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PROPERTIES OF SODIC SOILS IMPROVED WHEN AMENDED WITH GYPSUM AND MUNICIPAL WASTE IN AN INCUBATION EXPERIMENT

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ABSTRACT

An incubation experiment was conducted under controlled conditions for 90 days to study the collaborative effect of gypsum and municipal solid waste compost (MSWC) on two soils varying in electrical conductivity (EC_e) and sodium adsorption ratio (SAR). Treatments, (T_0) control, (T_1) 100% soil gypsum requirement (SGR), (T_2) 75% SGR + 1.2 g MSWC kg^{-1} soil, (T_3) 50% SGR + 2.5g MSWC kg^{-1} soil, (T_4) 25% SGR + 3.8 g MSWC kg^{-1} soil and (T_5) 5.0 g MSWC kg^{-1} soil, were mixed in soil-I (EC_e: 25.7 dS m^{-1}; SAR 48.2; sandy clay loam) and soil-II (EC_e: 22.4 dS m^{-1}; SAR 78.2; sandy loam) at the start of incubation. After 90 days of incubation, treatments significantly ($P \leq 0.05$) influenced EC_e, SAR, bulk density (BD), tensile strength (TS) of aggregates and percent water stable aggregates (%WSA). There was 51 and 56%; 63 and 38%; 26 and 28% decrease in EC_e, SAR, and bulk density over control treatment with T_3 soil-I and soil-II, respectively. Similarly, organic matter content, porosity, aggregate stability and tensile strength were increased as compared with control. To measure CO_2 release, soil samples with all the above mentioned treatments were separately incubated in enclosed jars for 60 day. Data relating to cumulative CO_2 release indicated that C mineralization rate was higher in MSWC amended samples. Results of this experiment revealed that combined effect of organic and inorganic amendments improves the physical and chemical condition of salt-affected soil.

Keywords: Gypsum, incubation, municipal waste, sodic soils.

INTRODUCTION

Salt-affected soils have become a serious problem of land degradation all around the world (Vanessa *et al.,* 2009). In Pakistan, saline soils are the soils which have $EC_e > 4$ dS m^{-1} and ESP < 15 and saline sodic soils are the soils which have $EC_e > 4$ dS m^{-1} and ESP > 15. A lot of research has been undertaken to determine the main properties of salt-affected soils and their amelioration, especially in the sense of soil structure and plant health (Bramley *et al.,* 2003; Gardner, 2004). In salt-affected soils, the most commonly used ameliorant to

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maintain the soil electrolyte level and to improve the soil physical and hydraulic properties, is gypsum ($CaSO_4.2H_2O$) (Keren, 1996). It provides Ca^{2+} ions to displace Na^+ ions, due to which concentration of electrolyte increases and thus improve permeability and soil structure (Rengasamy *et al.,* 1984). It has been reported that addition of gypsum caused a decrease in microbial activity. Clark (2004) found that deep ripping with or without gypsum had no significant effect on the grain yield in highly clay sodic subsoils. Although, gypsum amendment has a fine impact on the chemical properties of the soil but this has minimum impact on the soil biological properties (Clark *et al.,* 2009).

In degraded areas, the level of soil organic matter is low due to low level of biomass accumulation (Wong *et al.,* 2005). So it is important to maintain the high level of soil organic matter as it can improve the soil structure and aggregation (Oades, 1988), high nutrient level and high value of cation exchange capacity (Von Lutzow *et al.,* 2002).The addition of organic materials can also be used to improve the condition of degraded soils (Muneer and Oades, 1989). Inputs of organic materials greatly affect the microbial activity and can improve the soil structure (Bronick and Lal, 2005). Clark *et al.* (2007) found that quantity of organic matter is inherently low in subsoils, so addition of organic matter in the subsoil not only increases the chemical and biological fertility but also positively affects the soil structure and thus nutrients become available to plants from subsoil. Addition of organic materials to improve the soil structure is also effective in the case of surface soils (Baldock *et al.,* 1994). So the biological approach of adding organic matter to reduce the hazards of salt-affected soils may be more effective than only with inorganic methods of reclamation (Clark, 2009). Present research was conducted to determine effects of organic amendments and gypsum on the physical, chemical and biological properties of two saline-sodic soils.

MATERIALS AND METHODS

Soil and treatments

Two soils, varying in EC_e, SAR and texture, were sampled from 0-30 cm layer from Multan (Table 1). Soil samples were properly tagged, packed in clean plastic bags and transported to laboratory at Department of Soil Science, Faculty of Agricultural Sciences and Technology, Bahauddin Zakariya University, Multan (Pakistan). Soil samples were spread on a polythene sheet and kept one week for air drying. Samples were crushed to pass through a 2 mm sieve.

Different soil properties measured before incubation are given in Table 1. To measure initial values of bulk density, cores (having diameter of 5.4 cm and 6.0 cm height) were separately sampled from 0-5, 5-10, 10-15 cm depths. Bulk density was measured as of oven dried weight of soil to bulk volume (volume of core). Soil pH was measured in saturated soil paste while EC_e and soluble cations were determined in soil extract (U.S. Salinity Laboratory Staff, 1954). Soil texture was measured by hydrometer method (Moodie *et al.,* 1959). Sodium Adsorption ratio (SAR) was determined by the following formula:

$$SAR = \frac{Na^{-}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

Plastic pots (internal length was 26 cm and internal diameter was 28 cm) having small hole at the bottom were filled with 10 kg of soil-I or soil-II. Following treatments were thoroughly mixed in each soil: (T_0) control, (T_1) 100% soil gypsum requirement (SGR), (T_2) 75% SGR + 1.2 g MSWC kg^{-1} soil, (T_3) 50% SGR + 2.5 g MSWC kg^{-1} soil, (T_4) 25% SGR + 3.8 g MSWC kg^{-1} soil and (T_5) 5.0 g MSWC kg^{-1} soil. These treatments were replicated thrice and were arranged in complete randomized design. Pots were incubated at 25° C temperature for 90 days.

Water stable aggregates, tensile strength and soil respiration

After 60 days of incubation, water stable aggregates were measured as described by Clark *et al.* (2009). Fifty grams of 5-8 mm dry (105°C for 24 hours) soil aggregates were placed on the nest of sieves of sizes 4.75, 2.00, 1.00, 0.50 and 0.25 mm. The portion of soil remained on each sieve was washed off by water into a 100 ml beaker and dried at 105^0C for 24 hours. Water stable aggregates (WSA) were determined by the following equation: $\% WSA = 100 \times (M_1 + M_2 + M_3 + M_4 + M_5) / M_0$. %WSA, GMD, and MWD were calculated by the method of Kemper and Rosenau (1986).

Tensile strength (TS) was measured by following the method of Dexter and Kroesbergen (1985). Diameter of each aggregate size (2-4 mm, 4-6 mm and 6-8 mm) was measured with vernier caliper. Aggregates were crushed by placing them between two round plates of crushing equipment for each treatment. The TS was measured by following equation: $TS = 0.576\frac{F}{dagg2}$, Where: F is breaking force (N) = $Ma\left(\frac{X1}{X2}\right)$, d_{agg}^{2} = mean aggregate diameter, 0.576 = coefficient, M = mass of water (g), a = acceleration due to gravity (9.81 m s^{-2}), X1= distance of hook from pivot (m) and X2 =distance of plate from hinge (m).

Soil respiration was measured by using 0.5 N KOH solution. Soil samples of 100 g were mixed with similar treatments [(T_0) control, (T_1) 100% soil gypsum requirement (SGR), (T_2) 75% SGR + 1.2 g MSWC kg^{-1} soil, (T_3) 50% SGR + 2.5 g MSWC kg^{-1} soil, (T_4) 25% SGR + 3.8 g MSWC kg^{-1} soil and (T_5) 5.0 g MSWC kg^{-1} soil]. These were placed into petri dishes enclosed in plastic containers. The plastic containers also had a 20 ml of 0.5 N KOH to trap the CO_2 released. Three blanks were also prepared without soil to account for the amount of CO_2 absorbed by the KOH in the headspace of the plastic jars. The CO_2 release was determined seven times during a 60 days incubation study. The amount of CO_2 release was calculated according to the following equation:

$$Co_2 = 0.5 \times \left(\frac{\text{Volume of KOH X Comcentration of KOH}}{1000} \right) - \left(\frac{\text{Volume of HCl X Comcentration of HCl}}{1000} \right) \times 22 \times 44 \times 100$$

Release of CO_2 was measured in mg CO_2-C kg^{-1} of dried soil. All analyses were replicated three times.

Statistical analysis

The results were analysed by MSTATC statistical package (Anonymous, 1986). Analysis of variance (ANOVA) was used to assess the differences among treatments, followed by least significant difference (LSD) test at a 0.05 probability level.

RESULTS AND DISCUSSION

Soil EC, pH and SAR

There was a significant ($P \leq 0.05$) effect of gypsum, compost and their combination on pH of both soil types. The pH decreased after the application of amendments compared with control treatment in both soils. A significant decrease in pH was observed in T3 (50% SGR + 2.5 g MSWC kg^{-1} soil) in both soils (Table 2). The decrease in the values of pH were more pronounced in the surface layer (0-5 cm) than that of the subsurface (5-15 cm) soil layers for both soils.

Amendments significantly ($P \leq 0.05$) decreased the EC_e of both soils (Table 2). Decrease in EC_e over control was 37, 27, 51, 39 and 22% in Soil-I and 42, 32, 56, 45, and 27% in Soil-II, respectively with T1, T2, T3, T4 and T5. However, EC_e remained above the threshold value ($EC_e \leq 4.0$ dS m^{-1}) as described by U.S. Salinity Lab. Staff (1954). In both treated soils, the EC_e on lower soil layers was greater than top layer. Results are similar with those of Awad (1983) and Wahby (1986), who reported that gypsum application helped leaching of salts through soil profile.

Table 1. Physical and chemical properties of soils used for experiment.

Determinants	Soil-I	Soil-II
% Sand	46.4	55.8
% Silt	25.6	27.4
% Clay	28.0	16.8
Textural class	Sandy clay loam	Sandy loam
pH of saturated soil paste	8.1	8.5
Electrical conductivity (dS m^{-1})	25.7	22.4
Sodium adsorption ratio ($mmol_c$ $L^{-1})^{1/2}$	48.2	78.2
Organic carbon (%)	0.23	0.17

Table 2. Electrical conductivity, pH, organic matter (OM) content, geometric mean diameter (GMD), mean weight diameter (MWD), water stable aggregates (WSA), bulk density (BD) and tensile strength (TS) of soils after 60 days of incubation.

Depth (cm)	Soil	Treatment	EC	pH	SAR	OM	GMD	MWD	WSA	BD	TS
			dS m^{-1}	-	(mmol$_c$ L^{-1})$^{1/2}$	%	mm	mm	%	Mg m^{-3}	kPa
0-5	Soil-I	T0	25.7	8.13	48.2	0.13	0.68	1.36	5.9	1.50	51
		T1	16.1	8.09	28.1	0.66	0.65	1.39	6.4	1.38	52
		T2	18.3	8.10	26.2	0.73	0.67	1.46	6.3	1.28	63
		T3	12.3	8.03	18.0	0.99	0.68	1.70	7.1	1.08	75
		T4	15.4	8.07	35.4	0.65	0.67	1.55	6.7	1.26	63
		T5	19.8	8.09	27.2	0.83	0.65	1.31	6.1	1.34	52
	Soil-II	T0	22.5	8.53	78.2	0.15	0.68	1.30	5.6	1.46	53
		T1	13.2	8.26	58.2	0.65	0.66	1.42	6.4	1.34	59
		T2	15.4	8.21	56.5	0.75	0.66	1.45	6.4	1.25	67
		T3	9.8	8.16	48.2	1.14	0.67	1.72	7.2	1.07	76
		T4	12.3	8.25	65.3	0.83	0.68	1.63	6.8	1.22	66
		T5	16.4	8.26	57.2	0.93	0.65	1.27	6.0	1.33	58
5-10	Soil-I	T0	27.8	8.22	49.2	0.03	0.70	1.32	5.2	1.55	52
		T1	17.1	8.03	29.1	0.28	0.70	1.40	5.4	1.36	63
		T2	19.3	7.98	27.2	0.67	0.67	1.14	5.1	1.28	63
		T3	14.3	7.81	19.0	0.76	0.71	1.67	6.3	1.20	75
		T4	16.4	7.87	36.4	0.62	0.69	1.31	5.3	1.33	63
		T5	20.3	7.89	28.2	0.67	0.67	1.00	4.4	1.39	53
	Soil-II	T0	23.5	8.63	78.9	0.05	0.71	1.27	4.8	1.46	57
		T1	14.2	8.42	59.3	0.58	0.67	1.21	5.4	1.38	65
		T2	16.4	8.39	57.4	0.63	0.67	1.38	5.9	1.27	67
		T3	10.2	8.31	49.2	0.89	0.68	1.64	6.7	1.17	76
		T4	13.3	8.35	66.3	0.73	0.66	1.33	5.7	1.30	67
		T5	17.3	8.38	58.3	0.81	0.66	1.15	5.4	1.42	65
10-15	Soil-I	T0	28.8	8.24	49.3	0.04	0.69	1.24	5.0	1.57	52
		T1	17.7	8.08	29.3	0.21	0.70	1.45	5.6	1.41	62
		T2	19.6	8.00	27.2	0.62	0.76	1.43	5.6	1.43	64
		T3	14.6	7.84	19.2	0.72	0.72	1.87	6.8	1.26	74
		T4	16.9	7.88	36.4	0.57	0.70	1.46	5.6	1.46	65
		T5	20.8	7.89	28.2	0.65	0.68	1.16	4.9	1.46	62
	Soil-II	T0	23.8	8.65	79.5	0.05	0.70	1.15	4.5	1.58	58
		T1	14.7	8.44	59.6	0.51	0.68	1.16	4.8	1.41	66
		T2	16.8	8.40	58.1	0.60	0.67	1.26	5.3	1.42	68
		T3	10.7	8.34	49.8	0.81	0.66	1.48	6.6	1.22	79
		T4	13.8	8.36	66.8	0.71	0.68	1.20	5.0	1.46	68
		T5	17.8	8.39	59.1	0.78	0.64	1.04	5.0	1.57	66
LSD of interaction ($P \leq 0.05$)			0.2	0.05	0.2	0.01	0.3	0.03	0.03	0.08	2

Where, (T_0) control, (T_1) 100% soil gypsum requirement (SGR), (T_2) 75% SGR + 1.2 g MSWC kg^{-1} soil, (T_3) 50% SGR + 2.5 g MSWC kg^{-1} soil, (T_4) 25% SGR + 3.8 g MSWC kg^{-1} soil and (T_5) 5.0 g MSWC kg^{-1} soil.

Sodium adsorption ratio decreased significantly ($P \leq 0.05$) with application of amendments (Table 2). Over control, decrease in SAR was 42, 46, 63, 27 and 44% in Soil-I and 26, 28, 38, 17 and 27% in Soil-II, respectively with T1, T2, T3, T4 and T5. In both soils, however, SAR remained above threshold level of <13.3 (U.S. Salinity Laboratory Staff, 1954). The decrease in SAR was essentially due to removal of exchangeable sodium from the soil. The rate of decrease in SAR was greater in upper soil layer than in lower depth. This pattern was attributed to the decreasing Ca^{2+}: Na^{+} ratio in the soil solution as it moved down through the soil profile displacing exchangeable Na^{+} (Hussain *et al.,* 2001).

Soil organic matter content

Compost and gypsum treatments significantly ($P \leq 0.05$) increased organic matter in both soils. Over control, maximum increase in the organic matter was observed with T3 (50% SGR + 2.5 g MSWC kg^{-1} soil) in both soils (Table 2). Comparatively high OM was observed for soil sandy clay loam compared with sandy loam soil. This can be related with differential decomposition rate of OM in soils. Data in Table 3 indicate that increase in OM was more pronounced in the surface layer (0-5 cm) than that of the sub-surface (5-15 cm) soil layers for both soils. Municipal solid waste compost is a valuable organic waste that improves OM and C (Fernandez *et al*., 2013).

Bulk density and porosity

Gypsum, compost and their combination significantly ($P \leq 0.05$) decreased bulk density in both soils (Table 2). Bulk density of both soils was minimum (1.08 and 1.07 Mg m^{-3} for soil-1 and soil-2, respectively) in 0-5 cm layer soils were treated with T3. Maximum bulk density (1.50 and 1.46 Mg m^{-3} for soil-I and soil-II, respectively) was also noted in 0-5 cm layer but it was only in control treatment. Compared with control treatment, the bulk density of soils collected from 0-5 cm layer was decreased by 9, 14, 26, 16 and 10% in Soil-I and by 9, 14, 28, 16 and 11% in Soil-II, respectively with T1, T2, T3, T4 and T5. Gypsum and compost improved soil structure and created aggregation because Ca^{2+} accumulates on the exchange sites and improved the aggregation. This effect was more pronounced in the upper layer (0-5) than the deeper layers (5-10 and 10-15). These results are in accordance with those of Wong and Ho (1991), who attributed the decrease in soil bulk density to the effect of gypsum on improving the physical properties of soil via stability of aggregates and increasing total pore spaces.

There was a significant ($P \leq 0.05$) effect of gypsum, compost and their combination on porosity in both soil types. The porosity increased after the application of amendments compared with control treatment. A considerable increase in porosity was observed in T3 (50% SGR + 2.5 g MSWC kg^{-1} soil) in both soils (Table 2). Comparatively, high porosity was observed for Soil-I compared with Soil-II. A wide range of pore sizes exists in well-aggregated soils both between and within aggregates (Dalal and Bridge, 1996). Pore space, size and amount can influence soil organic carbon and its turnover; conversely, soil organic carbon and soil texture could influence porosity (Thomsen *et al.*, 1999). These results are in agreement with that obtained by El-Shanawany (1985), who reported that applied gypsum, particularly at high rates gave the highest values of total soil porosity.

Table 3. Aggregate size distribution in <0.25, 0.25-0.50, 0.50-1.00 and 1.00-2.00 mm size fractions.

Treat-ment	Soil-I					Soil-II				
	2-1	1-0.5	0.5-0.25	<0.25	Macro Aggre-gates	2-1	1-0.5	0.5-0.25	<0.25	Macro Aggre-gates
0-5 cm depth										
T0	10.33^{c}	16.86^{d}	27.60^{e}	944.1^{a}	54.73^{d}	8.667^{f}	13.33^{e}	25.26^{d}	941.0^{a}	47.25^{f}
T1	11.33^{b}	18.13^{b}	36.60^{d}	936.9^{b}	66.03^{c}	10.80^{d}	16.20^{d}	34.53^{b}	938.5^{c}	61.53^{d}
T2	14.00^{b}	20.86^{b}	38.33^{b}	935.5^{b}	73.19^{c}	11.46^{c}	17.73^{bc}	35.13^{b}	936.9^{d}	64.32^{c}
T3	16.06^{a}	26.13^{a}	39.33^{a}	928.4^{d}	81.46^{a}	15.31^{a}	24.00^{a}	36.33^{a}	930.2^{f}	75.64^{a}
T4	14.93^{c}	21.93^{b}	37.86^{c}	932.9^{c}	74.72^{b}	12.03^{b}	20.00^{b}	35.60^{b}	932.3^{e}	67.63^{b}
T5	10.86^{e}	19.93^{c}	35.26^{d}	937.9^{b}	66.05^{c}	9.88^{e}	19.06^{c}	31.60^{c}	939.8^{b}	60.54^{e}
5-10 cm depth										
T0	7.53^{f}	15.20^{f}	21.13^{e}	952.2^{a}	43.86^{e}	5.533^{f}	13.53^{f}	19.06^{f}	956.2^{a}	38.12^{f}
T1	12.33^{d}	19.20^{d}	25.06^{d}	946.0^{b}	56.59^{d}	10.66^{d}	17.13^{c}	23.33^{d}	946.5^{d}	51.00^{d}
T2	13.26^{c}	22.80^{b}	28.80^{bc}	941.2^{e}	64.86^{b}	12.60^{b}	20.00^{b}	25.80^{c}	941.3^{e}	58.40^{bc}
T3	15.60^{a}	23.53^{a}	30.80^{a}	934.1^{f}	69.93^{a}	14.46^{a}	21.60^{a}	29.93^{a}	937.6^{f}	65.99^{a}
T4	14.40^{b}	21.46^{c}	29.13^{ab}	942.2^{d}	64.99^{b}	11.86^{c}	20.00^{b}	27.40^{b}	947.4^{c}	59.26^{b}
T5	11.33^{e}	18.60^{e}	27.53^{bc}	944.2^{c}	57.46^{c}	9.533^{e}	16.60^{d}	21.73^{e}	949.1^{b}	47.86^{e}
10-15 cm depth										
T0	8.600^{e}	15.53^{d}	18.93^{f}	950.6^{a}	43.06^{e}	6.600^{e}	13.40^{d}	18.06^{e}	955.^{a}	38.06^{e}
T1	12.60^{c}	17.46^{c}	22.53^{d}	944.5^{b}	52.59^{c}	9.200^{c}	15.80^{bc}	21.73^{d}	951.5^{b}	46.73^{c}
T2	14.46^{b}	18.93^{bc}	23.93^{c}	943.5^{c}	57.32^{b}	10.80^{b}	16.33^{b}	22.00^{c}	946.6^{e}	49.13^{b}
T3	19.60^{a}	23.20^{a}	31.00^{a}	932.2^{d}	73.80^{a}	11.60^{a}	18.26^{a}	25.66^{a}	934.4^{f}	55.52^{a}
T4	14.80^{b}	19.60^{b}	28.20^{b}	944.4^{b}	62.60^{c}	10.60^{b}	16.53^{b}	24.33^{b}	949.6^{d}	51.46^{c}
T5	11.26^{d}	17.40^{c}	20.40^{e}	950.2^{a}	49.06^{d}	8.933^{d}	14.60^{cd}	20.40^{d}	950.4^{c}	43.93^{d}

Where, (T_0) control, (T_1) 100% soil gypsum requirement (SGR), (T_2) 75% SGR +1.2 g MSWC kg^{-1} soil, (T_3) 50% SGR + 2.5 g MSWC kg^{-1} soil, (T_4) 25% SGR +3.8 g MSWC kg^{-1} soil and (T_5) 5.0 g MSWC kg^{-1} soil.

Water stable aggregates and wet fraction

Treatments significantly affected water stable aggregate (%WSA) for both soils (Table 2). Almost similar was the effect of gypsum, municipal solid waste compost and their combination on WSA of both soils. Maximum WAS was 7.24 and 7.07 in T3; whereas minimum was 5.58 and 5.88 in control treatments, respectively for Soil-I and Soil-II. There was 23% and 17% increase in %WSA with T3, respectively over control treatment in Soil-I and Soil-II. In this sense, Goldberg *et al.* (1990) and Nadler *et al.* (1996) suggested that the effect of organic matter on soil structure is a function of the size scale of the soil particles analysed. Thus, in clay-sized aggregates, organic matter acts over the particle charge (Goldberg *et al.,* 1990); whereas in coarse sand-sized aggregates, organic matter acts as a binding agent, through roots and hyphae (Tisdall and Oades, 1982).

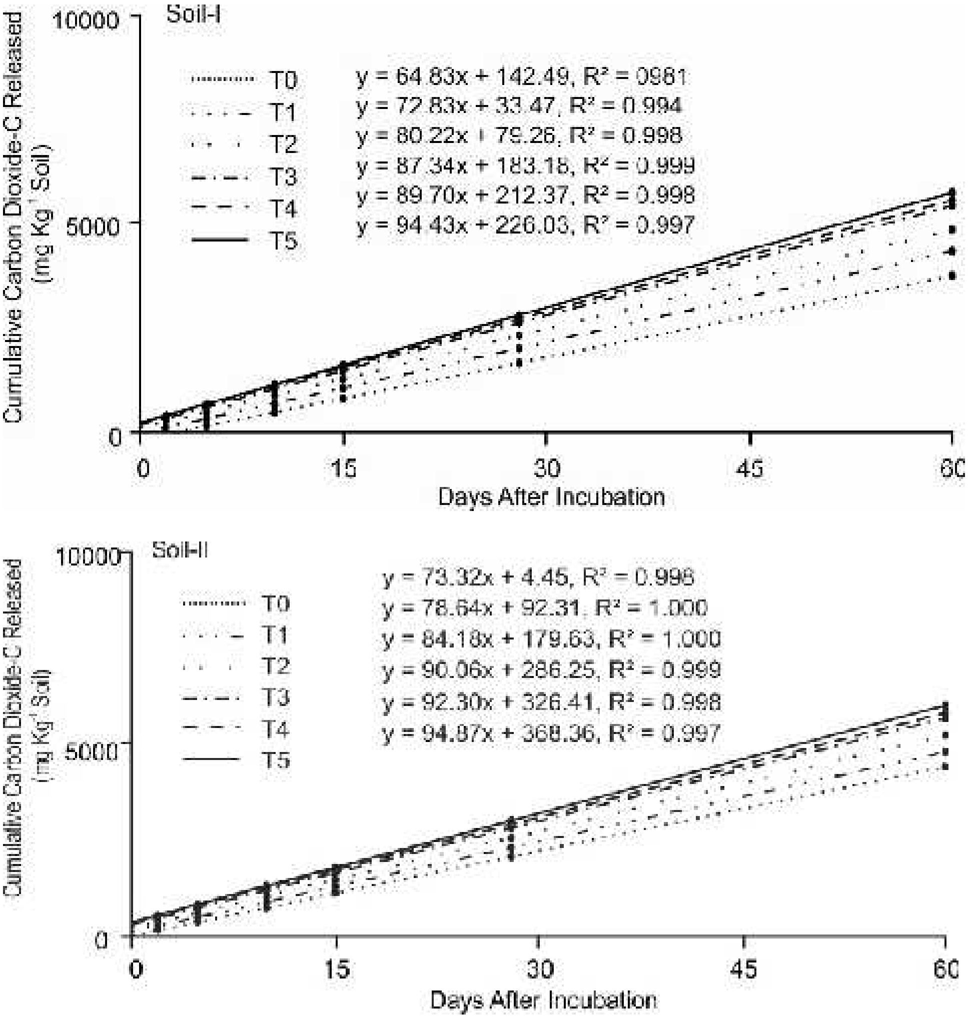

Figure 1. Cumulative CO_2-C release from two soils amended with gypsum and MSWC and incubated in closed jars for 60 days. Where, (T_0) control, (T_1) 100% soil gypsum requirement (SGR), (T_2) 75% SGR + 1.2 g MSWC kg^{-1} soil, (T_3) 50% SGR + 2.5 g MSWC kg^{-1} soil, (T_4) 25% SGR + 3.8 g MSWC kg^{-1} soil and (T_5) 5.0 g MSWC kg^{-1} soil.

Gypsum, municipal solid waste compost and their combinations significantly (*P*≤0.05) affected wet aggregate fraction (Table 3). Almost similar was the effect of gypsum, MSWC and their combinations on aggregate fractions of both soils. Maximum macro aggregates fraction was 81.46 and 75.64 g kg^{-1} in T3; whereas minimum were 54.73 and 47.25 g kg^{-1} in control treatment for Soil-I and Soil-II, respectively. Similarly, minimum micro aggregates were 928.4 and 930.2 g kg^{-1} in T3; whereas maximum were 944.1 and 941 g kg^{-1} in control treatment, respectively for Soil-I and Soil-II. Comparatively more macro aggregates were formed with treatments in the case of Soil-I compared with Soil-II (Table 3). The proportion of macro- and micro- aggregates decreased with increase in soil depth. Moreover, the effects of gypsum and MSWC on distribution of soil mass in WSA are manifested through change in organic carbon concentration as is evidenced by decrease in WSA with increase in soil depth.

Aggregate diameter

Mean weight diameter (MWD) represents %age of large aggregates retained on the sieves. The MWD increased significantly with treatments (Table 2). Maximum MWD was 1.72 and 1.70 mm in T3 for Soil-I and Soil-II, respectively; whereas minimum MWD was 1.26 and 1.36 mm with the same treatment for Soil-I and Soil-II. The increase in MWD with T3 could be due to increased microbial activity. Moreover, greater MWD corresponds to greater AS (Le Bissonnais, 1996; Mullins *et al.,* 1990).

Treatments significantly affected GMD in both soils. The GMD increased after the application of amendments compared with control treatment. A considerable increase in GMD was observed in T3 (50% SGR + 2.5 g MSWC kg^{-1} soil) in both soils. Maximum GMD was 0.68 and 0.67 mm with T3 Soil-I and Soil-II, respectively; whereas minimum GMD was 0.56 and 0.57 mm in control treatment for Soil-I and Soil-II, respectively (Table 3). The GMD was increased by 18, 16, 21, 16 and 14 %; 14, 14, 18, 12, and 12 %, respectively with T1, T2, T3, T4 and T5 for Soil-I and Soil-II compared with control treatment. The GMD increased with increase in depth. Comparatively more increase in GMD occurred in Soil-I compared with Soil-II at a given treatment. This trend is due to the higher organic carbon concentration (Filho *et al.,* 2002) especially when gypsum at 50% SGR and MSWC at 2.5 g kg^{-1} was mixed with soil during incubation. This generally influences the formation and stabilization of soil aggregates (Abid and Lal, 2008).

Tensile strength

Tensile strength (TS) of soil aggregate is defined as an applied force per unit area to break an aggregate. Gypsum, compost and their combination significantly affected TS of soil aggregates (Table 2). Tensile strength (kPa) was increased by 14, 24, 35, 19 and 7% for soil-I; 15, 22, 33, 15 and 10% for soil-II with T1, T2, T3, T4 and T5 over control treatment, respectively. There are three opinions regarding relationship between soil organic carbon and tensile strength such as negative correlation, positive correlation and no relationship (Dexter, 1984; Ley *et al*., 1993; Guerif, 1994). The positive correlation is due to the function of organic carbon in aggregate formation and stabilization leading to increase in TS. Present study confirms the positive relationship of soil TS with soil organic carbon. Kay (1993) proved experimentally that increasing carbon content could strengthen the bonds between soil primary particles especially in clay soils, thus resulting in increase of the TS of the soil.

Soil respiration

Carbon dioxide release from soil samples followed linear trend with high values of regression coefficient (>0.980) for both soils (Fig. 1). Amended soils had significantly ($P \leq 0.05$) higher rate of respiration as compared to un-amended samples (T0). This trend was due to mineralization of C present in MSWC by microorganisms. Results are similar with those reported by Farooq *et al*. (2012); these characteristics imposed a positive effect of organic matter on CO_2 emission. Wong *et al.* (2009) reported that combination of gypsum and compost increased the CO_2 emission. A considerable increase in CO_2 was observed in T3 (50% SGR + 2.5 g MSWC kg^{-1} soil) in both the soils. Compared with control treatment, the cumulative CO_2 was increased by 84% in Soil-I and 81% in Soil-II with T3 (Fig. 1). Increased CO_2 release might be due to effect of organic waste and gypsum that improved the physical, chemical and biological condition of soils (Hanay *et al.,* 2004).

CONCLUSION

It is concluded from the study that the adverse physical and chemical conditions of salt-affected soils can be improved by adding gypsum (inorganic) and municipal waste (organic).

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