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Amelioration of soil salinity through sulphur sources and its impact on cotton production

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ABSTRACT

Cotton being the vital component of south Asia's agricultural landscape for centuries, deeply intertwined with the region's history, culture, and economy. Amendment of excessive sodium (Na^+) ions as main cause of soil salinity is accomplished with divalent cations like calcium (Ca^{++}) that percolate off Na^+ ions from root zone. The viable option is gypsum application and to hurdle out its insolubility is to add sulphuric acid and getting desires. A trial comprising of five combinations of gypsum and sulphuric acid in comparison to control to effectively solubilize and augment gypsum efficacy in saline sodic soil was conducted. Prior to experiment pH, EC and ESP of soil ranged from 8.39 to 8.54, 13.04 to 14.04 and 34.25 to 37.91 respectively and clued sodic nature with ESP > 15. Sulphuric acid and gypsum were utilized 30 days earlier to planting in corresponding plots in addition to 150-90-60 kg ha^{-1} NPK as recommended dose. After harvest, same were again analyzed for physicochemical attributes along with soil samples physicochemical characteristics. Statistical analysis remained confident with respect to all i.e. yield and its allies, soil pH, EC and ESP as well as solubility of gypsum and reclamation of soil when 50% gypsum + 50% sulphuric acid were applied. Thus 50% gypsum+50% sulphuric acid is recommended as most economic and optimum dose as an operative ameliorative approach for salt exaggerated soils. 50% gypsum+50% sulphuric acid also illustrated highest produce of 3246.30 kg ha^{-1} seed cotton showing an increase of 81% more yield over control.

Keywords: Salinity control, combinations, sulphuric acid, gypsum soil pH, electrical conductivity.

INTRODUCTION: Cotton (Gossypium hirsutum L.) playing a crucial role as the main crop for fiber and being the second-largest producer of vegetable oil worldwide. Approximately 26% of Pakistani farmers cultivate cotton across 1937 thousand hectares, yielding a production of 8.3 million bales (Mehran, 2023). Saline soils are increasing at unprecedented rate all over the globe. Approximately, 7% of the world's land is saline in nature. It is estimated that almost 800 M hectares of the land is salt affected (FAO, 2008), including 20% of the irrigated land, refraining about 2 M ha of area from production every year (Munns and Tester 2008). These types of soils are abundant in arid and semi-arid regions facing water scarcity. Saline sodic soils need efficient, inexpensive management with less degradation of the soil environment. This goal can be got if a divalent cation i.e. calcium is applied which will sorb onto the exchange sites while desorbing monovalent Na^+ into the soil solution. The desorbed sodium ions will be drained off the soil or leached down from the root zone through excess irrigation. However, in most of the cases saline sodic soils have Ca in calcite i.e. $CaCO_3$ form at different depths that is extremely low soluble and have very less contribution in soil amelioration. One of the most established technologies of saline sodic soils amelioration is the use of chemical amendments. Some of these amendments directly supply calcium to soil whereas others benefit in dissolving $CaCO_3$ (Qadir and Oster, 2002). Though, this technology is costly and cannot be afforded by the subsistence farmers in developing countries. This amendment is most costly on account of more utilization by industries and less funding for chemicals procurement (Qadir and Oster, 2002). To understand and improve the salt effected soils gypsum was mostly applied previously on account of its low cost, easy accessibility and application in comparison to other chemicals. However, Sulphur is also reported as a well-known strategy for salt amelioration. Presently Sulphur is mostly applied in the form of sulphuric acid which reacts with the native calcium carbonate and form $CaSO_4.2H_2O$ (Abd El Hady and Shaaban 2010). This Ca perhaps replaces adsorbed Na (Abdelhamid *et al*., 2013). Sulphur application enhanced the tolerance level against salinity. Similarly, favorable soil settings by dropping influence of salinity have been described in *Zea mays* (Manesh *et al*., 2013), *Brassica napus* (Al- Solimani et al., 2010) and *Triticum astivum* L. (Ali *et al*., 2012).

OBJECTIVE: The current study was designed to find out optimum level of gypsum and sulphuric acid as an ameliorant for improved seed cotton yield of cotton in salt effected areas.

MATERIAL AND METHODS: The trial was conducted at Cotton Research Station Dera Ismail Khan (D.I.Khan) (31º49' N latitude & 70 º55' E longitude). Preliminary site selection was carried out on already available information. Soil samples of the selected soil were obtained and assessed for pH, EC and ESP cluing its range from 8.39 to 8.54, 13.04 to 14.04 and 34.25 to 37.91 respectively. Thus, the experimental site exhibited sodic characters having ESP > 15. The ESP was calculated as suggested by Richards, 1954; ESP =

$$\frac{\text{Exchangeable Na } (\frac{me}{100}\text{g of soil})}{\text{Cation Exchange Capacity } (\frac{me}{100}\text{g of soil})} \times 100$$

Soil sampling and sample analysis: Prior to soil amendments, samples were obtained at soil depth of 30 cm and assessed for pH, electrical conductivity, cations (Na, K, Ca and Mg) and CEC so as to determine the exchangeable sodium percentage to get know how of the initial important soil chemical makeup (Richards, 1954). The amount of gypsum needed for each experimental unit was intended. Sulphuric acid was enhanced by substitution of sodium relative to gypsum (FAO, 1988). Chemical alteration treatments were arranged in laboratory. The experiment was comprised of the following 6 treatments, T_1. control; T_2. gypsum @100% of soil gypsum requirements (SGR); T_3. sulphuric acid @ 25% + 75% gypsum; T_4. sulphuric acid @ 75% + 25% gypsum; T_5. sulphuric acid 50% + 50% gypsum; T_6. sulphuric acid @ 100 of SGR. To investigate the treatment effect, these were smeared 30 days prior to planting at soil depth of 30 cm and attempted to leach down by applying the canal water for fifteen days. In control plot no alteration was subjected.

Sulphuric acid and gypsum application and crop tested: Gypsum was disseminated and combined with soil by ploughing whereas H_2SO_4 was applied after mixing with irrigation water. Three recurrent leaching and pounding operations were performed. After leach down process, cotton was sown in randomized complete block design (RCBD) with 3 repetitions. Cotton crops were sown on 1st May and fertilized 150:90:60 of N:P:K. Urea, SSP and SOP fertilizers as source of fertilizer. Whole volume of phosphorus and potassium and 1/2 of nitrogen was smeared at planting time. All recommended cultural practices were followed.

Data recording and statistical analysis: Data were recorded from 5 randomly selected plants in each treatment for plant height (cm), No. of bolls plant^{-1} and weight of boll (g). Seed cotton yield (kg ha^{-1}) was recorded from the two pickings performed after 140 and 160 days of sowing of each plot and then converted into yield hectare^{-1}. Besides these plant attributes, the soil samples from each treatment was also collected after crop harvest and analysed again for various physico-chemical attributes like pH, ECe and ESP. Recorded data was statistically analysed by applying ANOVA suitable for randomized complete block design as per the recommendations of Steel *et al*. (1997). Means depicting significant differences were separated by applying the LSD test at 5% probability level.

RESULTS: Seed cotton yield (kg ha^{-1}) and related attributes: Yield as influenced by soil amendments of sulphuric acid and gypsum in comparison to control is offered in table 2. Statistical analysis exposed that various soil amendments remarkable influenced the seed cotton yield (table 1). It was perceived that in non-amended treatment, seed cotton yield was 1782 kg ha^{-1} whereas it was maximum (3246.30 kg ha^{-1}) where 50% sulphuric acid +50% gypsum was utilized, reflecting a significant increase of 81% in comparison to control. There also observed 16% increase in

25% sulphuric acid + 75% gypsum and 37% increase in 75% sulphuric acid + 25% gypsum application as compared to control. This increased seed cotton yield was on account of increased plant height, bolls per plant and boll weight along with favourable growth environment as compared to control and other treatments explored in this experiment. Treatment of 50% sulphuric acid + 50% gypsum produced maximum seed cotton yield which was 20% more than 100% sulphuric acid alone. The application of 50% sulphuric acid + 50% gypsum might increase the electrical conductivity of soil on account of discharge of sodium ions from exchange complex of the soil. Produce for the amended soil was remarkably excellent than untreated (control). This might be because of sulphuric acid and gypsum improving soil conditions and favoring plant growth which resulted in the better production under saline sodic soil conditions. Bolls plant^{-1} is main independent yield contributing trait. Statistical analysis depicted significant differences for bolls plant^{-1} in different treatments (table 1). Soil amended with 50% sulphuric acid + 50% gypsum showed maximum (34.95) number of bolls per plant followed by the plants treated with 100% gypsum (table 2). Minimum number of bolls per plant was recorded in control where no soil amendments were made. Boll weight is 2nd main yield contributing trait after number of bolls and have great contribution in enhancing the seed cotton yield. Hence maximum boll weight essentially obtains importance for development of cotton crop. Analysis of variance discovered that various amendments remarkably affected the boll weight (table 1). Highest weight of 3.07 g was documented in the plant treated with 50% sulphuric acid + 50% gypsum while lowest weight of 2.38 g was noted in control (table 2). Such variances in boll weight might be due to variation in prevailing growth conditions due to various amendments of soil. Plant height is very important yield attribute having significant association with bolls number and hence ultimate optimistic impact on yield. Mean performance of plant height portrayed remarkable variances amongst various amendments applied (table 1). Highest plant height of 139.88 cm was documented in the plot treated with 50% sulphuric acid + 50% gypsum which was similar with 100% gypsum treated plants (table 2). Lowest plant height of 113.89 cm was noted in unamended plots.

Soil properties: The soil pH was determined by obtaining extract of 1:5 saturated soil paste which ranged from 8.39 to 8.54. After applying different amendments through same procedure the pH was determined and noted significant reduction in the soil pH (table 3). Minimum pH or maximum alteration impact was observed in 50% sulphuric acid + 50% gypsum treated plants (table 4). 8.94% reduction in soil pH was documented where 50% sulphuric acid + 50% gypsum was applied. Similarly, 100% SA and 100% gypsum also significantly reduced the soil pH. This reduction in pH might be attributed to the interchange of calcium on soil complex and elimination of sodium ions.

The electrical conductivity of the soil extract already prepared earlier than experiment for soil pH determination was measured gave quite high reading and ranged from 13.04 to 14.04 (table 4). After amending soil with different combinations of SA and gypsum it significantly reduced EC_e (table 2). A maximum decline of 57% in EC_e was observed in the soil treated with 50% sulphuric acid + 50% gypsum. Other treatments also significantly reduced the EC_e in comparison to control. This lower electrical conductivity might be correlated with sodium ions dissolution from soil complex and as an improvement factor, it might leach down to deep soil due to application of the treatments. The ESP of the soil before application of amendments was quite high and ranged from 34.25 to 37.91. Application of different combinations of SA and gypsum significantly reduced this ESP (table 3). A maximum decline of 37% in ESP was observed in the soil treated with 50% sulphuric acid + 50% gypsum (table 4). Other amendments also significantly reduced the ESP as compared to control where no soil amendments were made.

Source of variation	Degree of freedom	Plant height (cm)	Number of bolls plant^{-1}	Weight of boll (g)	Seed cotton yield (kg ha^{-1})
Replication	2	3.218	1.1896	0.0829	22711
Treatment	5	353.653**	64.4682**	0.2418**	1067060**
Error	10	13.740	9.1395	0.0666	27178
CV%	-	2.94	10.11	9.50	6.39

Table 1: Mean squares of seed cotton yield and related attributes as influenced by 2 bases of sulphur (sulphuric acid and gypsum)..

Treatment	Plant height (cm)	Bolls/plant	Boll weight (g)	Seed cotton yield (kg/ha)
Control	113.89 c	22.83 d	2.38 b	1782 c
Gypsum @100% of SGR	137.50 a	34.41 ab	3.01 a	3226 a
SA 25% + 75% gypsum	115.45 c	26.76 cd	2.47 b	2077 c
SA 75% + 25% gypsum	123.43 b	29.31 bc	2.62 ab	2453 b
SA 50% + 50% gypsum	139.88 a	34.95 a	3.07 a	3246 a
SA @ 100% of SGR	126.59 b	31.18 abc	2.75 ab	2687 b
$LSD_{0.05}$	6.74	5.50	0.47	299.92

Table 2: Relative impact of 2 sources of sulphur (sulphuric acid and gypsum) on seed cotton yield and linked attributes.

Source of variation	Degree of freedom	pH before sowing	pH after harvest	EC before sowing	EC after harvest	ESP before sowing	ESP after harvest
Replication	2	0.010	0.0055	0.723	0.0442	0.935	0.834
Treatment	5	0.009^{NS}	0.2676**	0.609**	18.948**	7.480**	37.402**
Error	10	0.003	0.0030	0.105	0.105	0.453	0.675
CV%	-	0.72	0.68	2.40	3.90	1.89	3.08

Table 3: Mean squares of pH, EC and ESP before and after soil amendments with 2 bases of sulphur (sulphuric acid and gypsum)

Treatment	pH before harvest	pH after harvest	EC before harvest	EC after harvest	ESP before harvest	ESP after harvest
Control	8.54	8.48 a	13.04 c	12.23 a	34.45 b	31.74 a
Gypsum @100% of SGR	8.42	7.87 d	13.98 a	5.94 e	37.18 a	24.40 d
SA 25% + 75% gypsum	8.48	8.26 b	14.04 a	9.79 b	34.70 b	28.63 b
SA 75% + 25% gypsum	8.50	8.19 b	13.67 ab	8.78 c	37.91 a	27.90 b
SA 50% + 50% gypsum	8.39	7.64 e	13.08 bc	5.58 e	34.75 b	21.60 e
SA @ 100% of SGR	8.44	8.02 c	13.22 bc	7.44 d	34.25 b	26.06 c
$LSD_{0.05}$	NS	0.10	0.59	0.58	1.22	1.50

Table 4: Relative impact of 2 sources of sulphur (sulphuric acid and gypsum) on soil pH, EC and ESP.

DISCUSSIONS: Plant attributes: Various soil amendments are utilized for salt amelioration in salt affected soils like calcium chloride, Sulphur, sulphuric acid and calcium sulphate. Among these gypsum is greatest frequently utilizing alteration on account of their early solubilization, easy and cost effective obtainability and easy management (Amezketa *et al.*, 2005; Abd El-Hady and Shaaban, 2010). In calcareous soils having high pH, sulphuric acid may also be added on account of their reaction with $CaCO_3$ to produce gypsum (Wei *et al.*, 2006). Findings of the present investigation depicted that various rate of gypsum and sulphuric acid considerably enhanced seed cotton yield and their linked attributes (table 3). It was recorded that 50% sulphuric acid + 50% gypsum is the best soil amendment for improvement in seed cotton yield. This significant improvement in comparison to control can be on account of ameliorative performance of these alterations by lessening side effects of salinity. This might be by substituting sodium ions from exchange sites. The leach down of sodium ions from root zone, enhanced the physical attributes of soil leads to improved growing of crop in such amendments (Mohamed *et al.*, 2012). Similar crop improvements have also been recorded previously by Mahmood *et* *al*. (2010). As sulpher is important and indispensable plant nutrient and equally requires as of P (Ali *et al*., 2008). It is also protein structural unit having significant contribution in chlorophyll synthesis (Scherer *et al*., 2008). Thus it can be estimated that if sulpher in soil is not in optimum level, the yield potential of any crop cannot be fully achieved Tarafdar *et al*. (2005). Similarly, favorable pH of the soil is essential for soil nutrients obtainability (Wei *et al*., 2006). Sulphuric acid and gypsum application in the present investigation reduced the soil pH and thus improved the plant nutrients availability on account of their synergic impact with nitrogen (Chaubey *et al*., 1993), phosphorus (Rahman et al., 2011) iron and manganese (Modaihsh *et al*., 1989) and zinc (Kayser et al., 2001). Sulphur application enhanced the tolerance level against salinity. Similarly favorable soil settings by dropping influence of salinity have been documented in *Zea mays* (Manesh *et al*., 2013), *Brassica napus* (Al- Solimani *et al*., 2010) and *Triticum astivum* (Ali *et al*., 2012), which strengthened results of the current investigation.

Soil properties: Post-harvest soil samples analysis for pH, ECe and ESP revealed that linear falling trend in comparison to control in these soil attributes were observed due to the soil amendments with sulphuric acid and gypsum levels. Reduction of soil pH is of utmost importance on account of medium for plant growth having nutrient obtainability, providence of supplementary nutrients and threats of salinity. Sulphur sources are considered as the most adequate amendment for reducing the pH for any crop improvement (Tarek *et al*., 2013). In the present investigation, the pH reduction towards neutrality with sulphuric acid and gypsum might be due to direct effect of sulphuric acid (Singh *et al*., 2006). Current findings are in complete accordance to the previous outcomes of Kubenkulov *et al*. (2013) who also described that sulphur and gypsum are understandable amendments that regulates soil pH, EC, ESP, etc for saline sodic soils. Moreover, these alterations leached down the sodium from root zone which might be major reason to congregate pH, EC and ESP towards safe limits (Abdel-Fattah, 2012; Abdelhamid *et al*., 2013). A remarkable decrease in soil pH due to 50% sulphuric acid + 50% gypsum was also previously reported by Worku *et al*. (2016). Hussain *et al*. (1993) also observed a remarkable decreasing trend in pH of soil during the assessment of reclamation impact with sulphuric acid, gypsum and other alteration factors for long term. Similarly, Murtaza *et al*. (2012) elaborated that utilization of pyrites and gypsum at 50% GR, tremendously decreased ESP and EC when they are applied in saline sodic soils..

CONCLUSIONS: The instant results concluded that 50% H_2SO_4 and 50% gypsum application results in excellent crop yield and enhanced soil physicochemical attributes on account of decreasing the soil pH, ECe and ESP. based on these results combined utilization of H_2SO_4 and gypsum is considered as the most advantageous for managing the saline soil with calcareous natur.

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LIFE SCIENCE REPORTING: In current research article no life science threat was reported

ETHICAL RESPONSIBILITY: This is original research, and it is not submitted in whole or in parts to another journal for publication purpose.

INFORMED CONSENT: The author(s) have reviewed the entire manuscript and approved the final version before submission.

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