

STRATEGIES FOR SOIL AMELIORATION USING SULPHUR IN SALT AFFECTED SOILS

K. AHMED^{1*}, G. QADIR¹, A.R. JAMI¹, A.I. SAQIB¹, M.Q. NAWAZ¹,
M.A. KAMAL², E. HAQ¹

* E-mail: khalilahmeduaf@gmail.com

Received: May 13, 2016. Accepted: July 29, 2016. Published online: October 31, 2016

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 $\{EC_e = 6.10 \text{ dS m}^{-1}$, $pH_s = 9.21$ and $SAR = 41.67 \text{ (mmol L}^{-1})^{1/2}$, $SO_4-S = 16.0 \text{ (mg kg}^{-1})$ 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)

¹ Soil Salinity Research Institute, Pindi Bhattian, Pakistan

² Department of Agronomy, University of Agriculture, Faisalabad, Pakistan

INTRODUCTION

Among environmental stresses soil salinity is one of the most important threats to sustainable agriculture of arid and semi-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 accomplished through 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: $\text{S}^0 \rightarrow \text{S}_2\text{O}_3^{2-} \rightarrow \text{S}_4\text{O}_6^{2-} \rightarrow \text{S}_3\text{O}_6^{2-} \rightarrow \text{SO}_3^{2-} \rightarrow \text{SO}_4^{2-}$ (Jaggi *et al.*, 2005). This SO_4 as a result of S oxidation is further oxidized to

STRATEGIES FOR SOIL AMELIORATION USING SULPHUR IN SALT AFFECTED SOILS

H₂SO₄, which reacts with the native CaCO₃ to form (CaSO₄ 2H₂O), 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, SO₄-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: T₁ = Control; T₂ = S @ 25% of SGR; T₃ = S @ 50 % of SGR; T₄ = S @ 75 % of SGR; T₅ = S @ 100% of SGR; T₆ = S @ 125 % of SGR; T₇ = Gypsum @ 100% SGR.

Elemental granular sulfur (90%) and gypsum (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 m². 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 $P \leq 0.05$

STRATEGIES FOR SOIL AMELIORATION USING SULPHUR IN SALT AFFECTED SOILS

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 T₁ (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 by control (T₁).

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 affected soil, 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 (Amezketta *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.

REFERENCES

- Abd El-Hady M., Shaaban S.M. 2010 - Acidification of saline irrigation water as a water conservation technique and its effect on some soil properties. Am. Eurasian J. Agric. Environ. Sci., 7: 463-470.
- Abdallah M., Dubousset L., Meuriot F., Etienne P., Avicé J.C., Ourry A., 2010 - Effect of mineral sulphur availability on nitrogen and sulphur uptake and remobilization during the vegetative growth of *Brassica napus* L. J. Exp. Bot., 61(10):2335-2346.
- Abdel-Fattah M.K., 2012 - Role of gypsum and compost in reclaiming saline-sodic soils. Journal of Agriculture Veterinary Science, 1: 30-38.
- Abdelhamid M., Eldardiry E., Abd El-Hady M., 2013 - Ameliorate salinity effect through sulphur application and its effect on some soil and plant characters under different water quantities. Agricultural Sciences, 4: 39-47.
- Abdel-Kader A.A.S., 2005 - Improvement of yield and quality of henna (*Lawsonia alba*, Lam.) Plant. Ph.D. Thesis, Fac. Agric., Assiut Univ., Egypt.
- Abdou S.A., 2006 - Effect of applied elemental sulfur and sulfur-oxidizing bacteria (*Paracoccus versutus*) into calcareous sandy soils on the availability of native and applied phosphorus and some micronutrients. The 18th World Congress of Soil Science, July 9-15, 2006, Philadelphia, Pennsylvania, USA.
- Ali A., Arshadullah M., Hyder S.I., Mahmood M.A., 2012 - Effect of different levels of sulfur on the productivity of wheat in a saline sodic soil. Soil and Environment, 31(1): 91-95.
- Ali R., Khan M.J., Khattak R.A., 2008 - Response of rice to different sources of sulfur (S) at various levels and its residual effect on wheat in rice-wheat cropping system. Soil and Environmental Sciences, 27 (1): 131-137.
- Ali Y., Aslam Z., 2005 - Use of environmental friendly fertilizers in saline and saline sodic soils. IJEST, 2 (1): 97-98.
- Al-Solimani S.G., El-Nekhlawy F.S., Al-Morshedy M.H., 2010 - Improvement of canola seed yield and quality using sulphur and

- irrigation intervals under different irrigation water salinity levels. Arab Universities Journal of Agricultural Sciences, 18(2): 263-270.
- Amezketta E., Aragüés R., Gazol R., 2005** - Efficiency of sulfuric acid, mined gypsum and two gypsum by-products in soil crusting prevention and sodic soil reclamation. Agronomy Journal, 97: 983-989.
- Azza A.M., Mazhar M., Zaghloul S., Yassen A.A., 2006** - Response of *Dalbergia sissoo* to sulphur application under saline condition. Am. Eurasian J. Agric. Environ. Sci., 1(3):215-224.
- Balbaa A.M., 1995** - Management of problem soils in arid ecosystems. CRC/Lewis Publishers, Boca Raton.
- Blake-Kalff M.M.A., Hawkesford M.J., Zhao F.J., McGrath S.P., 2000** - Diagnosing sulfur deficiency in field-grown oilseed rape (*Brassica napus* L.) and wheat (*Triticum aestivum* L.). Plant and Soil, 225(1): 95-107.
- Chaubey A.K., Dwivedi, K.N., Buddesh M., Mani, 1993** - Response of linseed to N and S fertilization in alluvial soil of central region of U.P. Indian J. Agric. Chem., 26: 91-96.
- Choudhary O.P., Josan A.S., Bajwa M.S., Kapur M.L., 2004** - Effect of sustained sodic and saline-sodic irrigation and application of gypsum and farmyard manure on yield and quality of sugarcane under semi-arid conditions. Field Crop. Res., 87: 103-116.
- De Kok L.J., Castro A., Durenkamp M., Stuiver C.E.E., Westerman S., Yang L., Stulen I., 2002** - Sulfur in plant physiology. Proceedings No. 500, The International Fertiliser Society, York, UK, 1-26.
- El-Tarabily K.A., Abdou A.S., Maher E.S., Satoshi M., 2006** - Isolation and characterization of sulfur-oxidizing bacteria, including strains of *Rhizobium*, from calcareous sandy soils and their effects on nutrient uptake and growth of maize (*Zea mays* L.). Aus. J. Agric. Res., 57(1):101-111.
- Feizi M., Hajabbasi M.A., Mostafazadeh-Fard B., 2010** - Saline irrigation water management strategies for better yield of safflower (*Carthamus tinctorius* L.) in an arid region. Aust. J. Crop Sci., 4(6): 408-414.
- Fischer R.A., Byerlee D., Edmeades G.O., 2010** - Can technology deliver on the yield challenge to 2050? Expert Meeting on How to feed the World in 2050. Food and Agriculture Organization of the United Nations Economic and Social Development Department. http://www.fao.org/fileadmin/templates/wsfs/docs/Issues_papers/HLEF2050_Technology.pdf
- Györi Z., 2005** - Sulfur content of winter wheat grain in long term field experiments. Communications in soil science and plant analysis. J. Cereal Sci., 36: 373-382.
- Hamza M.A., Anderson W.K., 2003** - Responses of soil properties and grain yields to deep ripping and gypsum application in a compacted loamy sand soil contrasted with a sandy clay loam soil in Western Australia. Aus. J. Agric. Res., 54(3): 273-282.
- Hilal M.H., Abd-Elfattah A., 1987** - Effect of CaCO_3 and clay content of alkaline soils in their response to added sulphur. Sulfur in Agriculture, 11: 15-19.
- Hussain N., Hassan G., Arshadullah M., Mujeeb F., 2001** - Evaluation of amendments for the improvement of physical properties of sodic soil. Int. J. Agr. Biol., 3: 319-322.
- Jaggi R.C., Aulakh M.S., Sharma R., 2005** - Impacts of elemental S applied under various temperature and moisture regimes on pH and available P in acidic, neutral and alkaline soils. Biol. Fertil. Soils, 41(1): 52-58.
- Jez J., 2008** - Sulfur: a missing link between soils, crops and nutrition. Agronomy Monograph no.50, Am.

STRATEGIES FOR SOIL AMELIORATION USING SULPHUR IN SALT AFFECTED SOILS

- Soc. Agron, Crop Sci. Soc Am., Soil Sci. Soc. Am., p. 323.
- Kampf A.N., Fior C.S. Fior, Leonhardt C., 2006** - Lowering pH value with elemental sulfur in the substrate for ex vitro acclimatization. ISHS Acta Horticulturae 812: III International Symposium on Acclimatization and Establishment of Micro propagated Plants.
- Kacar B., Katkat A.V., 2007-** Plant nutrition. 3rd Edn., Nobel Press, Ankara, Turkey.
- Kayser A., Schroder T.J., Grunwald A., Schulin R., 2001** - Solubilization and plant uptake of zinc and cadmium from soils treated with elemental sulfur. International Journal of Phytoremediation, 3: 381-400.
- Kubenkulov K., Naushabayev A., Hopkins D., 2013** - Reclamation efficiency of elemental sulfur on the soda saline soil. World Appl. Sci. J., 23 (9): 1245-1252.
- Mahmood I.A., Shahzad A., Salim M., Ali A., Zaman B., Mir A. , 2010** - Effect of calcium on nitrogen utilization by rice in saline soils. Pak. J. Sci. Ind. Res., 53(3): 164-168.
- Manesh A.K., Armin M., Moeini M.J., 2013** - The effect of sulfur application on yield and yield components of corn in two different planting methods in saline conditions. Intl. J. Agron. Plant Prod., 4 (7): 1474-1478.
- McGrath S.P., 2003** - Sulfur: a secondary nutrient ? Not any-more ! New AG International, 70-76.
- Modaihsh A.S., Al-Mustafa W.A., Metwally A.I., 1989** - Effect of elemental sulfur on chemical changes and nutrient availability in calcareous soil, Plant and Soil, 116: 95-101.
- Mohamed H.A.H., Ali E.A.D.M., Mohammed H.I., Idris A.E., 2012** - Improving the properties of saline and sodic soils through integrated management practices. Global Journal of Plant Ecophysiology, 2(1): 44-53.
- Muhammad A.J., Rafiq M., Baqi A., Rahman H., Wahab F. , 2007** - Effect of different sources of sulfur on soil properties and physiochemical characteristics of *Citrus limon* L. (cv. Lisbon) grown on alkaline soil in fata. Sarhad J. Agric., 23(1): 95-99.
- Qadir M., Oster J.D., Schubert S., Noble A.D., Sahrawat K.L., 2007-** Phytoremediation of sodic and saline-sodic soils. Advances in Agronomy, 96: 197-247.
- Rahman M.M., Abdou A.S., Darwish F.H.A.I., El-Tarabily K.A., Awad M.A., Golam F., Azirun M.S., 2011** - Influence of elemental sulfur on nutrient uptake, yield and quality of cucumber grown in sandy calcareous soil. Aust. J. Crop Sci., 5(12): 1610-1615.
- Rengasamy P., 2010** - Soil processes affecting crop production in salt-affected soils. Funct. Plant Biol., 37(7): 613-620.
- Rice R.W., Gilbert R.A., Lentini R.S., 2006** - Nutritional requirements for Florida sugarcane. UF-IFAS Extension SS-AGR-228 Gainesville, FL: University of Florida.
- Scherer H.W., 2001** - Sulphur in crop production: invited paper. Eur. J. Agron., 14:81-111.
- Scherer H.W., Pacyna S., Spoth K.R., Schulz M., 2008** - Low levels of ferredoxin, ATP, and leghemoglobin contribute to limited N₂ fixation of peas (*Pisum sativum* L.) and alfalfa (*Medicago sativa* L.) under S deficiency conditions. Biol. Fertil. Soils, 44(7): 909-916.
- Schueneman T.J., 2001** - Characterization of sulfur sources in the EAA. Soil Crop Sci. Soc. Fla. Proc., 60: 49-52.
- Singh J., Kairon M.S., 2001** - Yield and nutrient contents of cotton (*Gossypium hirsutum*) and sunflower (*Helianthus annuus*) as influences by applied sulfur in irrigated

- inceptisol. Indian J. Agr. Sci., 71(1): 35-37.
- Singh R.N., Singh S., Singh B., 2006** - Interaction effect of sulphur and boron on yield, nutrient uptake and quality characters of soybean (*Glycine max* L. Merrill) grown in acidic upland soil. J. Indian Soc. Soil Sci., 54 (4): 516-518.
- Stamford N.P., Freitas A.D.S., Ferraz D.S., Santos C.E.R.S., 2002** - Effect of sulphur inoculated with *Thiobacillus* on saline soils amendment and growth of cowpea and yam bean legumes. The Journal of Agricultural Sciences, 139(3): 275-281.
- Steel R.G.D., Torrie J.H., Dickey D.A., 1997** - Principles and procedures of statistics: a biometrical approach. 3rd Ed. Mc Graw Hill book Co. Inc. New York, USA. 400-428.
- Tandon H.L.S., 1991** - Sulfur research and agricultural production in India. 3rd Ed. The Sulphur Institute, Washington, D.C. USA., 140p.
- Tarafdar J.C., Sharma S.K., Bhandari S.C., Saini V.K., 2005** - Assessment of microbial biomass under integrated nutrient management in soybean-winter maize cropping sequence. J. Indian Soc. Soil Sci., 53 (3): 346-51.
- Tarek M.A.S., El-Keltawi N.E., Khan M.A., Nan M., L.J. Zhao, 2013** - Plant growth and flowering of cape jasmine (*Gardenia jasminoides* Ellis) in various substrates amended with sulphur. Global Journal of Plant Ecophysiology, 3(2): 36-43.
- Tzanakakis V.A., Paranychianakis N.V., Londra P.A., Angelakis A.N., 2011** - Effluent application to the land: changes in soil properties and treatment potential. Ecol. Eng., 37: 1757-1764.
- US Salinity Lab Staff, 1954** - Diagnosis and improvement of saline and alkali soils. USDA Handbook 60, Washington DC, USA.
- Wei X., Hao M., Shao M., Gale W.J., 2006** - Changes in soil properties and the availability of soil micronutrients after 18 years of cropping and fertilization. Soil Till. Res., 91: 120-130.
- Wilson C.S., Lesch S.M., C.M. Grieve, 2000** - Growth stage modulates salinity tolerance of New Zealand spinach (*Tetragonia tetragonioides*, Pall.) and red orach (*Atriplex hortensis* L.). Annals of Botany, 85(4): 501-509.
- Zaman B., Ali A., Salim M., Niazi B.H., 2002** - Role of sulphur for potassium/sodium ratio in sunflower under saline conditions. Helia, 25(37): 69-78.
- Zhang Z.Y., Sun K.G., Lu A.Y., X.B. Zhang X.B., 1999** - Study on the effect of S fertilizer application on crops and the balance of S in soil. J. Agr. Sci., 5: 25-27.
- Zhao F.J., Salmon S.E., Withers P.J.A., Monaghan J.M., Evans E.J., Shewry P.R., McGrath S.P., 1999** - Variation in the bread making quality and mineralogical properties of wheat in relation to sulfur nutrition under field conditions. J. Cereal Sci., 30(1): 19-31.