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Evaluation of Amendments for the Improvement of Physical Properties of Sodic Soil

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ABSTRACT

A field experiment was conducted to evaluate the effect of different amendments and their combination on various properties (physical and chemical) of sodic soil and the resultant impact on wheat crop. The treatments of this study were; control, farm yard manure (FYM = 10 t ha^{-1}), gypsum (equivalent to soluble carbonates + bicarbonates), gypsum + FYM, sulfuric acid (equivalent to neutralize carbonates + bicarbonates), sulfuric acid + FYM, gypsum + sulfuric acid (half of each), gypsum + sulfuric acid (half of each) + FYM. All the amendments were applied, 30 days leaching provided, wheat was grown and soil was analyzed after the harvest of this crop. It was observed that gypsum + sulfuric acid + FYM decreased bulk density but increased the porosity, void ratio, water permeability and hydraulic conductivity more than all other treatments. The differences were statistically significant. The effects of other combinations (gypsum + FYM, gypsum + sulfuric acid and sulfuric acid + FYM) were, in general, significant as compared with sole application of amendments. However, FYM had non-significant effect on these physical properties. Combinations of gypsum + FYM, sulfuric acid + FYM and gypsum + sulfuric acid also gave significant results than control. The EC_e decreased non-significantly by applying all the treatments except FYM, gypsum + sulfuric acid and combination of all the three amendments which decreased EC_e significantly. A slight increase was also observed in sulfuric acid based treatments. However, pH of the soil decreased significantly in all the treatments; whereas, FYM had no significant effect on soil pH. Sodicity parameter (SAR) of the soil decreased significantly when soil was treated with sulfuric acid, gypsum, FYM and their various combinations. All the treatments enhanced the subsequent wheat yield, which was assessed to be significant except FYM alone. The best treatment in this regard was also the combination of all the three amendments. Thus, application of amendments in the lesser quantities (equivalent to soluble carbonates + bicarbonates of soil) in combination may be a good strategy to reclaim the sodic soils.

Key Words: Gypsum; Sulfuric acid; HCl; $CaCl_2$; FYM

INTRODUCTION

For reclamation of sodic and saline sodic soils, various amendments like gypsum, $CaCl_2$, HCl, H_2SO_4 and farmyard manure are required. These amendments either change insoluble soil calcium to soluble form or supply calcium directly, which replaces the absorbed sodium from sodic and saline-sodic soils. Previous work has shown that sulfuric acid proved to be more effective in reducing Exchangeable Sodium Percentage (ESP) of the soil than gypsum (Vadyanina & Roi, 1974). Water penetration into sodic soil was also improved with sulfuric acid treatment. One of the important factors constantly being overlooked was to record the changes in the physical characteristics of soil after reclamation. In most soil of the Punjab (Pakistan), the major soluble anions are bicarbonates, sulfates and chlorides. A major amount of gypsum added to the soil is utilized in neutralizing or precipitating the soluble carbonates and bicarbonates. Since carbonates and bicarbonates in the soil are in the solution phase, they freely react with added gypsum (Abrol *et al*., 1978). It was economically feasible to reclaim most alkali soils provided that effective drainage and adequate irrigation water is available. Simple leaching can reclaim saline soils whereas black alkali soils need proper amount of gypsum, sulfur, Iron sulfate and aluminum sulfate along with leaching. Bower *et al*. (1951) applied lime, sulfur, and gypsum alone and in combination with manure and found that infiltration was the greatest with (gypsum + manure) treatment and the highest decrease in ESP occurred in case of gypsum treated plots. Decrease in pH was more in upper 12 inches soil. They observed that sulfuric acid was more effective in decreasing soil pH than gypsum and sulfur. Haq (1966) tried gypsum, H_2SO_4, press-mud, FYM etc. for reclaiming saline sodic soil. He observed comparable results in respect of reduction in pH, EC_e and ESP with H_2SO_4 and gypsum treatments.

Kausar and Muhammad (1972) reclaimed sodic soil by gypsum application followed by leaching in much shorter time as compared to biological methods. They also observed an increase in hydraulic conductivity, exchangeable and soluble Ca + Mg and decreased in exchangeable Na^+, K^+, ESP, free lime, pH, EC_e and SAR with gypsum treatment. Muhammad and Khaliq (1975) reported that decrease in EC_e, lime, pH and increase in hydraulic conductivity, soluble and exchangeable Ca and Mg was more with sulfur than with gypsum alone or in combination with FYM. Yahia *et al*. (1975) concluded that sulfuric acid was more effective than gypsum, especially for soil having higher ESP value. Sulfuric acid dissolved Ca CO_3, which in turn enhanced water penetration. Gupta and Bajpai (1977) observed that addition of gypsum, H_2SO_4 or $CaCl_2$ improved the physical as well as chemical properties of saline-alkali soil under regular flushing. Ghafoor (1980) applied gypsum, sulfuric acid, HCl and HNO_3 in equivalent amounts to calcareous saline-sodic soil and found that all treatments increased the hydraulic conductivity except simple leaching. Gorbunov (1980) observed improvement of soil structure and increased water permeability.

According to Sharma *et al*. (1982), the soil pH, EC_e $CaCO_3$, exchangeable Na^+, CO^{2-}_3, Cl^- and dispersion ratio decreased considerably; whereas, exchangeable Ca^{2+}+ Mg^{2+}, hydraulic conductivity, water infiltration and redistribution increased as a result of gypsum application. Field measurements suggested that gypsum did not affect the bulk density in the profile, but increased water penetration. Increased hydraulic conductivity (K), aggregate stability (ASI) and air-filled porosity were obtained when samples collected from gypsum treated plots were tested in the laboratory (Sharma, 1971). Hydraulic conductivity and drainage porosity were the most important properties affecting sub-surface drainage under steady condition.

Amendments are costly inputs and sometimes are not affordable by the poor farmers. Recently, demands have been emerging to divert the direction of research to reclaim the sodic soils with minimum inputs or at least in split doses in order to curtail the initial investment. Hussain *et al*. (2000) reported that splitting of gypsum into two equal doses (25% GR.) was very useful to reclaim the saline sodic soil, although the reclamation time was increased. The present studies were conducted not only to find the effectiveness of different amendments in amelioration of such soils but also to investigate the new basis for working out the quantities of reclamants like soluble carbonates + bicarbonates.

MATERIALS AND METHODS

A field experiment was conducted on the sodic soil at research farm of Soil Salinity Research Institute, Pindi Bhattian during the year 1998-1999. Undisturbed soil samples from the four repeats were collected for bulk density and hydraulic conductivity. The disturbed samples were also obtained, air-dried, ground, mixed, passed through 2-mm sieve and analyzed for their chemical and physical characteristics (Table I). The treatments of the experiment were as under:

T_1= Control; T_2= FYM @ 10 t ha^{-1}; T_3= Gypsum (equal to soluble CO_3 + HCO_3 of soil); T_4= Gypsum (T3) + FYM @ 10 t ha^{-1}; T_5=H_2SO_4 alone (equal to soluble CO_3 + HCO_3 neutralization value); T_6= H_2SO_4 (T_5) + FYM @ 10 t ha^{-1}; T_7= Gypsum+H_2SO_4 (half of each as in T_3 & T_5); T_8= Gypsum (T_3) + H_2SO_4 (T_5) + FYM @ 10 t ha^{-1}

All the amendments along with Farmyard Manure were applied on October 6, 1998. Gypsum and FYM were mixed with soil while H_2SO_4 was applied through irrigation water. The experiment was laid down according to randomized complete block design (plot size 2.5 x 2.4 m) with four replications. Then, the soil was leached for 30 days. Wheat crop was sown after applying the appropriate doses of fertilizers. The yield of crop was recorded and soil was sampled and analyzed again for physical and chemical characteristics. Hydraulic conductivity (K) and particle density (dp) were measured according to the method of US Salinity Laboratory Staff (1954). Bulk density (db), total porosity (ft) and void ratio (e) were measured by core sampling method and subsequent calculations (Loveday, 1974).

Electrical conductivity (EC) and pH of soil-saturated paste were determined and Sodium Adsorption Ratio of the soil was also computed (US Salinity Laboratory Staff, 1954)

RESULTS AND DISCUSSION

Soil physical properties

Bulk density. Dry Bulk density is ratio of oven dried weight of soil to its volume. Higher value of Bulk density means more weight per unit volume. So, when more soil was packed in the same volume, the soil became more compact and defective from agriculture point of view. Due to less pore space these soils were impermeable to water. On decrease of the value of bulk density soil became more porous and effective for root respiration and water permeability:

Data (Table II) indicated that bulk density was significantly improved as a result of all the treatments. The most effective treatment was the combination of gypsum, sulfuric acid and FYM followed by gypsum + FYM. The sole application of amendments was, although significant in effect but inferior to combinations. Differences among the various amendments were not statistically noticeable. The bulk density value was decreased to 1.437 g cm^{-3} when all the three amendments were combined. A decrease in dispersion ratio may be the reason for improvement in bulk density (Gobunov, 1980).

Table I. Soil analysis of the experimental site

Characteristic	Unit	R_1	R_2	R_3	R_4
Bulk density.	g cm^{-3}	1.7742	1.7410	1.7649	1.7434
Particle density	g cm^{-3}	2.7172	2.7128	2.7128	2.7030
Total porosity.	-	0.3185	0.3826	0.3814	0.3519
Hydraulic conductivity	cm hr^{-1}	0.3612	0.3495	0.3876	0.3882
EC_e	dSm^{-1}	5.0000	3.8000	3.7000	4.3000
PH_s	-	9.1800	8.7500	8.6900	8.9600
SAR	$(mmol\ L^{-1})^{1/2}$	76.2000	59.5000	56.0000	67.0000
Textural class	-	Sandy clay loam	Sandy clay loam	Sandy clay loam	Sandy clay loam

Porosity and void ratio. Porosity and void ratio are the physical soil properties derived from bulk density and particle density and indicate the total pores and the ratio of voids to the solids. The effect of various amendments and their combination on total porosity, percent pore space and void ratio of the sodic soil was significant statistically (Table II). The most efficient treatment here was also the combination of gypsum, sulfuric acid and FYM. The most inferior treatment was sole application of FYM, even which was significantly better than control. The treatments of gypsum and sulfuric acid proved superior to FYM but inferior to various combinations. There is inverse relationship between bulk density and porosity/void ratio. Therefore, a decrease in the value of former resulted in an increase in the latter.

Table II. Effect of different amendments on bulk density, total porosity, percent pore space and void ratio of sodic soil (average of four replications)

Treat.	Bulk density ($g. cm^{-3}$)	Total porosity	Percent pore space	Void ratio
T_1	1.7434 a	0.3577 g	35.77 g	0.5576 e
T_2	1.6412 b	0.3962 f	39.62 f	0.6555 d
T_3	1.6375 b	0.4266 e	42.66 e	0.6595 cd
T_4	1.5119 c	0.4530 d	45.30 d	0.6614 c
T_5	1.6568 b	0.4896 c	48.96 c	0.6622 c
T_6	1.6159 b	0.4947 bc	49.47 bc	0.6802 b
T_7	1.6013 b	0.5064 ab	50.64 ab	0.6851 b
T_8	1.4137 d	0.5155 a	51.55 a	0.6910 a

Hydraulic conductivity. The distinguishing characteristics of slowly permeable saline sodic and sodic soils are high contents of exchangeable sodium and low hydraulic conductivity. The hydraulic conductivity measurements provide an indication of relative water transmission rate of the soil. The data on the effect of various treatments on the hydraulic conductivity are shown in Table III. The data indicated that all the treatments did help in increasing the hydraulic conductivity significantly. It was maximized when gypsum, sulfuric acid and FYM were combined together (T_8). Single application of amendments (gypsum, FYM & sulfuric acid) also increased this parameter and the numerical values were significantly higher than control but lower than the different combinations. Various combinations of organic and inorganic amendments proved better but no statistical difference was adjudged among them. As regards the reclamation efficiency in terms of improving hydraulic conductivity, various amendments proved useful but their combinations may be regarded the best. Researchers like Yahia *et al*. (1975), Haq (1966) and Kausar and Muhammad (1972) found that H_2SO_4 and gypsum were more effective in improving the hydraulic conductivity of saline sodic or sodic soils. But in contrast, Bower *et al*. (1951) regarded combination of amendments as the best. The present studies are also in agreement with the latter view. The improvement in bulk density in different combinations may be the main cause of increase in hydraulic conductivity. Ghafoor (1980) also noted increase in the value of this parameter when different amendments were applied to the saline sodic soil.

Water permeability. Soil permeability is the ease with which gases, liquids or plant roots penetrate or pass through a bulk mass of soil or a layer of soil. Water permeability of sodic soil decreases due to excess exchangeable sodium, which causes dispersion of the soil and soil becomes more compact. So, water cannot pass through the soil mass. The data of Table II shows that H_2SO_4 and gypsum increased the water permeability significantly than control but the difference indicated by FYM was non-significant. The differences with respect to water permeability due to various combinations were more effective. However, the best treatment was combined application of gypsum, FYM and sulfuric acid. An improvement in bulk density, porosity and void ratio would have contributed into enhanced water permeability. The combination of different amendments, thus, proved more useful.

Table III. Effect of different amendments on hydraulic conductivity and water permeability of sodic soil (means of four replications)

Treatment	Hydraulic conductivity ($cm\ hr^{-1}$)	Water permeability (cm^2)
T_1	0.33 d	30.38×10^{-8} d
T_2	1.77 c	40.37×10^{-8} d
T_3	2.79 b	63.52×10^{-8} c
T_4	3.83 a	87.48×10^{-8} b
T_5	2.77 b	82.83×10^{-8} b
T_6	3.74 a	84.22×10^{-8} b
T_7	3.85 a	89.02×10^{-8} b
T_8	3.93 a	108.10×10^{-8} a

Soil chemical properties

Electrical conductivity. Electrical conductivity of the soil extract indicates concentration of soluble salts in the soil solution. The changes in EC_e are given in Table IV. A slight decrease occurred when different amendments were applied in combination or alone except H_2SO_4 or its combination with FYM, when it increased a little. However, the observed differences were non-significant in comparison to control. The best treatment found in these studies was the combination of all the three amendments tried i.e. gypsum, H_2SO_4 and FYM. A significant decrease in EC_e was observed for this combination. Among the possible reasons may be the improvement in porosity and hydraulic conductivity, which resulted in enhancing the leaching of salts. Sharma *et al*. (1982) also reported decrease in EC_e.

Soil pH. High pH denotes the dominance of sodium among the cations and carbonates/bicarbonates from anions. Data of Table IV indicates that this important chemical parameter decreased significantly in all the treatments as compared to control. These treatments proved statistically similar and had no significant differences between themselves. However, the treatment T_2 (FYM) had non-significant effect on the soil pH in comparison with T_1 (control). Minimum pH value was recorded with gypsum + H_2SO_4+ FYM followed by H_2SO_4 alone. This may also be attributed to the removal of carbonates and bicarbonates of sodium to a greater extent after reclamation. Similar results were obtained by Haq (1966), Muhammad *et al*. (1969), and Muhammad and Khaliq (1975).

Table IV. Effects of different amendments on EC_e, pH and SAR of sodic soil (average of four replications)

Treatments	EC_e	pH_s	SAR (mmol $L^{-1})^{½}$
T_1	3.61 a	8.94 a	40.66 a
T_2	3.04 b	8.80 a	32.05 b
T_3	3.21 ab	8.50 b	27.27 bc
T_4	3.05 b	8.44 b	27.94 bc
T_5	3.92 a	8.30 bc	22.84 c
T_6	3.83 a	8.37 bc	16.35 d
T_7	3.08 b	8.38 bc	15.37 d
T_8	2.85 b	8.29 c	14.74 d

Sodium adsorption ratio (SAR). The data of various treatments on the sodium adsorption ratio (SAR) of the soil after reclamation are presented in Table IV. Sodium adsorption ratio decreased significantly when it was treated with H_2SO_4, gypsum and FYM. The differences within these treatments were non-significant. However, the decrease in sodium adsorption ratio was more and significant when various combinations were tried. The most effective treatment was the combination of all the three amendments. The sodic soil was reclaimed and SAR was reduced to the permissible limit of 15 here. The next better treatments were the combined application of H_2SO_4 with gypsum or FYM. The minimum decrease in SAR was recorded with FYM. Comparatively less reduction in case of gypsum or FYM alone may be due to slow reaction of these amendments in smaller span of time. Gypsum has less solubility and takes more time for complete reclamation of sodic soil. The decrease in SAR was essentially due to the removal of exchangeable sodium from the soil complex. The results are in agreement with those of Chaudhry and Warkentin (1968).

Crop yields. Data indicated that wheat yield was significantly increased (Table V) when different amendments were added before sowing of the crop and subsequent leaching was provided. However, the effect of single application of FYM was not assessed to be appreciable when compared with control. Different combinations of amendments were proved to be more effective in this regard. The most superior combination was gypsum + H_2SO_4 + FYM. The improvement in physical and chemical properties of salt affected soil, as observed in the earlier section, was the major reason for enhancement of crop yield.

Table V. Effect of Amendments on the Yield of Wheat Crop (t ha^{-1})

Treatments	Yield of wheat crop (t ha^{-1})
T_1	2.04 c
T_2	2.42 c
T_3	3.17 b
T_4	3.28 b
T_5	2.86 b
T_6	2.98 b
T_7	3.36 b
T_8	3.78 a

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