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STRATEGIES FOR SOIL AMELIORATION USING SULPHUR IN SALT AFFECTED SOILS

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ABSTRACT. Effective use of salt affected soils needs the development of the most efficient and suitable reclamation technology to optimize farm management and better crop yields. Different chemical methods and amendments are used to reclaim the salt affected soils and after reclamation such soils may be used for sustainable agricultural production. Choice of a chemical amendment depends on its availability, cost, handling and time of application. Application of sulfur is very effective technique to suppress the uptake of undesired toxic elements and to improve the quantity and quality of produce in salt affected soils. So, a three-year field experiment was carried out to evaluate the comparative reclamation efficiency of two sulfur sources, i.e elemental sulfur and gypsum to improve the soil conditions by reducing the salinity/sodicity impact and yield characteristics of rice and wheat crop. A saline-sodic field {(EC_e = 6.10 dS m^{-1}, pH_s = 9.21 and SAR = 41.67 (mmol $L^{-1})^{1/2}$, SO_4-S = 16.0 (mg kg^{-1}) and soil gypsum requirement (SGR) of 9.10 t ha^{-1} for 0-15 cm soil depth} was selected. The treatments included were: control, gypsum application @ 100 SGR, S application @ 25, 50, 57, 100 and 125 % of SGR. Statistical analysis of three-year pooled data showed that varying levels of sulfur and gypsum significantly improved soil properties and rice-wheat yield than control, however, gypsum @ 100% of soil GR was at par with S @ 125 and 100% of SGR in term terms of improving yield component of both test crops and reducing soil pH_s, EC_e and SAR. Efficiency of treatment could be arranged as gypsum @ 100% SGR = S @ 125 % of SGR= S @ 100% of SGR> S @ 75 % of SGR> S @ 50 % of SGR> S @ 25% of SGR>control.

Keywords: gypsum; sulfur; reclamation; rice; wheat; crop rotation; salinity.

Abbreviations used: 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)

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INTRODUCTION

Among environmental stresses soil salinity is one of the most important threats to sustainable agriculture of arid andsemi-arid regions of world (Rengasamy, 2010). Soil salinity, limitations of water, global food requirements and urbanization is forcing agriculture to more marginal lands (Fischer *et al.,* 2010). There is an imperative to develop an efficient and economical strategy for effective use of salt affected soils, which are, usually, reclaimed by chemical methods (Qadir *et al.,* 2007; Feizi *et al.,* 2010) and may be used after reclamation (Chaudhary *et al.,* 2004). Amelioration of impoverished degraded salt affected soils can be accomplishedthrough several amendments, such as $CaCl_2$, H_2SO_4 and $CaSO_4$ (Hilal and Abd-Elfattah, 1987; Qadir *et al.,* 2007).

In past decades research, to understand and to improve the salt affected soil was focused on gypsum, due to its comparatively low price, accessibility and easy application, as compare to other chemical amendments. However, as reported earlier, sulfur is also well known for amelioration and improvement of alkaline soils (Hilal and Abd-Elfattah, 1987).

Sulfur is an essential element for plant growth as it helps in synthesis of peptides, which contain cysteine like glutathione, various secondary metabolites (Scherer *et al.,* 2008; Abdallah *et al.,* 2010) vitamins (B, biotine and thiamine) and chlorophyll in the cell (Kacar and Katkat, 2007). Plants need sulfur in same amount as phosphorus (De Kok *et al.,* 2002; Ali *et al.,* 2008) and for the proper soil nutrient balance, optimizing crop yield and good quality produce it is very important to apply optimum amount of sulfur in the soil along with other nutrients, which are necessary for plant (Scherer, 2001; Jez, 2008).

Sulfur not only increasing crop production and quality of the produce, but also improves soil conditions for healthy crop growth (Tandon, 1991; Zhang *et al.,*1999; Abdou, 2006; El-Tarabily *et al.,* 2006). Application of S fertilizer in salt affected soils is a viable procedure to counteract uptake of unnecessary toxic elements (Na^+ and Cl^-), which encourage selectivity of K/Na and ability of calcium ion to decrease the harmful impacts of sodium ions in plants (Wilson *et al.,* 2000; Zaman *et al.,* 2002). Elemental sulfur is considered as an adequate and cost effective amendment for soda-saline soils (Tarek *et al.,* 2013) and recommended when soil pH exceeds 6.6 for the purpose of reducing pH this 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 group of autotrophic bacteria slowly is oxidized: $S° \rightarrow S_2O_3^{2-} \rightarrow S_4O_6^{2-} \rightarrow S_3O_6^{2-} \rightarrow SO_3^{2-} \rightarrow SO_4^{2-}$ (Jaggi *et al.,* 2005). This SO_4 as a result of S oxidation is further oxidized to

H_2SO_4, which reacts with the native $CaCO_3$ to form ($CaSO_4$ $2H_2O$), which is the cheapest soluble calcium source (Abd El-Hady and Shaaban, 2010) and in the soil solution; this dissolved calcium probably replaced the adsorbed sodium (Abdelhamid *et al.*, 2013). Kubenkulov *et al.* (2013) used elemental sulfur of refinery and reported it as most comprehensible amendment for the soda-saline soils. As reported earlier, sulfur is considered as an adequate and cost effective amendment for alkali soil reclamation (Tarek *et al.,* 2013; Kampf *et al.,* 2006). Beneficial effects of sulfur on plant establishment under saline sodic environment had also been reported in maize (Manesh *et al.*, 2013), Dalbergia sissoo (Azza *et al.*, 2006), sunflower (Zaman *et al.*, 2002), canola (Al-Solimani *et al.*, 2010) and wheat (Ali and Aslam, 2005; Ali *et al.*, 2012).

So keeping the above fact a study was planned to identify the optimum level of sulfur as an ameliorant for better yield of rice-wheat crop rotation in salt affected soils.

MATERIALS AND METHODS

Experimental site

A field study was carried for three consecutive years (2011 to 2013), following rice-wheat crop rotation, i.e starting in July 2011 (rice) and ending in April 2013 (wheat) at Soil Salinity Research Institute, Pindi Bhattian, Pakistan (altitude 184 m, latitude 31.8950° N and longitude 73.2706° E), to investigate the effect of varying levels of sulfur through two sources (gypsum and elemental sulfur) on chemical soil properties and productivity of rice wheat crop under salt affected conditions. The experimental site was fairly uniform, saline-sodic and loam (sand 45%, silt 30% and clay 25%) 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 depth. The average weather conditions were: 10.9 ± 2.3°C minimum temperature, 42.7 ± 2.8°C maximum temperature, 38.2 ± 4.5% minimum relative humidity, 72.6 ± 4.8% maximum relative humidity, maximum sunshine hours, 14 h and 9 min. and minimum sunshine hours,7 h and 33 min.

Treatments

The experiment was laid out with three replications under randomized complete block design (RCBD). The experiment was conducted in the same field, comprising 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%) andgypsum (80% pure, 30 mesh size) were applied 30 days before sowing in respective treatment plots and were leached with canal water for 15 days. There was no addition of any amendments in control plots. The treatments were replicated on plots with size 6×4 m^2. Rice seedlings (Shaheenbasmati) were transplanted in 2nd week of July and were fertilized @110, 90 and 60 kg ha^{-1} of NPK. Urea, single super phosphate (SSP) and sulphate of potash (SOP) were used as source of fertilizer. Whole amount of P and K fertilizers and 50% N were applied at transplanting of rice nursery while; remaining 50% N was applied after one month of transplanting. The application of $ZnSO_4$ (33%) @ 12.5 kg ha^{-1} was done after 10 days of transplanting. At maturity rice crop was harvested, and wheat crop (Inqlab 91) was sown in Rabi season (November), within same layout. Fertilizer, at the rate of 120-110-70 NPK kg ha^{-1}, was applied for wheat crop. All other agronomic practices were followed uniformly as and whenever required.

Observations recorded

Yield attributes paddy/grain and straw yield for both the crops (wheat and rice) were recorded at maturity. Composite soil samples were collected from each experimental plot and then analyzed for determination of soil pH_s, EC_e and SAR by following the methods as described by the US Salinity Lab. Staff, 1954. These soil samples were collected before the start of experiment and after harvesting of each crop in each season.

Statistical analysis

The data collected during three consecutive years were averaged and then analyzed statistically by using the technique of analysis of variance (ANOVA) under randomized complete block design and least significance difference (LSD) test at 0.05 probability was used for comparison of various treatments' means (Steel *et al.,* 1997).

RESULTS

Effect of sulfur and gypsum on rice grain yield (Mg ha^{-1})

Paddy yield is a critical yield attribute in rice production, which was affected significantly by all the treatments (*Table 1*). Average of three seasons showed that varying levels of sulfur and gypsum had significant effect on rice paddy yield (*Table 1*). Treatment using gypsum @ 100% SGR recorded the statistically ($P \leq 0.05$) maximum paddy yield (4.00 Mg ha^{-1}), which was followed by S @ 125 % of SGR (3.92 Mg ha^{-1}) and S @ 100 % of SGR (3.87 Mg ha^{-1}); however, statistically, all the treatments were at par. Whereas minimum paddy yield (1.89 Mg ha^{-1}) was recorded in control where no amendment was used, followed by S @ 25% of SGR.

Table 1 - Comparative effect of two sources of sulfur (sulfur and gypsum) on rice paddy yield (Mg ha^{-1})

Treatments	2011	2012	2013	Mean
Control	1.62 F	1.81 E	2.24 E	1.89 E
S @ 25% of SGR	2.13 E	2.35 D	2.98 D	2.48 D
S @ 50 % of SGR	2.79 D	2.81 C	3.54 C	3.05 C
S @ 75 % of SGR	3.14 C	3.51 B	3.72 B	3.46 B
S @ 100% of SGR	3.71 B	3.82 A	4.08 A	3.87 A
S @ 125 % of SGR	3.68 B	3.93 A	4.16 A	3.92 A
Gypsum @ 100% SGR	3.86 A	3.95 A	4.18 A	4.00 A
LSD	0.1260	0.1453	0.1812	0.2254

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

Effect of sulfur and gypsum on rice straw yield (Mg ha^{-1})

As far as straw yield is concerned mean value of three consecutive seasons showed statistically difference between the applied treatments and maximum straw yield (9.24 Mg ha^{-1}) were with application of gypsum @ 100% SGR (*Table 2*), followed by S @ 125 % of SGR and S @ 100 % of SGR with straw yield of (9.02 Mg ha^{-1}) and (8.89 Mg ha^{-1}), respectively, and difference among these treatment was not large enough to reach level of significant ($P \leq 0.05$). While minimum straw yield (4.55 Mg ha^{-1}) were recorded in control, followed by S @ 25% of SGR with paddy yield of 5.84 Mg ha^{-1}.

Table 2 - Comparative effect of two sources of sulfur (sulfur and gypsum) on rice straw yield (Mg ha^{-1})

Treatments	2011	2012	2013	Mean
Control	3.86 F	4.27 F	5.51 E	4.55 E
S @ 25% of SGR	5.10 E	5.54 E	6.88 D	5.84 D
S @ 50 % of SGR	6.69 D	6.82 D	7.40 C	6.97 C
S @ 75 % of SGR	8.06 C	8.35 C	8.79 B	8.40 B
S @ 100% of SGR	8.43 B	8.61 BC	9.63 A	8.89 A
S @ 125 % of SGR	8.55 B	8.68 B	9.81 A	9.02 A
Gypsum @ 100% SGR	8.86 A	8.98 A	9.87 A	9.24 A
LSD	0.2938	0.2806	0.4857	0.4006

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

Table 3 - Comparative effect of two sources of sulfur (sulfur and gypsum) on wheat grain yield (Mg ha^{-1})

Treatments	2011	2012	2013	Mean
Control	0.54 F	1.98 D	2.30 E	1.60 E
S @ 25% of SGR	1.31 E	2.34 C	2.55 D	2.06 D
S @ 50 % of SGR	1.57 D	2.55 C	2.92 C	2.35 C
S @ 75 % of SGR	1.76 C	2.85 B	3.23 B	2.61 B
S @ 100% of SGR	2.00 B	3.22 A	3.71 A	2.97 A
S @ 125 % of SGR	2.03 B	3.39 A	3.73 A	3.05 A
Gypsum @ 100% SGR	2.19 A	3.40 A	3.74 A	3.11 A
LSD	0.1550	0.2582	0.2393	0.1995

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

Effect of sulfur and gypsum on wheat grain yield (Mg ha^{-1})

Concerning the effect of different amendments on wheat grain yield, data showed a noticeable effect of all the treatment used than control (no amendment) (*Table 3*). Overall mean values for grain yield (3.11Mg ha^{-1}) was highest in gypsum @ 100% SGR, followed by S @ 125 % of SGR and S @ 100 % of SGR, which were statistically alike. While T_1 (control) led to minimum grain yield of 1.60 Mg ha^{-1}, in comparison with those of applied treatments.

Effect of sulfur and gypsum on wheat straw yield (Mg ha^{-1})

Use of amendments in salt affected soil had pronounced effect on straw yield characteristic of wheat crop and magnitude of increased was more noticeable than field with no amendment used (*Table 4*). A progressive increase in case of straw yield (4.73 Mg ha^{-1}) was computed in gypsum @ 100% SGR, followed by S @ 125 % of SGR and S @ 100 % of SGR which were, however, statistically at par among themselves. When compare these value with control, lowest straw yield (2.16 Mg ha^{-1}) was given bycontrol (T_1).

Table 4 - Comparative effect of two sources of sulfur (sulfur and gypsum) on wheat straw yield (Mg ha^{-1})

Treatments	2011	2012	2013	Mean
Control	1.18 F	2.55 D	2.75 E	2.16 D
S @ 25% of SGR	2.85 E	3.04 C	3.26 D	3.05 C
S @ 50 % of SGR	3.45 D	3.32 BC	3.61 C	3.46 BC
S @ 75 % of SGR	3.88 C	3.50 B	3.85 B	3.74 B
S @ 100% of SGR	4.56 B	4.34 A	4.78 A	4.56 A
S @ 125 % of SGR	4.58 B	4.51 A	4.82 A	4.64 A
Gypsum @ 100% SGR	4.77 A	4.55 A	4.89 A	4.73 A
LSD	0.1175	0.4104	0.1646	0.5855

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

Table 5 - Comparative effect of two sources of sulfur (sulfur and gypsum) on soil qualities after harvest of rice and wheat

Treatments	2011			2012			2013		
	pH_s	Ec_e	SAR	pH_s	Ec_e	SAR	pH_s	Ec_e	SAR
Control	9.00	4.15	36.56	8.98	4.12	36.36	8.92	4.92	33.88
S @ 25% of SGR	8.92	4.00	31.52	8.89	3.98	29.20	8.80	3.79	27.80
S @ 50 % of SGR	8.90	3.95	29.81	8.86	3.85	27.62	8.75	3.58	26.69
S @ 75 % of SGR	8.89	3.88	28.8	8.84	3.79	26.83	8.73	3.54	25.00
S @ 100% of SGR	8.86	3.85	28.48	8.83	3.78	24.91	8.62	3.46	22.80
S @ 125 % of SGR	8.85	3.82	27.86	8.82	3.76	24.82	8.58	3.40	21.70
Gypsum @ 100% SGR	8.85	3.80	25.10	8.81	3.75	20.22	8.60	3.41	21.40

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 three years of experimentation (*Table 5*). Nearly all salinity indicators, i.e pH_s, EC_e and SAR were gradually decreased with varying levels of sulfur and gypsum @ 100% SGR. Among all the treatments, S @ 125 % of SGR was most effective to dropped pH_s value by 6.84%, followed by gypsum @ 100% SGR lowering pH_s value by 6.62%, whereas with control decreased in pH_s was only 3.14% of their respective initial values. Similarly, gypsum @ 100% SGR appreciably lowered the EC_e and SAR by 44.09% and 60.04%, respectively, and S @ 125% of SGR and S @ 100% of SGR lowered the EC_e and SAR by 44.26%, 43.27% and 55.36%, 54.45%, respectively, at the end of study, and control (untreated) was less efficient in decreasing all these salinity indicators when, compared with the amendments.

DISCUSSION

Recently, several amendments are being used for amelioration of salt affectedsoil, such as $CaCl_2$, elemental sulphur (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, lowcost, availability and ease of handling (Amezketa *et al.,* 2005; Abd El-Hady and Shaaban, 2010). Nonetheless, present situation urge, the need of search of new types of amendments and, respectively, to technology of their application on the soda-saline soils. On calcareous soils with pH more than 6.6, sulfur may also be added which is microbiologically oxidized to H_2SO_4, which reacts with the native $CaCO_3$ to form gypsum (Balbaa, 1995; Wei *et al.,* 2006). Results of our study revealed that varying levels of sulfur and gypsum significantly ($P< 0.05$) increased yield attributes of rice and wheat crop than non amended soil (*Tables 1-4*). Mean value of three season depicted gypsum @ 100% SGR and S @ 100 and 125 % of SGR basis proved best to improve yield component of rice and wheat crops in term of paddy/grain and straw yield. Significant increase ($P< 0.05$) in these parameters 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 reproductive growth in these treatments (Hussain *et al.,* 2001; Tzanakakis *et al.,* 2011; Mohamed *et al.,* 2012). Significant yield increases in winter wheat with addition of S and Ca have been described by (Mahmood *et al.,* 2010).

Sulfur (S) is one of the essential nutrients for growth of plant. Its requirement is the same as of phosphorus (De Kok *et al.,* 2002; Ali *et al.,* 2008). Sulfur (S) is a building block of protein and plays a vital role in the synthesis of chlorophyll (Scherer *et al.,* 2008). Without optimum level of sulfur in soil, crops cannot reach their full potential regarding yield or protein content (McGrath, 2003; Gyori, 2005; Zhao *et al.,* 1999; Blake-Kalff *et al.,* 2001; Tarafdar *et al.,* 2005). Furthermore, sulfur and Ca improve K/Na selectivity and increases the action of Ca^{2+} in reducing the injurious effects of Na^+ in plants (Wilson *et al.,* 2000). Likewise, 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 essential plant nutrients, due to synergic effect with N (Chaubey *et al.,* 1993), P (Singh and Kairon, 2001; Rahman *et al.,* 2011) Fe and Mn (Modaihsh *et al.,* 1989) and Zn (Kayser *et al.,* 2001; Singh *et al.,* 1990), leading to promotive effect on plant growth. Previously, sulfur has been reported to have beneficial effects on plant establishment under saline sodic environment. Sulfur application help in alleviating the adverse effect of brackish water and improved the growth parameters in Dalbergia sissoo (Azza *et al.,* 2006). Root zone application of sulfur significantly increased the tolerance level of sunflower against salinity by increasing the fresh and dry weight (Zaman *et al.,* 2002). Similarly favourable soil conditions by reducing the impact of salinity/sodicity with sulfur has been reported in maize (Manesh *et al.,* 2013), canola (Al-Solimani *et al.,* 2010) and wheat (Ali and Aslam, 2005; Ali *et al.,* 2012), which reinforced the findings of our study.

Sol qualities

Composite soil sample were taken after the harvest of each crop and analyzed for pH_s, Ec_e and SAR. Results showed a gradual falling trend in reducing adverse soil properties, associated with sodic soils (pH_s, Ec_e and SAR) in all treatments receiving sulfur and gypsum than untreated soil (*Table 5*). Change in soil pH_s is very important characteristic, as it indicate an overall picture of the plant growth medium, including nutrient availability, fate of added nutrients and sodicity hazard. Elemental sulfur is considered as an adequate and cost effective amendment for lowering the pH value of the substrate for growing of plants and flowers (Abdel-Kader, 2005; Kampf *et al.,* 2006; Tarek *et al.,* 2013). In our study, this change in pH towards neutrality, in soil treated with sulfur would be due to direct effect of H_2SO_4 produced by added sulfur (Singh *et al.,* 2006). Our results are reinforced by previous literature, that sulfur inoculated with *Thiobacillus* reduced pH (8.2 to 4.7) and electrical conductivity of the soil saturation extract from 15.3 to 1.7 mS/cm (Stamford *et al.,* 2002). Similarly, Muhammad *et al.* (2007) and Kubenkulov *et al.* (2013) also reported the sulfur and gypsum as comprehensible amendment, which regulate the soil pH and total soluble salts (TSS) for the soda-saline soils. Meanwhile, applied amendments (gypsum and sulfur) accelerated the leaching of Na^+ ions from root zone, which seems the main cause to converge the values of pH_s, EC_e and SAR toward safe limit (Abdel-Fattah, 2012; Hamza and Anderson, 2003; Abdelhamid *et al.,* 2013).

CONCLUSION

Rice-wheat cropping system is very important in Pakistan and South Asian countries. Approximately half of the rice cultivated area in the Punjab, Pakistan is salt-affected, which is a major constraint to increase crop yields. Findings of the present study suggested that application of sulfur is also an effective technology in improving the chemical properties, like pH_s, Ec_e and SAR of salt affected soils and, subsequently, yield attribute of rice wheat crop. S @ 100 and 125% of SGR gave similar results as that of gypsum @ 100% SGR for amelioration of salt affected soils. Nonetheless, second-best treatment was lower rate of sulfur S @ 100% of SGR, which could also be an effective and suitable alternative amendment for improving the different qualities of salt affected soils and yield of rice-wheat crop.

This is the first report of its kind and will lead us to develop a technology for the reclamation of saline-sodic soils under similar ecological conditions, subsequently making these marginal lands cultivable, which is remarkably encouraging.

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