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Use of Municipal Solid Waste Compost in Combination of Sulphur in Sodic Soil Reclamation under Rice Crop (*Oryza sativa*)

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ABSTRACT

Combined use of municipal solid waste compost enriched with sulphur and gypsum can provide a convincing solution for ameliorating sodic soils and sustaining crop productivity. In this context, a controlled condition study was carried out on composting of MSW alone and its enrichment with element sulphur and gypsum followed by evaluation of the efficiency of MSW compost and products of its enrichment for amelioration of sodic soil. A pot experiment was conducted during 2020 to 2021 at Central Soil Salinity Research Institute, Karnal, Haryana (India) on two levels of soil sodicity (highly sodic soil pH 10.09 and moderate sodic soil pH 8.72) to evaluate the efficacy of sulphur and gypsum enriched MSW compost on sodic soil reclamation and sustainable yield production of rice. Three treatments (MSW+ES, MSW+G and MSW compost alone) were applied in different doses in sodic soil (highly and moderate sodic). MSW+ES (T_4) significantly reduced the soil pH_2 up to 13.5%, Na^+ up to 32%, ESP up to 41% and enhanced grain yield 33% as compared to control (non-amended soil). Out of all amended doses D_3 (@ 300 g/ 15 kg soil) was found most effective in reducing pH, Na^+ about 13.8 and 30.6, respectively. MSW compost alone or MSW enriched with gypsum was not much effective in sodicity reclamation. This study has proved that MSW enriched with sulphur can be used as an effective solution for improving soil physico-chemical properties and crop productivity in sodic soils.

Key words: Elemental sulphur, municipal solid waste, compost, organic carbon, reclamation, sodicity

INTRODUCTION

Land degradation due to excess salt accumulation, nutrients insufficiency and water scarcity are major threats in arid and semi-arid regions for agricultural production and sustainability (Yadav *et al.*, 2020). Saline-sodic soils are characterized by poor physical conditions due to swelling, slaking and dispersion of clay that leads to deterioration of soil structure, surface crusting, decline in infiltration rate and hydraulic conductivity. In India, about 6.73 million ha is salt affected land including salinity of which about 3.77 million ha area is reported as sodic soil (ICAR-Central Soil Salinity Research Institute, 2015). Long-term use of high residual alkalinity water causes rise in soil pH and exchangeable sodium percentage (ESP), which impose stress on crops and decline in yield and production (Minhas *et al.*, 2019). Application of phosphogypsum, gypsum, element sulphur and other chemical amendments acts as a source of Ca^{2+} tends to replace exchangeable Na^+, are effective for the reclamation of sodic soils, but they fail to improve soil physical and biological properties, which are important for sustaining crop productivity. Gypsum is the most common chemical amendment used for reclamation of sodic soils due to its low cost, high solubility, ease of use and widespread availability. Use of sulfur-containing amendments helps in solubilizing native soil calcite and lowers the soil pH (Chaganti *et al.* 2015; Noori *et al.*, 2021). Apart from chemical amendments, recycled organic waste application is also quite effective in reducing the soil sodicity. To satisfy the escalating food demand for burgeoning population under the circumstances of declining accessibility of quality gypsum, organic amendments is an effective mean of sodicity reclamation (Sundha *et al.*, 2020). In India, MSW production was about 62 Mt which was @ 450 g/capita/day in 2015 (CPCB, 2016). India also produces large quantities of industrial byproducts for example press-mud phosphogypsum and elemental sulfur, which are not managed and used properly. These

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wastes can be transformed into valuable products through composting with MSW and can be used as an alternative to gypsum for sodicity reclamation. Organic amendments, sulfur, phosphogypsum and gypsum enriched municipal solid waste compost (MSWC) have potential to recover the soil physico-chemical properties and structure. Organic acids formed with microbial respiration help in solubilization of native $CaCO_3$ and favour the sodium replacement from exchange complex. Organic matter present in composts can recover soil aggregation, stability in soil structure, soil water retention and stimulate soil microbial activity (Zaman *et al.*, 2020). Therefore, the present study was aimed at estimating the efficiency of elemental sulphur and gypsum enriched MSWC in sodic soil reclamation, their effects on soil physico-chemical properties and its subsequent effect on rice (*Oryza sativa*) yield.

MATERIALS AND METHODS

MSW was collected from Karnal Municipal Corporation, Karnal, Haryana (India). It was segregated into organic matter, textile, plastic, glass and wood, etc. The segregated bio-degradable part of MSW was composted alone and in combination with elemental sulphur (ES) and gypsum (G) in 1×1×1.2 m^3 compost pits for 125 days. The MSW was composted in three treatment combinations. These treatment combinations consisted of 200 kg MSW; 200 kg MSW + 50 kg G and 200 kg MSW+10 kg ES. Respective types of mature MSW compost (MSWC) samples were analyzed for various physico-chemical properties (Table 2).

Soil having two sodicity levels was used for present experiment. Moderate sodic (S_1) having pH 8.72 soil was collected from experimental field of ICAR-Central Soil Salinity Research Institute, Karnal (Haryana) located at latitude of 29°43′ N and longitude of 76°58′ E. Highly sodic (S_2) having pH 10.09 soil was collected from the Sitamai village located at latitude of 29°78′ N and longitude of 76°76′ E of Karnal district in Haryana. Each type of soil was air-dried, ground and mixed thoroughly for homogeneity. Samples were taken from both types of soil for estimation of initial chemical characteristics (Table 1). Different does of MSWC amendments were added in soil and mixed homogeneously. Three doses levels, namely, D_1 (75 g), D_2 (150 g) and D_3 (300 g) of MSWC amended treatments were mixed with 15 kg of soil (in both S_1 and S_2). Each pot was filled with 15 kg of soil containing different levels of amended treatment doses. Soil without use of any amendment and only addition of recommended dose of N: P: K (150:60:40 kg/ha) was taken as a control (T_1). Soil having MSW compost alone named as T_2, MSW+G as T_3 and MSW+ES as T_4. Rice crop (CSR-30) was grown in *kharif* season in 2020 and 2021. Yield parameter (grain) was recorded at maturity in both the seasons. Soil samples were collected from each treatment pot having different dose levels after the harvest of rice crop and were analyzed for physico-chemical parameters like EC, pH (1:2), organic carbon (OC), available nitrogen (N), sodium (Na^+), calcium (Ca^{2+}), exchangeable sodium percentage (ESP) and bicarbonate (HCO_3^-).

Data generated from the experiments were analyzed with appropriate statistical method of analysis of variance (ANOVA) technique, (SAS) for random block design (MSWC amended

Table 1. Properties of the sodic soil

Parameters	Unit	S_1 (Moderate sodic)	S_2 (Highly sodic)
pH (1:2)	-	8.72	10.09
Electrical conductivity (EC_2)	(dS/ m)	0.87	1.65
Available nitrogen (N)	(kg/ha)	76.17	67.93
Phosphorus (P)	(kg/ha)	38.44	28.18
Available potassium (K)	(kg/ ha)	224.53	174.5
Sodium (Na^+)	(meq/l)	43.2	67.8
Calcium (Ca^+)	(meq/l)	2.18	1.24
Bicarbonate (HCO_3^-)	(meq/l)		
Organic carbon (OC)	(g/kg)	2.13	1.51
Exchangeable sodium percentage (ESP)	-	45.22	70.87

treatments) and split-split factorial (soil and crop yield) using SAS 9.2 software (SAS Institute, 2001) and pair-wise comparison of the treatments effect using LSD (least significance difference) test at P≤0.05.

RESULTS AND DISCUSSION

Significantly higher pH_2 was recorded in treatment having MSW alone, while MSW enriched with elemental sulphur (ES) reduced the pH_2 up to 32.3% followed by MSW+G (4.2%) as compared to MSW alone (Table 2). Treatment having MSW+ES showed significantly highest EC_2 (6.43 dS/m). MSW+G and MSW were statistically similar and showed lowest EC value. Lowest nitrogen content was estimated in MSW treatment, rest of the treatments were found statistically similar. MSW+ES showed significantly higher phosphorus followed by MSW+G and MSW. Potassium percentage was observed significantly higher in MSW+ES followed by MSW+G and lowest in MSW. MSW+ES had greater amount of organic carbon (8.93%) than MSW + G and MSW. Treatment MSW + ES showed maximum reduction in pH and increased N, P, K and OC% which led to the assumption that this treatment could act as a good ameliorant for sodic soil.

Applied enriched MSWC significantly reduced the soil pH after harvest of rice over the initial values (Fig. 1A). S_1 (moderately sodic soil) showed significantly lower pH value i.e. 11.8% lower than S_2 (highly sodic soil). All the MSWC treatments showed significant decline in pH over the control. Highest decline was observed in T_4 (13.5%) followed by T_3 (10.1%) and T_2 (8.7%) as compared to T_1 (control). Doses level had significant impact on soil pH. Higher percentage of amendment doses led to greater reduction of pH in D_3 and D_2 as compared to D_1. Highest reduction was observed in D_3 (13.8%) followed by D_2 (11.6%) and D_1 (9.4%). Lowest pH value in T_4 treatment could be due to application of MSW compost as organic source of amendment. Organic amendments declined soil pH due to adsorption of hydrogen ion by their specific negative sites. Elemental sulphur that was activated during the composting process was microbiologically oxidized to sulfuric acid, which reacted with the native calcium carbonate to form gypsum (Ahmed *et al.*, 2017).

Supplement of Ca through gypsum helped exchange reaction between Na clay and Ca and reduced alkaline hydrolysis. All the applied factors (sodicity levels, treatments and doses amendments) had significant effect on soil salinity after rice harvest (Fig. 1A). Significant lower EC was recorded in S_1 than S_2 (1.08 and 2.29 dS/m, respectively). Highest EC was observed in T_4 treatment (67.8%) followed by T_3 (53.9%) and lowest in T_2 (10.4%) over T_1. D_1 had lowest value of salinity (26.9%) followed by D_2 (38.2%) and D_3 (74%) over control. Sulphur and gypsum reactions with alkali salts produced soluble sulphates and enhanced the soil EC, indicating dissolved soil minerals. Sundha *et al.* (2020) stated that amended soil showed higher value of EC than control soil. Application of gypsum and elemental sulfur with MSWC in sodic soils could hasten Na^+ leaching, reduced exchangeable sodium percentage (ESP). S_1 (34.19 meq/l) showed significantly lower Na^+ concentration than S_2 (51.61 meq/l). Concentration of sodium was lowest in T_4 followed by T_3 and T_2, while control (T_1) had highest Na^+ concentration (Fig. 1B). D_3 showed 30.6% Na^+ reduction followed by D_2 (27%) and D_1 (23.1%) than control. Soils treated with elemental sulphur with compost had significantly lower Na^+ concentrations than soils treated with ES alone, which may indicate that the compost enhanced the activity of sulfur-oxidizing bacteria (Day *et al.*, 2019). Rezapour (2014) found that elemental sulphur (ES) applied with manure, at 12 g sulphur kg/

Table 2. Chemical properties of mature Karnal MSW compost with various amendments

Treatments	pH	EC (dS/m)	N (%)	P (%)	K (%)	OC (%)
MSW	7.46^A	4.11^C	1.18^B	0.27^C	0.61^B	8.14^B
MSW+G	7.15^B	4.43^C	1.23^A	0.29^B	0.64^{AB}	8.25^B
MSW+ES	5.05^D	6.43^A	1.23^A	0.30^A	0.66^A	8.93^A
MSW+G+ES	5.51^C	5.74^B	1.22^A	0.31^A	0.64^{AB}	8.82^A
SEd±	0.03	0.15	0.01	0.01	0.01	0.11
C. D. (P=0.05)	0.07	0.29	0.03	0.01	0.02	0.21

A, B, C and D show significant difference between treatments.

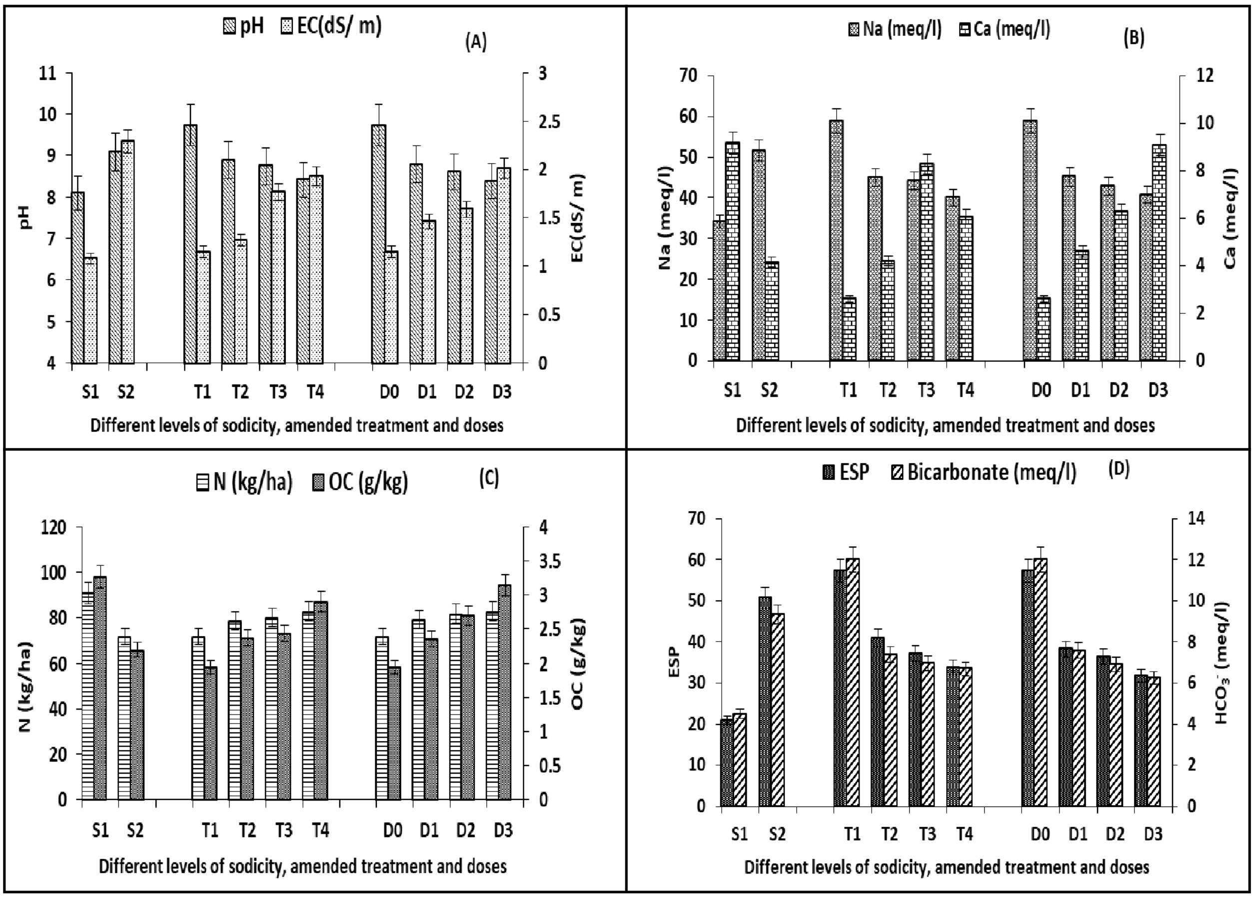

Fig. 1. Effect of sodicity, amended treatments and doses on soil (A) pH and EC, (B) Na^+ and Ca^+, (C) N and OC and (D) ESP and bicarbonate (HCO_3^-).

soil and 18 g manure kg/soil, successfully decreased pH in a 14-week greenhouse study. It is possible that with sufficient time, compost can support recovery of microbial activity in this disturbed soil and improve the efficacy of elemental sulphur for reducing Na^+ concentrations. Reverse trend was followed by calcium. Sodicity level S_2 (4.16 meq/l) showed significantly lower Ca^+ value than S_1 (9.14 meq/l). Significantly higher Ca^+ was estimated in T_3 followed by T_4 and T_2 over control (Fig. 1B). Calcium showed significant increment with doses increment. Gypsum is a good source of Ca^+ and most commonly used amendment for sodic soil reclamation, but on calcareous soils with pH more than 6.6, sulfur may also be added which is microbiologically oxidized to sulfuric acid, which reacts with the native calcium carbonate to form gypsum (Ahmed *et al.*, 2017). The decaying of organic matter leads to release of H^+ that reacts with native $CaCO_3$ and liberates more calcium for sodium exchange, helping to reclaim sodic soils. S_1 (90.91 kg/ha) showed significantly higher nitrogen than S_2 (71.84 kg/ha). Significantly higher nitrogen was estimated in T_4 (15.3%) followed by T_3 (11.6%) and T_2 (9.3%) over T_1 (Fig. 1C). Significantly higher nitrogen content was found in D_3 (31.45 kg/ha) and lowest in control (23.85 kg/ha). Favourable soil pH affects nutrient availability and it is very probable that reduced pH by gypsum and sulphur application in the study improved availability of macro and micronutrients like nitrogen and phosphorus due to synergic effect leading to promotive effect on plant growth. Application of MSW compost (organic source) stimulates nitrogen mineralization in saline-sodic soils due to increase in organic matter solubilization (Singh *et al.* 2016). Highly sodic soil (S_2) had significantly lower OC content than moderate sodic soil (S_1). T_4 treatment showed significantly higher OC (49%) followed by T_3 (25.5%) and T_2 (21%) over control (Fig. 1C). Significantly higher OC content was observed in D_3 followed by D_2 and D_1 (61.5, 38.4 and 21%, respectively) over control (D_0). This was due to combined application of organic matter with

ES and gypsum amendments, which made the rhizospheric environment more conducive for increasing root biomass and improvement of soil physical properties. Incorporation of organic amendments in sodic soil increased soil enzymes and their activities, which were direct indicators of enhancing soil fertility (Singh *et al.*, 2019). Soil ESP was found significantly (58.5%) lower in moderate sodic soil (S_1) than highly sodic soil (S_2). Application of T_4 reduced ESP value up to 41% followed by T_3 (34.9%) and T_2 (28%) than T_1 (Fig. 1D). Application of higher doses of amended treatments reduced higher percentage of ESP of soil. D_3 reduced approximately 44% soil ESP followed by D_2 (36%) and D_1 (33%) over control (D_0). Significantly higher amount of bicarbonate was estimated in S_2 (9.33 meq/l) as compared to S_1 (4.51 meq/l). Significantly lowest bicarbonate concentration was recorded in T_4 (44%) followed by T_3 (42%) and T_2 (38.5%) over T_1 (Fig. 1D). Highest HCO_3^- was recorded in control (12.04 meq/l)) followed by D_1 (7.6 meq/l), D_2 (6.91 meq/l) and lowest in D_3 (6.24 meq/l).

The sodic soil caused significant reduction in rice yield. There was about 33% rice yield reduction in highly sodic soil (Fig. 2) than moderate sodic soil. Excess amount of salts adversely affected the soil physico-chemical and microbial process and plant growth which led to reduced rice yield. The application of enriched MSWC significantly improved the rice yield under sodic conditions. Highest rice yield was recorded in T_4 (2.6 t/ha) followed by T_3 (2.2 t/ha) and T_2 (1.95 t/ha), while lowest yield was recorded in T_1 (1.7 t/ha). Application of higher doses resulted in greater yield production. D_3 showed 48% higher rice yield followed by D_2 (31.2%) and D_1 (17.6%) than control (D_0). This might be because of organic amendments with

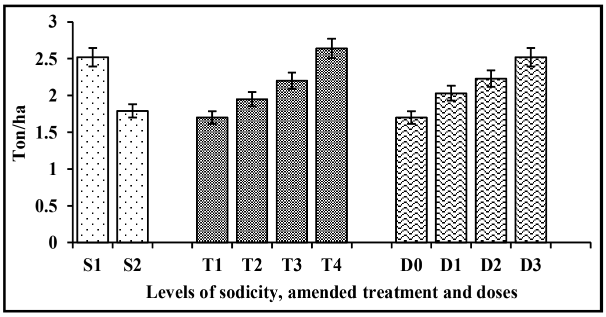

Fig. 2. Effect of sodicity, amended treatments and doses on rice grain yield during sodic soil reclamation.

ES and gypsum combination not only enhanced the amount of N, P and K in soil, but also increased their availability in the form of slow release in soil. Sulfur is one of the essential nutrients for growth of plant. Sulfur is a building block of protein and plays a vital role in the synthesis of chlorophyll. Without optimum level of sulfur in soil, crops cannot reach their full yield potential or protein content (Ahmed *et al.*, 2016). Furthermore under salt stress, sulfur and calcium improved K^+ /Na^+ selectivity and enhanced the action of Ca^{2+} in reducing the injurious effects of Na^+ in plants.

CONCLUSION

The application of ES and gypsum enriched MSWC effectively by reducing the soil sodicity and improving soil physical conditions. The availability of the major nutrients was improved and increase in soil OC content due to amelioration effect of applied enriched compost. The better soil conditions resulted in higher rice yields. The elemental sulphur enriched MSW composting proved more effective than gypsum enriched MSWC and MSW compost alone. The higher dose (@300 g/15 kg soil) found most effective in sodicity reclamation. In view of the decreasing availability of gypsum, addition of elemental sulphur enriched MSWC could be a low-cost alternative to costly amendments for reclamation of saline-sodic soils to improve their productivity in arid and semi-arid regions.

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