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Conjoint Use of Chemical Amendments and Municipal Solid Waste Compost for Amelioration of Degraded Sodic Soil

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Presence of salts in soil is one of the major challenges for restoration of degraded sodic lands. Reclamation of these soils through chemical amendments like gypsum and phosphogypsum is too expensive for marginal farmers. To provide a realistic solution for ameliorating sodic soils, through conjoint use of lower dose of chemical amendments with municipal solid waste (MSW) compost, a field experiment was conducted during 2015-16 to 2017-18 at ICAR-CSSRI, Research farm, Shivri, Lucknow (26°47′58″ N, 80°46′24″ E). The experiment was conducted on highly sodic soil having pH_2 9.8, EC_2 1.47 dS m^{-1}, and ESP 78. Reduced dose of gypsum or phosphogypsum @ 25% of gypsum requirement (GR) in combination with MSW compost @10 t ha^{-1} resulted in significant improvement in the soil physical, chemical and microbial properties over the recommended dose of gypsum or phosphogypsum (50% of GR). Combined use of gypsum or phosphogypsum @ 25% of recommended dose of gypsum along with MSW compost @ 10 t ha^{-1} increased about 10% soil organic carbon content, 13% available N, 42% bacterial population and 200% fungal population; and reduced 14% exchangeable sodium percentage over the recommended dose of inorganic amendments. With the application of gypsum @ 25% GR + on-farm MSW compost @ 10 t ha^{-1}, the soil bulk density decreased by 11% and the infiltration rate increased by 54% as compared to initial values. With the introduction of this approach there is saving of about 50% amount of inorganic amendments that can be utilized to reclaim double the degraded sodic lands and improve food security of resource poor farmers in the region. This also saved about 35.6% reclamation cost on account of reducing gypsum dose.

Key words: Amelioration, degraded sodic lands, gypsum, municipal solid waste compost

Accumulation of salts is a major factor for land degradation and reducing crop productivity in arid and semi-arid regions (Rengasamy 2008). About one billion hectare of soil around the world is affected from some degree of salinization and sodification problem (FAO 2008). Plant growth and nutrient availability in salt affected soils is inhibited due to low osmotic potential of soil solution, ion toxicity and ionic imbalance (Marschner 2012). Salt load in such soils also reduces microbial activities and microbial biomass (Chowdhury *et al.* 2011; Yan and Marschner 2012). About 6.73 million hectare (Mha) land representing 2.1% of India's cultivated land is classified unsuitable for cultivation due to salinity and sodicity (NRSA 2014). Of these, 2.8 Mha land are sodic in nature, primarily prevalent in the Indo-Gangetic alluvial plains. Restoration of these degraded sodic soils is of great importance to make these soils suitable for agriculture. Gypsum is the most commonly used chemical amendment for the reclamation of sodic soils. However, chemical amendment approach fails to improve the physical and biological properties of salt affected soils suffering from low hydraulic conductivity caused by dispersion (Hamza and Anderson 2003). Various organic amendments, such as farmyard manure (FYM), pressmud and municipal solid waste (MSW) compost alone and in combination with chemical amendments, have been investigated for their effectiveness in sodic soil reclamation and proven effective on improving physical properties of sodic soils for better crop growth, besides its role as fertilizer (Dhanushkodi and Subramanian 2012; Singh *et al.* 2017; Singh *et al.* 2018a). Management of MSW

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is one of the major challenges particularly in urban areas. It is expected that by 2025, waste production in the world may reach about 2.2 billion tonnes yr^{-1} (Hoornweg and Bhada 2012). India produces 12.74 million tonnes (Mt) MSW per day (CPCB 2012). Government of India has initiated integrated MSW management projects for composting and its efficient utilization but the use of compost in reclamation of salt affected soils has not been investigated. The MSW compost, with high organic matter content and low concentration of inorganic and organic pollutants allows an improvement of physical, chemical, biochemical and microbial characteristics and constitute low cost soil recovery (Walter *et al.* 2006). It could accelerate salt leaching; decrease both the exchangeable sodium percentage (ESP) and electrical conductivity (EC), and increase water infiltration, water holding capacity and aggregate stability (Tajada *et al.* 2006). Furthermore, MSW compost represents a source of nutrients that can improve soil fertility, may contribute to restoring the productivity of salt affected soils (Singh *et al.* 2018b). The industrial processed MSW compost available in the market being very costly (Rs. 5000 t^{-1}) restricts its use by the resource poor small and marginal farmers possessing sodic soils. On-farm composting of MSW combined with locally available agricultural wastes is a cost effective approach for turning organic waste materials into a farm resource (Singh *et al.* 2017).

The pressmud, an unused sugar industry by-product is another source of organic amendments is available in abundant quantity contains sizable quantities of macro and micronutrients, high calcium sulphate and organic matter. It also supplies Ca^{2+} directly to the soil which replaces excess Na^{+} from the soil exchange complex, and S present in pressmud get converted to sulphuric acid that lower down the soil pH thereby improving the physical, chemical and biological properties of sodic soils. Therefore, can be a useful amendment for reclamation of sodic soils otherwise, it is waste from sugarcane processing (Muhammad and Khattak 2011).

Most of the studies on use of organic amendments were confined to improve soil fertility and productivity of normal soils (Hanay *et al.* 2004). Contrary, very few studies were conducted on use of MSW compost and/or pressmud for amelioration of sodic soils.. Therefore, the present study was aimed i) to develop cost effective on-farm MSW compost to get nutrient rich quality compost and ii) to monitor the combined effect of organic and inorganic amendments on amelioration of degraded sodic soils.

Materials and Methods

Preparation of on-farm compost

To prepare on-farm compost, MSW was collected from ten different dumping sites of Lucknow city, mixed together, segregated into degradable and non-degradable materials. Degradable material along with agricultural wastes including mustard straw, rice straw, *Casuarina* and *Pongamia* leaves were mixed in 1:1 w/w ratio and filled in 360 cm long, 120 cm wide and 120 cm high vermi beds. Fresh cow dung @ 10 kg per 100 kg of composting material was made into slurry and layered in bed as natural inoculants. For rapid decomposition, three efficient degrading microbial cultures of *Aspergillus terreus*, *Trichoderma harzianum* and *Bacillus cereus* @ 100 mL culture in 10 L distilled water per 1000 kg composting mixture and 1.0 kg earthworm (*Eisenia foetida*) were added in order to hasten the composting process. Manual turning was performed at 15 days interval till maturity of compost to provide aeration. To maintain moisture (60% of water holding capacity), five litres of water was sprayed at 4 days interval throughout the composting period. To monitor the changes in moisture content, sample were collected from 3 places, mixed together and make a composite sample and analyzed moisture content on fresh weight basis. The industrial processed MSW compost was collected from A-Z municipal solid waste treatment plant, Kanpur to compare with on-farm MSW compost in terms of biochemical and microbial properties.

Biochemical composition of on-farm compost

After 120 days of composting, samples were collected from three places from 0-30 cm depth, mixed together and make a representative sample. Part of the sample was kept in refrigerator at 4 °C temperature for microbial study and the remaining sample was dried (65±1 °C) for 24 h, ground to pass through a 2-mm sieve, mixed thoroughly and used for the analysis of pH, EC, total carbon (C), total nitrogen (N), total phosphorus (P), and total potassium (K). The EC and pH were analyzed through digital pH meter (Systronics µpH System 361) and EC meter (Systronics, Conductivity TDS meter 308) using 1:5 waste: water ratio. Total C, P and K were determined following standard methods (Jackson 1973). Total N content was estimated by micro-Kjeldahl distillation method (Bremner and Mulvaney 1982). Heavy metal contents were analyzed in the acid digested samples using atomic absorption spectrophotometer (AAS). To analyze the microbial changes during composting, different selective media such as nutrient agar for total bacterial population, and potato dextrose agar for fungal population were used. The serial dilution of 10^{-4} of the compost sample was prepared for plate count. Spread plate technique was used to spread 1 µL sample of dilution on different media plates that were kept in incubator at 30 °C for 48 h. After incubation, viable colonies were counted using colony counter (Table 1).

Initial properties of experimental field

The soil samples collected from 0-15 cm soil depth were air-dried, ground in a pestle and morter and pass through a 2-mm sieve, homogenized through mixing and used to analyze soil physicochemical and biological properties. Sand, silt and clay contents were determined using International Pipette Method. The soil bulk density determined through intact cores was 1.6 g cm^{-3}, the infiltration rate measured using double concentric cylinder infiltrometer was 2.1 mm d^{-1}. The pH and EC of the soil was determined in 1:2 soil: water suspension showed that the soil was highly alkaline (pH 9.8, EC 1.47 dS m^{-1} and ESP 78). Organic carbon content was determined by rapid titration method (Walkley and Black 1934) and, available N were very low. The available P content determined by the Olsen sodium bicarbonate extraction (Olsen and Dean 1965) was medium (8.3 mg kg^{-1}). The concentrations of Na^+ and K^+ in saturation extract were measured by flame photometer and the concentration of Ca^{2+} and Mg^{2+} in soil extract was estimated by the Versenate method (Chang and Bray 1951). Carbonate (CO_3^-) and bicarbonate (HCO_3^-) contents were also determined in extract by titration with 0.01 *N* H_2SO_4 using phenolphthalein and methyl orange indicators. The gypsum requirement (GR) of sodic soil was estimated in laboratory employing modified Schoonover method (Schoonover 1952) was 15.2 t ha^{-1}. The soil was having very poor bacterial (1.3×10^6 cfu g^{-1}) and fungal population (2.0×10^4 cfu g^{-1}). The heavy metal contents like Co, Cr and Pb extracted with DTPA reagent (Lindsay and Norvell 1978) were 0.76, 0.070 and 1.13 ppm, respectively which were below the permissible limits described by MacLean *et al.* (1987). The initial physicochemical and biological properties of experimental field are presented in table 2.

Experimental design and treatment details

A field experiment was conducted comprising of eight treatments *viz.*, T_1: Gypsum @ 50% GR, T_2: Phosphogypsum @ 50% GR, T_3: Gypsum @ 25% GR + on-farm MSW compost @ 10 t ha^{-1}, T_4: Phosphogypsum @ 25% GR+ on-farm MSW compost @ 10 t ha^{-1}, T_5: Gypsum @ 12.5% GR + on-farm MSW compost @10 t ha^{-1}+ press mud @10 t ha^{-1}, T_6: Phosphogypsum @ 12.5% GR+ on-farm MSW compost @10 t ha^{-1} + press mud @10 t ha^{-1}, T_7: Gypsum @ 25% GR + industrial processed MSW compost @ 10 t ha^{-1} and T_8: Phosphogypsum @ 25% GR + industrial processed MSW compost @ 10 t ha^{-1} was conducted during 2015-16, 2016-17 and 2017-18 in a randomized block design, replicated thrice having plot size of 9 m × 10 m. The mineral grade gypsum ($CaSO_4.2H_2O$) having 18.3% Ca and 16.1% S; phosphogypsum containing 18.9% Ca and 16.4% S were mixed in the surface soil and proper reclamation protocol for reclamation of sodic soil was followed. The organic amendments like pressmud containing 0.23% S, 11% Ca, 1.65% Mg, 26% total C, 1.33% total N, 1.08% total P, 0.53% total K and 30-35% organic matter, MSW compost, and industrial

Table 1. Physicochemical and biological properties of on-farm MSW compost and industrial processed municipal solid waste composts

Quality parameters	On-farm MSW compost	Industrial processed MSW compost	Quality parameters	On-farm MSW compost	Industrial processed
pH (1:5)	7.36	7.48	Cu (ppm)	313	364
EC (dS m^{-1})	0.66	0.68	Cr (ppm)	61.6	45.5
Total N (%)	0.79	0.43	Pb (ppm)	59.2	29.3
Total P (%)	0.39	0.41	Zn (ppm)	377	483
Total K (%)	0.74	0.57	Cd (ppm)	7.42	7.30
Total C (%)	13.5	11.1	Ni (ppm)	60.30	49.1
C:N ratio	17.1	25.9	Bacterial population (cfu g^{-1})	98×10^5	48×10^5
Ca (ppm)	260	250	Fungal population (cfu g^{-1})	79×10^5	45×10^5
Mn (ppm)	447	480	Bulk density (g cm^{-3})	0.89	0.78

C: N ratio = carbon: nitrogen ratio

Table 2. Initial properties of experimental field at ICAR-CSSRI, Research farm, Shivri, Lucknow, Uttar Pradesh

Soil parameters	Value	Soil parameters	Value
Sand (%)	65.5	Na^+ (ppm)	342
Silt (%)	18.5	K^+ (ppm)	3.1
Clay (%)	16.0	Ca^{2+} (me L^{-1})	3.60
Textural class	Loam	Mg^{2+} (me L^{-1})	3.80
Bulk density (g cm^{-3})	1.60	CO_3^{2-} (me L^{-1})	6.00
Porosity (%)	42.4	HCO_3^- (me L^{-1})	22.0
Infiltration rate (mm d^{-1})	2.10	Co (ppm)	0.80
pH	9.80	Cr (ppm)	0.07
EC (dS m^{-1})	1.47	Cu (ppm)	3.20
ESP	78	Fe (ppm)	13.6
Organic carbon (g kg^{-1})	1.30	Mn (ppm)	7.60
Available N (mg kg^{-1})	30.7	Pb (ppm)	0.10
Olsen's P (mg kg^{-1})	8.30	Zn (ppm)	0.70
Available K (mg kg^{-1})	173	Bacterial count (cfu g^{-1})	1.3×10^6
GR (t ha^{-1})	15.2	Fungal count (cfu g^{-1})	2.0×10^4

processed MSW compost were applied @ 10 t ha^{-1} uniformly and mixed in surface soil (0-15 cm depth) through shallow ploughing in respective treatment plots. These amendments were added only once during initiation of experiment. Rice and wheat crops were grown in *kharif* (rainy) and *rabi* (winter) seasons, respectively. Recommended agronomic practices including basal dose of fertilizers were followed uniformly in all the treatments.

After three years of rice-wheat cultivation soil samples were collected from three places in each plot mixed together to make a composite sample. Part of the sample was kept in refrigerator at 4 °C for the analysis of microbial properties and the remaining sample were air-dried in shade, ground using pestle and morter, passed through 2-mm sieve and used to analyze soil physicochemical and microbial properties following standard analytical procedures. Micro-nutrient and heavy metal content in soil from different treatments were determined in DTPA extract as per the procedure given of Lindsay and Norvell (1978).

Statistical analysis of the data was performed subjected to the statistical analysis of variance to the experimental design using MSTAT-C version 2.1 developed by Russel (1994).

Results and Discussion

Synergistic effect of organic and inorganic amendments on soil properties

Physical properties: The bulk density of surface (0-15 cm) soil significantly reduced when organic sources of amendments were applied in conjunction with chemical amendments. Hussain *et al.* (2012) reported that application of chemical amendments in the lesser quantities in combination with organic amendments may be a good strategy to reclaim the sodic soils. Maximum reduction in bulk density was recorded with treatment T_3 (gypsum @ 25% GR+ on-farm MSW compost @10 t ha^{-1}) and lowest with T_1 (gypsum @ 50% GR) (Table 3). However, application of gypsum alone, while being successful in improving soil properties significantly, does not have much effect on soil physical properties. Several researchers have also reported inability of gypsum to improve physical and biological properties of soil (Sahin *et al.* 2002; Tajada *et al*. 2006). Infiltration rate varied from 11.15 to 18.20 mm d^{-1} under different treatments. Highest infiltration rate was recorded with treatment T_4 where phosphogypsum @25% GR and on-farm MSW compost @10 t ha^{-1} was applied. This might be due to enhancement of pore geometry and transmission pores by addition of organics (Singh *et al.* 2014).

Chemical properties: A significant reduction in soil pH, EC, and ESP; and increase in organic carbon content was observed over the initial values (Table 3). Maximum reduction in soil pH was recorded in treatment T_3 whereas, minimum in T_5. Furthermore, analysis showed that a significant reduction in ESP and improvement in soil organic carbon content was recorded in treatment T_3 over the initial values. Garcia *et al*. (1994) reported increase in soil organic carbon and enzymatic activities in the MSW treated plots. Maximum reduction in EC was recorded under treatment T_1 but there was no statistically significant difference between the treatments in this parameter. Available N content varied from 175 to 198 kg ha^{-1}. Maximum available N content (198 kg ha^{-1}) was recorded in treatment T_4 and minimum in treatment T_7. There was no significant difference between the treatments in this parameter but it increased significantly over the initial value. In our study, we have observed significant reduction in Na^+, CO_3^{2-} and HCO_3^- and improvement in K^+, Ca^{2+}, Mg^{2+} and Cl^-, was observed due to synergistic effect of gypsum and on-farm MSW compost followed by cultivation of salt tolerant varieties of rice and wheat (Table 3). Walter *et al*. (2006) reported that N, P and K levels increased significantly with the addition of MSW compost.

Biological properties

The microbial population increased with the application of amendments. Both bacteria and fungi population in soil increased over the initial value in all the treatments. Maximum bacterial population (11.0×10^7 cfu g^{-1}) was enumerated in treatment T_3 followed by T_4 (8.0×10^7 cfu g^{-1}) and T_7 (8.0×10^7 cfu g^{-1}). However, maximum fungal population (9.0×10^5 cfu g^{-1}) was observed in treatment T_4 and T_7. This indicated the higher improvement in soil microbial flora with the combined application of organic and inorganic amendments compared to only application of inorganic amendments *viz*., gypsum or phosphogypsum (Table 3). Walmsley and Cerdà (2017) found that the organic matter is the key factor on soil properties and the richness of macro fauna on citrus plantations soils. Yazdanpanah *et al.* (2016) reported that the organic amendments affected the soil hydrology, structure and the microbial respiration in semiarid lands. Mbarki *et al.* (2017) also observed that in vineyards the use of compost is very positive to reduce the soil degradation as a consequence of salinity.

Combined effect of organic and inorganic amendments on heavy metal content in soil

The micronutrients like Zn, Fe and Cu contents increased over the initial values whereas, Mn content decreased. Maximum increment in Fe content was recorded in treatment T_8 where industrial processed MSW compost was used in combination with phosphogypsum (Table 4). The concentration of heavy metal like Co and Cr was reduced over the initial value whereas, the concentration of Pb increased but it was below the permissible limit ascribed by MacLean *et al.* (1987). The highest concentration of Co (673 mg kg^{-1}) and Cr (0.069 mg kg^{-1}) was recorded in treatment T_5 and T_7 which were less than the initial value. The heavy metals in the environment are a topic that must be researched due to the diverse sourced found, from the fertilization, or from the traffic (Trujillo-González *et al.* 2016).

Conclusions

The on-farm MSW compost prepared through earthworms (*Eisenia foetida*) and degrading microbial strains produced nutrient rich and cost effective quality compost. Addition of MSW compost @ 10 t ha^{-1} with reduced dose of gypsum (@ 25% GR) in sodic soil followed by cultivation of salt tolerant varieties of rice and wheat reduced soil bulk density and increased infiltration rate significantly over the only use of gypsum or phosphogypsum @ 50% GR. This approach has also significantly reduced soil pH, EC and ESP and increased about 169% organic carbon over the application of gypsum or phosphogypsum @ 50% GR. Soil microbial flora improved with the combined application of organic and inorganic amendments compared to only application of gypsum

Table 3. Effect of organic and inorganic amendments on soil physicochemical and microbial properties after three years of amendment and cultivation of rice-wheat cropping system

Treatments	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	$LSD_{0.05}$
Bulk density (g cm^{-3})	1.57	1.53	1.41	1.46	1.48	1.52	1.48	1.41	0.03
Infiltration rate (mm d^{-1})	11.15	13.20	17.21	18.20	15.42	15.20	18.00	17.22	1.32
pH_2	9.00	8.86	8.84	8.98	9.21	9.12	8.99	8.93	ns
EC_2 (dS m^{-1})	0.76	0.78	0.44	0.65	0.62	0.54	0.77	0.76	0.12
ESP	30.0	30.0	30.0	28.0	30.0	34.0	30.0	32.0	0.23
OC (g kg^{-1})	3.10	3.20	3.40	3.50	2.60	2.80	3.00	3.00	0.30
Available N (kg ha^{-1})	184	182	190	198	179	175	178	185	15.2
Na^+ (ppm)	284	290	230	233	280	296	289	259	23.2
K^+ (ppm)	3.14	2.74	2.44	3.56	2.45	3.21	4.37	3.21	ns
Ca^{2+} (ppm)	12.0	13.92	19.92	12.00	19.92	13.92	23.16	19.92	1.13
CO_3^{2-} (meq L^{-1})	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	ns
HCO_3^- (meq L^{-1})	1.50	2.83	1.50	2.16	1.66	1.83	1.33	1.83	1.12
Bacterial population (cfu g^{-1})	7.8×10^7	7.0×10^7	11.0×10^7	8.0×10^7	7.0×10^7	7.0×10^7	8.0×10^7	7.0×10^7	-
Fungal population (cfu g^{-1})	4.0×10^5	5.0×10^5	8.0×10^5	9.0×10^5	3.0×10^5	4.0×10^5	9.0×10^5	8.0×10^5	-

Table 4. Micronutrient and heavy metal content in soil under different treatments after three years of reclamation following rice-wheat cropping system

Treatments	Co	Cr	Cu	Fe	Mn	Pb	Zn
				(mg kg^{-1})			
T_1	0.60	0.065	3.72	21.1	6.70	0.132	0.63
T_2	0.42	0.065	3.22	16.6	4.25	0.135	0.45
T_3	0.47	0.063	2.90	20.4	3.89	0.176	1.13
T_4	0.51	0.059	2.98	23.0	6.11	0.174	1.05
T_5	0.67	0.064	2.89	25.9	6.92	0.162	1.12
T_6	0.52	0.063	3.37	20.2	6.60	0.168	1.68
T_7	0.67	0.069	3.54	28.5	6.28	0.208	1.31
T_8	0.65	0.064	3.24	36.5	6.98	0.209	1.20
Initial*	0.76	0.070	3.18	13.6	7.6	0.113	0.77
$LSD_{0.05}$	0.04	NS	0.43	1.13	1.13	0.03	0.06

*Soil status before initiating the experiment; LSD = least significant difference

or phosphogypsum. This technology may trigger the reclamation process and be more cost effective, eco-friendly, acceptable to small and marginal farmers and sustainable. Composting of MSW and its use for reclamation of sodic soils is a cost effective approach for converting waste into best for improving soil health and harnessing productivity potential of sodic soils.

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