Na^+ selectivity and increases the action of Ca^{2+} in reducing the injurious effects of Na^+ in plants (Wilson et al., 2000). Similar results are observed in our study, that yield components of rice and wheat significantly increases with sulfur and gypsum application. Favorable soil pH affects crop nutrient availability (Wei et al., 2006) and it is very probable that reduced pH by sulfur and gypsum application in our study enhanced availability of macro and micronutrients like N (Chaubey et al., 1993; Motior et al., 2011), P (Singh and Kairon, 2001; Motior et al., 2011) Fe and Mn (Modaihsh et al., 1989; Motior et al., 2011) and Zn (Kayser et al., 2001; Singh et al., 1990) due to synergic effect leading to promotive effect on plant growth.

Our results coincide with the findings of different researchers who reported the beneficial effects of sulfur and calcium in growth and yield improvement of different crops (Mahmood et al., 2010; Hussain and Thomas 2010; Tanveer et al., 2013; Sarkar and Mallick, 2009; Najar et al., 2011).

Sol qualities

Composite soil sample were taken at end of study and analyzed for pH_s, EC_e, SAR and SO_4-S contents of soil. Results showed a sharp falling trend in salinity indicators (pH_s, EC_e and SAR) in all treatments receiving sulfur and gypsum than untreated soil (control). Since soil pH_s is a soil characteristic indicating an overall picture of the medium for plant growth, including nutrient availability, fate of added nutrients, and sodicity status, this change is very important. Elemental sulfur is considered as an adequate and cost effective amendment for lowering the pH value of the substrate (Roig et al., 2004; Kampf et al., 2006; Tarek et al., 2013) and this lowered pH as in our study may be due to formation of acid produced by added sulfur (Singh et al., 2006). Further release of Ca^{2+} from gypsum, which replaces the exchangeable Na^+ and its leaching from root zone might be the major reason of reduced pH_s, EC_e and SAR. Our results are inconsistent with finding of couple of studies that applied amendments (gypsum and sulfur) causes a substantial decrease in pH_s, EC_e and SAR of soil (Stamford et al., 2002; Abdel-Fattah, 2012; Abdelhamid et al., 2013; Kubenkulov et al., 2013; Muhammad et al., 2007).

Conclusion

Findings of the present study suggested that in salt affected soils, S @ 125 & 100% of SGR are as efficient as gypsum @ 100% of SGR, however, with respect to benefit cost ratio gypsum is the most economical amendment with second-best treatment of S @ 100% of SGR which could also be an effective, suitable but slightly expensive alternative amendment for improving the different qualities of salt affected soils and rice-wheat yield.

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