Journal of Soil Salinity and Water Quality 12(1), 70-79, 2020

Amelioration Potential of Sulphur and Phosphogypsum Enriched Municipal Solid Waste Compost in Saline-Sodic Soils

Gajender Yadav[1]*, Murlidhar Meena[2], Bhaskar Narjary[1], Parul Sundha[1], Kirti Yadav[1], Manisha Devi[1], Madhu Chaudhary[1], Asim Dutta[1] and RK Yadav[1]

[1]ICAR-Central Soil Salinity Research Institute, Karnal-132 001, Haryana, India
[2]ICAR-Directorate of Rapeseed-Mustard Research, Sewar, Bharatpur-321303, Rajasthan, India
**Corresponding author E-mail: Gajender@icar.gov.in*

Abstract

Salinity and sodicity severely influence soil physico-chemical properties and impose stress on plants, consequently decrease the crops yield in arid and semiarid regions. Sustainable management of Municipal Solid Waste (MSW) and other industrial by-products is another emerging challenge. MSW compost and some industrial byproducts can be utilized as amendments for reclamation of salt-affected soils. In this context, a controlled condition study was carried out on composting of MSW alone and its enrichment with gypsum, phosphogypsum, spent wash, elemental sulphur, and press-mud followed by assessment of the efficacy of MSW compost and products of its enrichment for amelioration of saline-sodic soil [pHs, electrical conductivity (ECe) and exchangeable sodium per cent of 9.55, 4.72 dS m^{-1} and 58.3, respectively]. A sequential leaching column experiment was also conducted, on homogenized mixture of saline-sodic soil with MSWC/enriched MSWC, to assess the salts release and removal efficiency of different byproducts enriched MSWC. Use of MSWC and its enrichment with organic and inorganic amendments reduced soil pH and EC with significant improvement in soil health. Elemental sulphur and phosphogypsum enriched MSWC application @ 20 Mg ha^{-1} significantly reduced soil pH and soluble salts and thus, proved more effective than gypsum, pressmud and spent wash enriched MSWC. In the view of decreasing availability and purity of mined gypsum, due to competing demand of gypsum in other sectors, elemental sulphur and phosphogypsum enriched MSWC can prove a low-cost alternative to costly amendments for reclamation of saline- sodic soils.

Key words: Elemental sulphur, Municipal solid waste compost, Phosphogypsum, Saline-sodic soil, Total cation mass

Introduction

Salt-induced land degradation, water scarcity and nutrients deficiency are serious threat to agricultural production and sustainability in arid and semiarid regions (Bossio *et al.,* 2017; Meena *et al.,* 2019). Soil salinity degradation problem extends over 20% of irrigated and 5% of total cultivated land throughout the world (Flower and Yeo, 1995). Excess amount of neutral soluble salts in saline conditions (Rengasamy, 2006; Yadav *et al.,* 2007) and salts which produce alkalinity on hydrolysis with exchangeable Na^+ in sodic soils (Muhammad and Khattak, 2011; Minhas *et al*., 2019) negatively impacts soil physico-chemical and biological properties and impose stress on plant processes, and consequently decreases the crop yield. Soil salinity disturbs water and nutrient accessibility and translocation through osmotic stress (Yadav and Dagar, 2016), while sodicity severely deteriorates the soil aggregation. Improving and maintaining health and fertility of salt affected soil is of paramount importance in Indian agriculture to meet the demands of food and nutritional security for an ever-increasing population. The total grain demand, for the expected world population of 1.6 billion, is likely to be 377 million tons by 2050. Currently global estimate of the salt-affected soil is about 1125 Mha (Wicke *et al.,* 2011) while in India SAS area extends over 6.74 Mha (3.77 sodic + 2.96 saline). It is likely to reach 16.2 Mha by 2050 (Central Soil Salinity Research Institute, 2015).

Arid and semi-arid areas face water deficiency in terms of quality as well as quantity (Jalali and

Merrikhpour, 2008; Yadav and Dagar, 2016). Long-term use of high residual alkalinity water also lead to increase in soil pH and exchangeable sodium percentage (ESP), which negatively affects crop yield and production (Choudhary *et al.,* 2011; Minhas *et al.,* 2019). Saline-sodic soil amelioration requires replacement of Na^+ from the colloid's cation exchange-sites and it's leaching in percolating water below the root zone (Ilyas *et al*., 1997; Minhas *et al*., 2019). Several chemical amendments are used for reclamation of saline-sodic soil such as $CaCl_2.2H_2O$, gypsum, phosphogypsum and elemental sulfur. Chemical amendments act as a source of Ca^{2+} to replace the exchangeable sodium from the cation exchange complex and improve the physical conditions of saline-sodic soils (Oster, 1982). To fulfill the increasing food demand for burgeoning population under the circumstances of decreasing availability of quality gypsum, these problem soils have to be reclaimed through organic amendments (Sundha *et al*., 2020).

Sustainable management of municipal solid waste (MSW) is one of the major problems of cities and towns. MSW generation has increased in India from 100 g day^{-1} $person^{-1}$ to 450 g day^{-1} $person^{-1}$ after independence. In India, the current total MSW generation is around 48 million tons per annum and it is expected to increase to 300 million tons by the year 2047. Country also produces huge quantities of industrial byproducts such as phosphogypsum, spent wash, press-mud and elemental sulfur, which are not managed and used properly. These wastes can be converted in to value added products through composting with MSW and can be used as an alternative to gypsum in reclamation of sodic soils.

Organic amendments, gypsum, phosphogypsum and sulfur enriched MSWC have potential to improve the soil physico-chemical properties and structure. Organic acids formed with microbial respiration help in solubilization of native $CaCO_3$ and favor the Na^+ replacement from exchange complex (Singh *et al.,* 2014; Shrivastva *et al.,* 2014). Use of stabilized and well matured MSWC has been also found to increase soil water infiltration, water holding capacity, organic carbon and nutrient status in saline-sodic soil (Lakhdar *et al.,* 2010; Oo *et al.,* 2013; Meena *et al.,* 2016). However, very little information is available on effectiveness of MSWC and its enrichment, using different waste materials/byproducts, products in amelioration of saline-sodic soils. Therefore, the present study was conducted to estimate the efficiency of MSWC in combination with gypsum, phosphogypsum, elemental sulfur, pressmud and spent wash for reclamation of saline-sodic soils.

Materials and Methods

MSW compost preparation and soil sampling

MSW was collected from Karnal Municipal Corporation, Karnal, Haryana. Biodegradable portion of MSW was manually segregated and used for compost preparation. Compost was prepared using MSW alone and in combination with gypsum (G), phosphogypsum (PG), spent wash (SW), elemental sulfur (S), and press-mud (PM). Compost pits (1 m × 1 m × 1.2 m) were filled with six mixtures viz., MSW 100 kg; MSW100 kg + 10 kg G; MSW 100 kg + 10 kg PG; MSW100 kg + 10 L SW; MSW100 kg + 2.0 kg S; MSW100 kg + 10 kg PM, and co-composted with Pusa compost inoculant for 125 days. Chemical characteristics of respective types of matured MSWC are presented in Table 1.

Table 1. Physico-chemical properties of well matured MSW compost

Treatments	EC ($dS\ m^{-1}$)	pH	N (%)	P (%)	K (%)	Ca^{2+} (%)	Mg^{2+} (%)	SO_4^{-2} (%)	Na^+ (%)
MSW	6.8	7.7	0.4	0.26	0.82	2.08	0.61	0.49	0.31
MSW+G	7.9	7.4	0.4	0.22	0.99	3.10	0.79	0.76	0.29
MSW+PG	8.8	7.6	0.5	0.22	0.92	3.43	0.72	0.77	0.35
MSW+SW	10.8	7.8	0.5	0.26	1.27	2.20	0.82	0.55	0.40
MSW+S	13.3	6.3	0.5	0.25	0.99	2.06	0.69	0.81	0.33
MSW+PM	9.3	7.4	0.6	0.38	0.86	2.60	0.76	0.63	0.34

MSW stands for municipal solid waste, G for gypsum, PG for phosphogypsum, SW for spent wash and S for elemental sulfur

Table 2. Changes in soil chemical properties after incubation as amended with different MSW composts

Treatments	pHs	ECe	CEC	ESP	Ca^{2+}	Mg^{2+}	Ca^{2+} + Mg^{2+}	Na^{+} (me L^{-1})	CO_3^{2-} (me L^{-1})	HCO_3^{-} (me L^{-1})	K^{+} (me L^{-1})
Initial Soil properties*	9.55	4.7	8.4	58.3	2.2	1.1	3.3	63.8	1.2	7.1	2.3
Control	9.48^{A}	4.37	8.41	55.62^{AB}	2.70^{B}	1.48^{B}	4.35^{D}	82.15^{B}	1.18^{B}	5.32	2.70^{D}
MSW	9.31^{A}	2.84	7.81	61.89^{A}	3.33^{B}	2.50^{B}	5.83^{D}	57.93^{B}	1.60^{AB}	4.1	2.85^{D}
MSW+G	8.44^{B}	3.06	8.23	39.37^{CD}	23.77^{A}	8.07^{B}	31.83^{B}	198.86^{A}	0.33^{C}	3.53	11.15^{B}
MSW+PG	8.17^{BC}	3.27	8.65	16.96^{E}	23.80^{A}	7.23^{B}	31.03^{B}	174.17^{A}	1.00^{BC}	4.57	9.76^{C}
MSW+SW	9.34^{A}	2.65	8.91	44.58^{BC}	8.53^{B}	5.60^{B}	14.13^{C}	198.83^{A}	1.53^{AB}	3.57	10.60^{BC}
MSW+S	7.88^{C}	3.67	8.5	24.51^{DE}	19.97^{A}	15.47^{A}	35.43^{A}	177.72^{A}	1.13^{B}	2.6	13.65^{A}
MSW+PM	9.29^{A}	3.40	8.41	55.51^{AB}	9.70^{B}	4.83^{B}	14.53^{C}	182.50^{A}	2.13^{A}	4.23	10.07^{BC}
LSD ($p \leq 0.05$)	0.3267	NS	NS	15.615	6.5231	5.8243	2.6054	25.362	0.6764	NS	1.2768

Note*: Initial soil properties are not included for LSD analysis. Same superscript letters in a column indicate that data are not significantly different with one another. Depictions as in Table 1

The bulk soil sample (0-30 cm soil layer) was collected from Bichhia village (29°59′N 76°25′) of Kaithal district in Haryana, India. The initial physico-chemical properties of soil are given in Table 2. The climate of the region is semi-arid and sub-tropical monsoonal. The region receives ~ 563 mm annual rainfall against >1580 mm evaporation.

Soil incubation with different amendments

The air dried saline-sodic soil (20 kg) was separately treated with each of six types of MSWC (@ 20 Mg ha^{-1} and incubated in tubs, by maintaining moisture at 60% of water holding capacity and room temperature (25 ± 2ºC) for 45 days, so as to stabilize the microbial activity and attain equilibrium. Soil pH, EC, Na^{+}, K^{+}, ESP, CEC, CO_3^{-}, HCO_3^{-}, Ca^{2+} and Mg^{2+} were determined as per the standard methods.

Soil column experiment

Soil column study was carried out, in a set of thirty six large PVC cylindrical tubes of 60 cm length and 14 cm internal diameter with a drainage hole at the bottom, in a completely randomized block design with three replications. The columns were filled with sand gravel up to a height of 5 cm and covered with a piece of filter paper to facilitate leaching and avoid clogging of drainage hole. Six types of incubated soils (7.250 kg) were filled up to 30 cm in batches with simultaneous tapping to achieve the desired bulk density (1.57 g cm^{-3}) as out lined by Chaganti *et al.* (2015).

The leaching experiment was conducted under saturated condition at room temperature. A constant water head of 13.5 cm was maintained at the top of the column using 2.3079 L water. De-ionized water having pH 7.7 and EC < 0.1 dS m^{-1} was used for leaching experiment. The leachate was collected at 24 hours interval continuously for 8 days. Collected leachate was filtered through a Whatman 42 filter paper and frozen (-20 °C) for later analyses. Determination of pH, EC, Ca^{2+} and Mg^{2+} were estimated by AAS (Analytika Jena, ZEEnit 700p; Germany). Na^{+} and K^{+} were measured with a flame photometer (Jackson, 1973). CO_3^{-} and HCO_3- were determined by methyl red and phenolphthalein endpoint titration method. After completion of the leaching, the soil columns were allowed to drain. Soil in the column was air-dried in the shade, removed from column with depth wise (0-10, 10-20, 20-30 cm) partitioning and analyzed for pH and EC.

Total mass (T_M) of summation of each of leached cations, from soil columns, was calculated using concentration (*Ci*) and the leachate volume (*Vi*) as per the following method given by Yazdanpanah and Mahmoodabadi (2013):

$$T_M = \sum_{i=1}^{i=8} (Ci \times Vi) \quad \text{...(i)}$$

Using the T_M value for each soil amendment (T_{Mt}) compared to that of the control (T_{Mc}), the change of cations mass (C_M%) was computed using the following equation:

$$C_M\% = \left[\frac{T_{Mt} - T_{Mc}}{T_{Mc}} \right] \times 100 \quad \text{...(ii)}$$

Accordingly, greater amount of C_M% implies higher efficiency of the amendment compared to the control in removing the cations out of soil column, while its negative value indicates that the control is more effective.

Statistical analysis

Data generated from the experiments were analyzed with appropriate statistical method of analysis of variance (ANOVA) technique (SAS) for random block design using SAS 9.2 software (SAS Institute, 2001) and pair wise comparison of the treatments effect using LSD (least significance difference) test at $p \leq 0.05$.

Results and Discussion

Changes in soil pH_s and EC_e after incubation

Incubating soil with MSW composts enriched with different amendments influenced the soil chemical properties. MSW+ S significantly decreased soil pH up to 1.67 units followed by 1.38 and 1.11 units with MSW+ PG and MSW+G, respectively as compared to initial soil which also remained significantly (P>0.002) lower than other treatments. The physico-chemical properties of incubated soil are given in Table 2.

Changes in pH and EC of soil leachate as affected by different composts

Leaching soil with application of different amendments enriched MSWC significantly declined the pH in leachate (Table 3). MSW+PG and MSW+S treatments significantly reduced the pH of leachate as compared to control and other treatments. The pH of the leachate decreased towards neutral in initial pore volumes and increased to alkaline range (7.94-8.84) in MSW+S and other treatments in the subsequent pore volumes (Table 3). This increase in leachate pH can be associated with alkaline hydrolysis of Na-clay followed by the loss of neutral salts during leaching from the soil columns. Leaching of CO_3^{2-} and HCO_3^- in the later pore volumes also contributed to increase in the leachate pH (Chaganti *et al.,* 2015). Jalali and Ranjbar (2009) also reported that control soils showed higher pH values of leachates due to release of CO_3^{2-} and HCO_3^- of Na^+ corroborating with our findings of soil alkalinity neutralization and initial decrease in leachate pH with application of differentially enriched MSWC. Similar results of decrease in leachates pH has also been reported by Zarabi and Jalali (2012).

Overall, EC of soil leachate with use of MSW+PG and MSW+S was significantly higher during all pore volumes up to 8^{th} day as compared to control and other treatments. The EC of leachate in treatment MSW+G also became significantly higher from 4^{th} day onwards and subsequently equivalent to MSW+PG and MSW+S and higher than other treatments. All the treatments led to a significant increase in EC for the first two pore volumes, thereafter EC started decreasing in the PV-III to PV-VII (Table 4). Chaganti *et al.,* (2015) reported that washing of inherent salts and capillary rise of electrolytes caused increase in leaching of salts and thus leachate EC in the initial pore volumes. Though the EC of leachates was numerically higher in all the amended soils, but it was significantly higher in MSW+PG and MSW+S than others. Among

Table 3. Changes in leachate pH as amended with different MSW composts

	pH							
Treatments	1st Day	2nd Day	3rd Day	4th Day	5th Day	6th Day	7th Day	8th Day
Control	8.40^{AB}	8.26^{A}	8.47	8.46^{B}	8.48^{B}	8.46^{B}	8.64^{B}	9.00^{B}
MSW	8.52^{A}	8.44^{AB}	8.65	8.48^{B}	8.75^{AB}	8.39^{B}	9.06^{AB}	8.93^{B}
MSW+G	8.51^{A}	8.71^{A}	8.79	8.81^{AB}	8.73^{AB}	8.34^{B}	8.70^{B}	8.89^{B}
MSW+PG	7.79^{B}	8.10^{B}	8.65	8.87^{A}	9.04^{A}	8.95^{A}	9.39^{A}	9.40^{A}
MSW+SW	8.30^{AB}	8.41^{AB}	8.48	8.64^{AB}	8.54^{B}	8.51^{B}	8.71^{B}	8.89^{B}
MSW+S	7.94^{B}	8.31^{B}	8.37	8.36^{B}	8.37^{B}	8.66^{AB}	8.62^{CD}	8.84^{B}
MSW+PM	8.37^{A}	8.26^{B}	8.34	8.64^{AB}	8.50^{B}	8.39^{B}	8.78^{B}	9.01^{B}
LSD ($p \leq 0.05$)	0.379	0.3679	NS	0.3246	0.3551	0.3903	0.4291	0.3216

Depictions as in Table 1. Same superscript letters in a column indicate that data are not significantly different with one another

Table 4. Changes in leachate electrical conductivity (EC, dSm^{-1}) as amended with different MSW composts

Treatments	1st Day	2nd Day	3rd Day	4th Day	5th Day	6th Day	7th Day	8th Day
Control	3.28^{B}	3.63^{C}	4.23^{BC}	4.09^{BC}	3.82^{A}	3.89^{A}	3.89^{A}	4.05^{A}
MSW	2.34^{B}	2.75^{C}	3.44^{BC}	3.82^{BC}	4.02^{A}	4.33^{A}	4.05^{A}	4.69^{A}
MSW+G	1.90^{B}	3.47^{C}	4.29^{BC}	9.39^{B}	11.75^{A}	11.49^{A}	16.14^{A}	5.75^{A}
MSW+PG	8.32^{A}	18.84^{A}	16.24^{A}	16.98^{A}	12.14^{A}	9.41^{A}	7.47^{A}	6.13^{A}
MSW+SW	2.81^{B}	2.63^{C}	3.41^{BC}	3.47^{BC}	3.47^{A}	4.34^{A}	4.17^{A}	4.68^{A}
MSW+ S	8.74^{A}	10.30^{B}	6.95^{B}	8.11^{BC}	7.16^{A}	6.57^{A}	5.68^{A}	4.75^{A}
MSW+PM	2.08^{B}	2.13^{C}	2.29^{C}	2.43^{C}	2.4^{A}	2.55^{A}	2.77^{A}	3.11^{A}
LSD ($p\leq0.05$)	4.9826	4.9422	4.373	6.9374	NS	NS	NS	NS

Table 5. Changes in leachate CO_3^-(me L^{-1}) concentrations during column study as treated with different MSW composts

Treatments	1st Day	2nd Day	3rd Day	4th Day	5th Day	6th Day	7th Day	8th Day
Control	1.33^{AB}	1.07^{AB}	0.270^{A}	0.67^{A}	1.67^{A}	1.4^{A}	2.07^{A}	3.87^{A}
MSW	1.07^{AB}	0.53^{B}	1.0^{A}	3.4^{A}	2.8^{A}	3.0^{A}	3.13^{A}	3.37^{A}
MSW+G	1.47^{AB}	2.07^{A}	1.73^{A}	1.93^{A}	1.87^{A}	1.53^{A}	1.93^{A}	1.47^{A}
MSW+PG	1.87^{AB}	1.87^{A}	2.53^{A}	4.4^{A}	2.87^{A}	2.6^{A}	4.13^{A}	3.6^{A}
MSW+SW	1.07^{AB}	1.40^{AB}	1.27^{A}	2.27^{A}	1.4^{A}	1.2^{A}	1.87^{A}	2.47^{A}
MSW+S	1.93^{A}	2.27^{A}	2.13^{A}	2.33^{A}	2.07^{A}	0.8^{A}	3.0^{A}	2.33^{A}
MSW+PM	0.67^{C}	0.53^{B}	1.0^{A}	0.73^{A}	0.87^{A}	1.2^{A}	1.93^{A}	2.4^{A}
LSD ($p\leq0.05$)	1.2048	1.2223	NS	NS	NS	NS	NS	NS

the treatments, higher leachate EC in MSW+PG followed by MSW+S may be due to enhanced leaching of electrolytes. Leachate of MSW+PG and MSW+S soil showed higher EC and lower pH compared to other treatments. Use of the various amendments enriched MSWC has been observed to improve structural stability of the soil and release of electrolytes because of chelation between humic substances and divalent cations (Li and Keren, 2009; Choudhary *et al.*, 2011; Chaganti *et al.,* 2015).

Leaching of anions

Among different types of MSWC treatments, higher amount of CO_3^{2-} was released from MSW+PG (1.87 to 4.4 me L^{-1}) and MSW+S (1.93 to 2.33 me L^{-1}) followed by MSW+SW treatments during 1-8 days of leaching (Table 5). The CO_3^{2-} release increased up to PV-IV and then started declining in almost all treatments except a slight increment in leachate collected on 8^{th} day. The HCO_3^- concentration of soil leachates increased significantly and consistently higher in MSW+PG and MSW+S treatments than all other treatments and control (Table 6) from day 1 to day 8. Sundha *et al.* (2018) and Zarabi and Jalali (2012) also reported incremental losses of HCO_3^- in leachates of MSWC amended soils.

Leaching of cations

The Ca^{2+} content of the leachate was significantly higher in MSW+PG and MSW+S compost

Table 6. Changes in leachate HCO_3^-(me L^{-1}) concentrations during column study as treated with different MSW composts

Treatments	1st Day	2nd Day	3rd Day	4th Day	5th Day	6th Day	7th Day	8th Day
Control	3.70^{AB}	2.87^{B}	1.63^{B}	1.10^{B}	4.03^{A}	1.10^{B}	2.13^{B}	3.70^{B}
MSW	3.43^{AB}	4.57^{AB}	4.13^{AB}	3.87^{AB}	2.87^{A}	2.77^{B}	4.87^{AB}	4.17^{B}
MSW+G	4.60^{AB}	7.20^{AB}	5.23^{AB}	4.73^{AB}	3.43^{A}	4.00^{AB}	2.93^{B}	2.30^{B}
MSW+PG	6.23^{A}	8.23^{A}	5.90^{A}	6.77^{A}	5.17^{A}	6.43^{A}	8.10^{A}	9.43^{A}
MSW+SW	3.90^{AB}	4.50^{AB}	2.87^{B}	4.73^{AB}	3.07^{A}	3.53^{AB}	3.50^{AB}	3.43^{B}
MSW+S	5.63^{AB}	5.07^{AB}	6.87^{A}	5.83^{A}	4.67^{A}	4.27^{AB}	4.43^{AB}	5.03^{AB}
MSW+PM	2.53^{A}	2.00^{B}	2.33^{B}	1.63^{B}	2.3^{A}	2.20^{B}	3.10^{B}	4.40^{B}
LSD ($p\leq0.05$)	3.308	4.2292	3.5664	4.5747	NS	2.7115	4.6168	3.4744

Table 7. Effects of different MSW composts on leachate Ca^{2+} concentrations

Treatments	1st Day	2nd Day	3rd Day	4th Day	5th Day	6th Day	7th Day	8th Day
Control	12.17^{D}	18.38^{C}	8.63^{C}	5.36^{E}	5.86^{D}	4.29^{D}	3.10^{E}	2.93^{D}
MSW	3.94^{E}	6.25^{E}	5.18^{D}	3.99^{E}	3.64^{D}	4.38^{D}	3.19^{E}	2.43^{D}
MSW+G	9.13^{DE}	9.33^{D}	10.10^{C}	17.48^{C}	16.49^{B}	14.07^{B}	29.78^{A}	33.42^{A}
MSW+PG	30.97^{B}	56.32^{A}	49.39^{A}	33.03^{A}	18.00^{AB}	10.63^{C}	7.33^{D}	4.43^{CD}
MSW+SW	8.43^{DE}	25.22^{B}	8.67^{C}	12.32^{CD}	7.80^{CD}	8.70^{C}	17.65^{B}	17.33^{B}
MSW+S	36.69^{A}	27.42^{B}	31.26^{B}	27.00^{B}	23.27^{A}	20.63^{A}	10.05^{C}	5.98^{C}
MSW+PM	21.05^{C}	27.24^{B}	11.69^{C}	10.90^{D}	12.46^{BC}	9.59^{C}	5.16^{DE}	4.63^{CD}
LSD ($p \leq 0.05$)	5.2829	2.9637	3.3487	5.1906	5.9069	2.1259	2.7048	2.2651

Table 8. Effects of different MSW composts on leachate Mg^{2+} concentrations

Treatments	1st Day	2nd Day	3rd Day	4th Day	5th Day	6th Day	7th Day	8th Day
Control	7.42^{C}	5.67^{C}	3.79^{D}	3.78^{D}	3.83^{BC}	2.60^{E}	1.74^{D}	1.65^{D}
MSW	2.57^{E}	4.95^{C}	3.31^{D}	2.59^{D}	2.57^{C}	2.61^{E}	2.67^{CD}	2.25^{CD}
MSW+G	4.07^{D}	5.05^{C}	7.10^{AB}	9.67^{A}	9.43^{A}	9.92^{A}	14.55^{A}	14.18^{A}
MSW+PG	9.25^{B}	14.23^{A}	7.88^{A}	7.13^{AB}	5.77^{B}	6.07^{B}	2.57^{CD}	2.00^{CD}
MSW+SW	4.40^{D}	10.89^{B}	3.23^{D}	7.97^{AB}	3.02^{C}	4.33^{CD}	5.62^{B}	4.63^{B}
MSW+S	15.25^{A}	13.35^{AB}	5.98^{BC}	6.61^{BC}	5.91^{B}	5.59^{BC}	4.06^{BC}	2.91^{C}
MSW+PM	7.23^{C}	6.35^{C}	5.45^{C}	4.46^{CD}	3.14^{C}	3.70^{DE}	2.24^{CD}	2.27^{CD}
LSD ($p \leq 0.05$)	1.3085	2.8285	1.2154	2.5408	2.2655	1.4234	2.0425	1.0665

treated soils. MSW+PG treatment recorded highest Ca^{2+} in leachate and it increased from 30.97 meL^{-1} on day 1 to 56.32 meL^{-1} on day 2 and then declined thereafter (Table 7). Ca^{2+} content of MSW+S compost treated soil leachate was the highest on 1st day and then declined subsequently up to 8th day of leaching. Whereas in MSW+G compost treatment, leachate Ca^{2+} concentrations increased continuously from day 1 to 8.

Likewise, the concentration of Mg^{2+} in leachate with MSW composts plus amendments showed a similar trend like Ca^{2+} for respective soil treatments (Table 8). MSW+PG treatment, leachate had highest Mg^{2+} content and increased from 9.25 meL^{-1} on day 1 to 14.23 meL^{-1} on day 2 and then started declining (Table 8). MSW+S compost treated soil, the highest leachate concentration was recorded on 1st day and then declined subsequently upto 8th day. In MSW+G compost treatment leachate Mg^{2+} concentrations increased consistently from day 1 to 8. Application of different composts treatments in soil enhanced the amount of Ca^{2+} and Mg^{2+} in soil leachates. The trend in concentrations of Ca^{2+} and Mg^{2+} was also reflected in combined concentrations of these two cations.

Application of various MSW composts had significant effect on Na^+ leaching. MSW+PG and MSW+S treated soils leachate recorded significantly highest (i.e more than three times on day 1) Na^+ content than control and all other treatments. The Na^+ content in MSW+PG treatment increased from 43.66 me L^{-1} on day 1 to 159.71 me L^{-1} on day 2, and then started declining afterwards (Table 9). Similarly, MSW+S treatment, the Na^+ concentration increased from 53.08 meL^{-1} on 1st day to 142.57 me L^{-1} on 2nd day and then started declining. In MSW+G treatment, Na^+ increased statistically similar to MSW+PG and MSW+S on 4th day and then started declining. Higher Na^+ concentration in leachates of these treatments indicates that addition of organic matter through different MSWCs coated soil particle surfaces, limited Na^+ adsorption and enhanced leaching of Na^+ (Wright *et al.,* 2008). The leaching behavior of cations has indicated that soil was never saturated for exchange reactions between Ca^{2+}/Mg^{2+} for Na^+.

The trend of K^+ release in leachate was similar to Na^+, the concentration of leached K^+ was significantly higher in MSW+PG and MSW+S treatments up to 4th day and then started

Table 9. Changes in leachate Na^+ concentrations amended with different MSW composts

Treatments	1st Day	2nd Day	3rd Day	4th Day	5th Day	6th Day	7th Day	8th Day
Control	11.49^{D}	19.92^{D}	10.56^{F}	21.59^{EF}	16.21^{C}	15.07^{E}	30.64^{C}	30.81^{DE}
MSW	12.97^{CD}	13.59^{D}	26.78^{C}	38.01^{D}	54.46^{B}	37.75^{C}	36.45^{BC}	40.37^{C}
MSW+G	16.12^{C}	28.26^{C}	25.62^{CD}	67.10^{C}	56.34^{B}	26.52^{D}	38.64^{BC}	50.77^{B}
MSW+PG	43.66^{B}	159.71^{A}	161.95^{A}	160.46^{A}	135.47^{A}	84.99^{A}	76.09^{A}	61.08^{A}
MSW+SW	12.21^{CD}	14.42^{D}	21.20^{D}	27.75^{DE}	20.36^{C}	26.94^{D}	33.64^{BC}	34.29^{CD}
MSW+S	53.08^{A}	142.57^{B}	82.47^{B}	81.08^{B}	51.89^{B}	49.97^{B}	47.25^{B}	34.09^{CD}
MSW+PM	10.33^{D}	14.93^{D}	15.51^{E}	15.62^{F}	14.51^{C}	15.16^{E}	27.39^{C}	24.22^{E}
LSD ($p \leq 0.05$)	4.2531	7.3944	4.4618	10.52	6.2955	7.2221	15.36	7.0213

Table 10. Changes in leachate K^+ concentrations amended with different MSW composts

Treatments	1st Day	2nd Day	3rd Day	4th Day	5th Day	6th Day	7th Day	8th Day
Control	0.75^{C}	0.43^{C}	0.73^{CD}	0.64^{C}	0.90^{D}	0.54^{D}	0.98^{C}	0.28^{D}
MSW	1.74^{BC}	0.92^{C}	1.00^{CD}	1.54^{C}	2.31^{CD}	1.73^{BCD}	1.27^{BC}	1.14^{BCD}
MSW+G	1.00^{C}	1.74^{C}	3.52^{BC}	5.62^{B}	7.49^{A}	5.56^{A}	8.09^{A}	6.95^{A}
MSW+PG	3.46^{AB}	9.85^{A}	13.55^{A}	9.64^{A}	6.09^{AB}	4.17^{AB}	3.25^{B}	1.97^{BC}
MSW+SW	0.98^{C}	0.81^{C}	0.68^{CD}	1.11^{C}	1.58^{CD}	1.53^{CD}	1.33^{BC}	1.23^{BCD}
MSW+S	3.89^{A}	5.38^{B}	4.49^{B}	4.85^{B}	3.76^{BC}	3.72^{ABC}	3.18^{B}	2.37^{B}
MSW+PM	0.56^{C}	0.21^{C}	0.45^{D}	0.36^{C}	0.71^{D}	0.64^{D}	0.90^{C}	0.45^{CD}
LSD ($p \leq 0.05$)	1.8523	2.5532	3.0238	2.6098	2.4941	2.4534	2.0774	1.6237

decreasing (Table 10). Whereas, the concentration of K^+ in MSW+G treatment started increasing from 4th day onwards and became significantly higher than all other treatments subsequently.

Changes in pH and EC of soil after leaching

After completion of eight leaching cycles, the pH and EC of column soils were determined by partitioning into 1-10 cm, 10-20 and 20-30 cm depths (Table 11). The pH of soil at all three depths was significantly decreased in MSW+PG and MSW+S compost treatments. The highest reduction in pH was recorded with MSW+S treatment where it was 7.94, 8.21 and 8.36 in 1-10, 10-20 and 20-30 cm depths, respectively. Results revealed that soil pH decreased by 1.19, 1.03 and 0.91 units in respective depths as compared to control. While in soil treated with MSW+PG, reduction in pH was 0.97, 0.65 and 0.45 units than control in respective depths. The treatment MSW+G significantly reduced the soil pH by 0.54 units (9.13 to 8.35) in upper 1-10 cm column soil only and there was no notable reduction in lower depths. The efficacy of different amendments with respect to reduction in soil pH was MSW+S >MSW+PG >MSW+G

Table 11. Changes of soil pH and EC after leachate as influenced with different amendments enriched MSW compost

Treatments	pHs			ECe (dS m^{-1})		
	0-10cm	10-20cm	20-30cm	0-10cm	10-20cm	20-30cm
Control	8.63^{A}	8.74^{A}	8.77^{A}	2.79^{A}	2.31^{B}	2.36^{B}
MSW	8.85^{A}	8.74^{A}	8.66^{A}	2.06^{B}	1.98^{B}	2.44^{B}
MSW+G	8.09^{B}	8.50^{AB}	8.41^{A}	0.81^{C}	1.53^{BC}	2.04^{B}
MSW+PG	7.66^{C}	8.09^{BC}	8.32^{B}	$0..70^{C}$	0.84^{C}	1.02^{C}
MSW+SW	8.53^{A}	8.81^{A}	8.62^{A}	1.53^{BC}	2.41^{AB}	3.94^{A}
MSW+S	7.44^{C}	7.71^{C}	7.86^{B}	0.91^{C}	0.86^{C}	0.83^{C}
MSW+PM	8.59^{A}	8.83^{A}	8.51^{A}	1.61^{BC}	2.92^{A}	4.15^{A}
LSD ($p \leq 0.05$)	0.3575	0.4798	0.433	0.454	0.4223	0.7129

Table 12. Percent Change of cation mass (C_M%) compared to control for applied treatments after leaching C_M%

Treatments	Na^+	K^+	Ca^{2+}	Mg^{2+}
MSW	-19.96^C	5.69^B	-73.89^E	-63.13^D
MSW+G	142.47^B	828.80^B	182.18^C	182.94^C
MSW+PG	2351.25^A	4174.62^A	1403.46^B	655.39^B
MSW+SW	-3.85^C	44.04^B	42.88^D	19.18^D
MSW+ S	2220.71^A	3874.06^A	1909.63^A	1164.77^A
MSW+PM	-33.95^C	-38.65^B	26.83^{DE}	-15.71^D
LSD ($p \leq 0.05$)	137.05	1074	112.89	153.89

>MSW+SW =MSW+PM =MSW =Control. All the treatments reduced the EC of soil after leaching. The soil EC was significantly lower in MSW+PG and MSW+S treatments than all other treatments. The soil EC of different treatments in ascending order was MSW+S <MSW+PG <MSW+G <MSW+SW =MSW+PM =MSW =Control.

Changes in pH and EC of the soil treated with different types of MSWC and leaching are linked with change in electrolytes concentration of soil solution. It appeared that supply of soluble Ca^{2+} through various amendments or solubilization of native soil $CaCO_3$ replaced Na^+ from the exchange complex with the consequent release of Na^+ in leachate. Nature, quantity and integration of composting of MSWC with different amendments had positive, but differential influence on decrease of soil alkalinity and leaching of salts. On mineralization, MSWC along with amendments release large quantity of CO_2, thereby decrease soil pH and leaching with deionized water washed away the soluble salts from soil and thus reduced soil EC (Jalali and Ranjbar, 2009).

Ameliorating effect of different amendments

Change of cation mass (C_M%) values as influenced with MSWCs were calculated by using Eq. (i) and (ii) and given in Table 12. The results of C_M% evaluation for Na^+ and K^+ indicated that treatments MSW+S and MSW+PG exhibited significantly higher values of C_M% than all other treatments. The treatment MSW+G also recorded significantly higher values for Na^+ and K^+ compared to MSWC alone and other treatments. Results from present study revealed that relative efficiency of different compost treatments in depleting Na^+ from soil column depends on the amendments added in MSW composting. It appears that phosphogypsum and elemental sulphur either added or facilitated to bring considerable amounts of Na^+ and K^+ to the soil solution; consequently, higher quantity of Na^+ and K^+ was removed. However, the addition of gypsum in MSW composting also resulted in higher C_M% values than MSWC alone. The negative value for C_M% obtained in MSWC, MSW+SW and MSW+PM, imply higher efficiency of control (untreated soil) in removing Na^+ and K^+ than these treatments.

The C_M% values for the Ca^{2+} and Mg^{2+} was in the order of MSW+S >MSW+PG >MSW+G. Among these three treatments, MSW+S treatment was significantly higher than MSW+PG which was significantly higher than MSW+G. (Table 12). It might be due to differential decomposition of different composts and consequent dissolution of calcite and dolomite (Hanay *et al.,* 2004). Different amendments used in MSW composting on decomposition produce organic acids (Wong et al. 2009) that enhance pCO_2 (Flavel and Murphy, 2006) and consequently increase dissolution of native $CaCO_3$.

Conclusions

Use of elemental sulfur, phosphogypsum and gypsum enriched MSWC @ 20 Mg ha^{-1} has ability to deplete the cations and improve reclamation of saline-sodic soil, its health and productivity in arid and semi-arid regions. MSW composting with elemental sulphur and phosphogypsum proved more effective than addition of gypsum, pressmud and spent wash. In view of the decreasing availability and purity of gypsum, addition of elemental sulphur and phosphogypsum enriched MSWC could be a low- cost alternative to costly amendments for reclamation of saline-sodic soils and improve their productivity in arid and semiarid regions.

Acknowledgements

The authors thank Scheme for Young Scientists and Technologists, DST (SP/YO/099/2016) for providing financial support and Director, ICAR-Central Soil Salinity Research Institute, Karnal, Haryana, for providing facilities during research work.

References

Bossio D, Critchley W, Geheb K, Van Lynden G and Mati B (2007) Conserving land protecting water. In: Molden D (ed*) Comprehensive Assessment of Water Management in Agriculture: Water for Food, Water for Life*. Stylus Publishing, LLC: Sterling, VA. pp. 551–584.

Chaganti VN, Crohn DM and S¡imuÚnek J (2015) Leaching and reclamation of a biochar and compost amended saline-sodic soil with moderate SAR reclaimed water. *Agricultural Water Management* **158:** 255–265. http://dx.doi.org/10.1016/j.agwat.2015.05.016.

Choudhary OP, Ghuman BS, Bijay-Singh, Thuy N and Buresh RJ (2011) Effects of long-term use of sodic water irrigation, amendments and crop residues on soil properties and crop yields in rice–wheat cropping system in a calcareous soil. *Field Crops Research* **121:** 363-372.

CSSRI (2015) *Vision 2050.*Central Soil Salinity Research Institute (Indian Council of Agricultural Research), Karnal -132 001, India pp 31.

Flavel TC and Murphy DV (2006) Carbon and nitrogen mineralization rates after application of organic amendments to soil. *Journal of Environmental Quality* **35:** 183–193.

Flower TJ and Yeo AR (1995) Breeding for salinity resistance in crop plants. *Austalian Journal of Plant Physiol*ogy **22:** 875-884.

Hanay A, Buyuksanmz F, Kiziloglu FM and Canbolat MV (2004) Reclamation of saline-sodic soils with gypsum and MSW compost. *Compost Science & Utilization* **12(4):** 175–179.

Ilyas M, Qureshi RH and Qadir MA (1997) Chemical changes in a saline-sodic soil after gypsum application and cropping. *Soil Technology* **10:** 247-260.

Jackson ML (1973) *Soil Chemical Analysis*. Prentice Hall India: New Delhi. pp. 498.

Jalali M and Merrikhpour H (2008) Effects of poor quality irrigation waters on the nutrient leaching and groundwater quality from sandy soil. *Environmental Geology* **53:** 1289-1298.

Jalali M and Ranjbar F (2009) Effects of sodic water on soil sodicity and nutrient leaching in poultry and sheep manure amended soils. *Geoderma* **153:** 194-204.

Lakhdar A, Iannelli MA, Debez A , Massacci A, Jedidi, N and Abdelly C (2010) Effect of municipal solid waste compost and sewage sludge use on wheat (*Triticum aestivum*): growth, heavy metal accumulation and antioxidant activity. *Journal of the Science of Food and Agriculture* **90:** 965–971.

Li F and Keren R (2009) Calcareous sodic soil reclamation as affected by corn stalk application and incubation: a laboratory study. *Pedosphere* **9:** 465-475.

Meena MD, Joshi P K, Narjary B, Sheoran P, Jat H S, Chinchmalatpure AR, Yadav RK and Sharma DK (2016) Effects of municipal solid waste compost, rice-straw compost and mineral fertilizers on biological and chemical properties of a saline soil and yields in a mustard–pearl millet cropping system. *Soil Research* **54(8):** 958-969.

Meena MD, Yadav RK, Narjary B, Yadav Gajender, Jat HS, Sheoran P, Meena MK, Antil RS, Meena BL, Singh HV, Meena VS, Rai PK, Ghosh A and Moharana PC (2019) Municipal solid waste (MSW): Strategies to improve salt affected soil sustainability: A review. *Waste Management* **84:** 38-53.

Minhas PS, Manzoor Qadir and Yadav RK (2019) Groundwater irrigation induced soil sodification and response options. *Agricultural Water Management* **215:** 74-85.

Muhammad D and Khattak RA (2011) Wheat yield and chemical composition as influenced by integrated use of gypsum, press-mud and FYM in saline-sodic soil. *Journal of the Chemical Society* of *Pakistan* **33:** 82-86.

Oo AN, Iwai CB and Saenjan P (2013) Soil properties and maize growth in saline and nonsaline soils using cassava-industrial waste compost and vermicompost with or without earthworms. *Land Degradation and Development* **26:** 300–310.

Oster JD (1982) Gypsum usage in irrigated agriculture: a review. *Fertilizer Researc*h **3**: 73-89.

Page AL, Miller RH and Keeney DR (eds) (1982) *Methods of Soil Analysis*, Part-2, Second Edition, *Soil Science Society of America Journal*, Madison, Wisconsin, USA.

Rengasamy P (2006) World salinization with emphasis on Australia. *Journal of Experimental Botany* **57:** 1017-1023.

Singh K, Mishra AK, Singh B, Singh RP and Patra DD (2014). Tillage effects on crop yield and physicochemical properties of sodic soils. *Land Degradation & Development* (In Press). DOI: 10.1002/ldr.2266.

Srivastava PK, Gupta M, Shikha Singh N and Tewari SK (2014) Amelioration of sodic soil for wheat cultivation using bioaugmented organic soil amendment. *Land Degradation & Development* **27:** 1245–1254.

Sundha P, Basak N, Rai A K, Yadav R K, Sharma P C, and Sharma D K (2020) Can conjunctive use of gypsum, city waste composts and marginal quality water rehabilitate saline-sodic soils?. *Soil and Tillage Research* **200:** 104608.

Sundha P, Basak N, Rai A K, Yadav R K and Sharma D K (2018) Utilization of municipal solid waste compost in reclamation of saline-sodic soil irrigated with poor quality water. *Journal of the Indian Society of Soil Science* **66(1):** 28-39.

Tucker BM (1985) The partitioning of exchangeable magnesium, calcium, and sodium in relation to their effects on the dispersion of Australian clay subsoils. *Australian Journal of Soil Research* **23:** 405–16. doi:10.1071/SR9850405.

USSL (1954) In: Richards LA (eds), *Diagnosis and Improvement of Saline and Alkali Soils*. USDA Handbook, Washington, DC pp 60.

Walkley AJ and Black IA (1934) An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* **37:** 29-38.

Wicke B, Smeets E, Dornburg V, Vashev B, Gaiser T, Turkenburg W, and Faaij A (2011) The global technical and economic potential of bioenergy from salt-affected soils. *Energy & Environmental Science* **4(8):** 2669-2681.

Wong VNL, Dalal RC, Greene RSB (2008) Salinity and sodicity effects on respiration and microbial biomass of soil. *Biology and Fertility of Soils* **44:** 943–953.

Wright A L, Provin T L , Hons F M , Zuberer D A and White R H (2008) Compost impacts on sodicity and salinity in a sandy loam Turf grass soil. *Compost Science and Utilization* **16:** 30-35.

Yadav RK and Dagar JC (2016) Innovations in utilization of poor-quality water for sustainable agricultural production. In: Dagar JC, Sharma PC, Sharma DK, Singh AK (eds) *Innovative Saline Agriculture*. Springer, New Delhi pp 219-263.

Yadav RK, Singh SP, Lal D and Kumar A (2007) Fodder production and soil health with conjunctive use of saline and good quality water in ustipsamments of a semi arid region. *Land Degradation and Development* **18:** 153-161.

Yazdanpanah N and Mahmoodabadi M (2013) Reclamation of calcareous saline–sodic soil using different amendments: Time changes of soluble cations in leachate. *Arabian Journal of Geosciences* **6(7):** 2519-2528.

Zarabi M and Jalali M (2012) Leaching of nitrogen and base cations from calcareous soil amended with organic residues. *Environmental Technology* **33:** 1577-1588.

Received: January 2020; Accepted: April 2020