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Effect of organic and inorganic amendments on amelioration of sodic soil and sustaining rice (*Oryza sativa*)-wheat (*Triticum aestivum*) productivity

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ABSTRACT

Management of degradation of sodic lands in arid and semi-arid regions is a global concern. Amelioration of these soils through chemical amendments like gypsum or phosphogypsum is a costly affair for resource poor farmers having sodic lands. Combined use of municipal solid waste (MSW) compost with chemical amendments can provide a realistic solution for ameliorating sodic soils and sustaining crop productivity. A field experiment was conducted during 2015 to 2016 at Shivri, Lucknow on highly sodic soil [pH 9.8, exchangeable sodium percentage (ESP) 78, organic carbon (OC) 1.30 g/kg and gypsum requirement (GR) 15.2 t/ha] to evaluate the influence of organic and inorganic amendments on amelioration of sodic soils and sustaining productivity of rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) cropping system. The treatments consisted of T_1: Gypsum (G) @ 50%GR, T_2: Phosphogypsum (PG) @ 50%GR, T_3: G @25%GR + on-farm MSW compost @10 t/ha, T_4: PG @25%GR+ on-farm MSW compost @10 t/ha, T_5: G @12.5%GR + on-farm MSW compost @10 t/ha + pressmud (PM) @10 t/ha, T_6: PG @12.5%GR+ on-farm MSW compost @ 10 t/ha + PM @ 10 t/ha, T_7: G @ 25%GR + industrial processed (IP) MSW compost @10 t/ha and T_8: PG @ 25%GR + IP MSW compost @10 t/ha. The results indicated that, application of reduced dose (25% of GR) of gypsum (T_3) in combination with on-farm MSW compost @10 t/ha reduced about 14% ESP and increased 11% soil bulk density, 54% infiltration rate, 10% soil organic carbon content, and 13% available N over the recommended practice (T_1). Productivity of rice and wheat crops enhanced to the tune of 4 and 12 %, respectively and thus farmers can save about ₹ 29444.00/ha on account of reducing the quantity of gypsum or phosphogypsum without any significant yield loss and the saved amount can be utilized to bring more area under reclamation. The maximum N content in rice and wheat grain was recorded with treatment T_4.

Key words: Crop productivity, Nutrient contents, Organic and inorganic amendments, Sodic soil amelioration

Soil degradation caused by salinization and sodification is a universal concern (Bhattacharya *et al.* 2015). Nearly one billion ha soil has some degree of salinization and sodification problem around the world (FAO 2007). The problem manifest itself mainly in arid and semi-arid regions with poorly drained soils and frequent addition of salts with faulty irrigation practices (Ayars and Tanji 1999). In India, about 6.73 million ha is salt affected land including salinity (predominantly chloride and sulfates of Na, Ca, and Mg) of which about 3.77 million ha are reported as sodic soil (predominantly sodium carbonates, and sodium silicate) (NRSA and Associates 1996, Sharma *et al.* 2006, Mandal *et al.* 2009). Sodic soils lack an adequate and continuous water supply to plants due to low infiltration rate, resulting in shallow wetting zones and temporary waterlogging problems, reduced water storage in the rhizosphere, extremely low water conductivity and low available moisture for proper plant growth resulting in poor crop productivity (Gao *et al.* 2008, Thimmappa *et al.* 2014). High pH associated with sodic soils reduces solubility of certain nutrients causing nutrient deficiencies. Amelioration of these soils by replacement of sodium ions from the soil cation exchange site necessitates application of chemical amendments (Sahin *et al.* 2002).

Generally, application of gypsum ($CaSO_4 \cdot 2H_2O$) @ 50% GR and leaching with ponding of good quality irrigation water for about 10 days is a standard practice used for the reclamation of sodic soils (Vishven and Singh 2011). However, gypsum based reclamation approach is failed to improve soil physical and biological properties. It has also been reported that reclamation of sodic soils through organic amendments like FYM and pressmud took long time and have little effect on reducing sodicity (Madejon *et al.* 2001). However, it has been proved by many researchers that addition of organic matter in sodic soils improves the

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soil physical and biological properties (Naeini and Cook, 2000, Singh *et al.* 2017). Moreover, availability of FYM and pressmud in required quantity is a serious concern. To find out alternate options for sustainable reclamation of sodic soil is the need of present hour. The municipal solid waste (MSW) which is imperative source of organic matter and available in rich quantity, if it is converted into resources can be a good source of organic matter for the reclamation of sodic soils. The decaying organic matter enhances soil CO_2 concentration and organic acid after decomposition of organic material and release H^+. The released H^+ increases $CaCO_3$ dissolution and librates more calcium (Ca) for sodium (Na) exchange helps in reclaiming sodic soils (Ghafoor *et al.* 2008). Therefore, the present study was initiated to investigate the combined effect of organic (MSW compost and pressmud) and inorganic (gypsum and phosphogypsum) amendments on amelioration of sodic soil and sustaining crop productivity.

MATERIALS AND METHODS

Field experiment was conducted at research farm of Central Soil Salinity Research Institute (CSSRI), Regional Research Station, Lucknow, Uttar Pradesh, India (26º 47' 58'' N, 80º 46' 24'' E) for two consecutive years in 2014-15 and 2015-16. The experimental site was classified as typic Natrustalfs (Sharma *et al.* 2006). Field experiment including 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, T_4: Phosphogypsum @ 25% GR+ on-farm MSW compost @ 10 t/ha, T_5: Gypsum @ 12.5 % GR + on-farm MSW compost @ 10 t/ha+ pressmud @ 10 t/ha, T_6: Phosphogypsum @ 12.5% GR+ on-farm MSW compost @ 10 t/ha+ pressmud @ 10 t/ha, T_7: Gypsum @ 25% GR+ industrial processed MSW compost @ 10 t/ha and T_8: Phosphogypsum @ 25% GR + industrial processed MSW compost @ 10 t/ha was conducted with three replications under randomized block design. Thirty days old seedling of rice variety CSR 36 was transplanted on 09.07.2015 and 11.07.2016. Without disturbing layout, subsequent wheat variety KRL 210 was sown on 26.11.2015 and 17.11.2016. Recommended dose of fertilizer 150 kg N: 60 kg P: 40 kg K/ha in rice and 120 kg N: 60 kg P: 40 kg K/ha in wheat were applied uniformly in all the treatments. Uniform quantity (25 kg/ha) of zinc sulphate was applied in rice in all the treatments. Half dose of N and full dose of P and K were applied at the time of transplanting of rice and sowing of wheat while, the remaining N was applied in two equal splits at tillering and panicle initiation stages in rice and at crown root initiation (CRI) and tillering stages in wheat. Soil samples collected from 0-30 cm soil depth and processed for analysis of soil properties. The pH and EC of the soil samples were determined in 1:2 soil: water suspension using digital pH and conductivity meter (Jackson 1973). Organic carbon content was determined by rapid titration method (Walkley and Black 1934). The concentration of Ca^{2+} and Mg^{2+} in soil saturation paste extract was estimated by the titration method using EDTA however, Na^+ and K^+ contents in extract were measured by flame photometer. Carbonate and bi-carbonate contents in extract were determined by titration with 0.01 N H_2SO_4 using phenolphthalein and methyl orange. Sand, silt and clay content were determined using International pipette method (Day 1965). For on-farm composting, MSW was collected from the Lucknow Municipal Corporation. Industrial processed MSW compost was collected from MSW treatment plant, Kanpur and pressmud from DSCL Sugar Ltd, Hardoi. The initial soil physico-chemical properties of experimental field are given in Table 1.

Leaf area was measured by the leaf area meter at the flag leaf stage and calculated using the formulae of Watson (1958). Based on dry matter accumulated by crop over times, crop growth rate (CGR) was calculated by formula described by Watson (1952). Panicles were threshed manually and the number of grains/panicle, 1000 grain weight, and fertility percent were analyzed. The crops were harvested from net plots (8m × 9m) and sun dried in the field and total biomass yield was recorded. After threshing, cleaning and drying the grain yield, straw yield and harvest index were computed. Grain yield of rice was recorded at 14% moisture content.

After the harvest of crops, grain and straw samples from each treatment were collected and processed to find out the N, P, K contents in grain and straw and nutrient uptake was calculated (Miyoshi 1991). Total N content in grain and straw was determined by digestion and distillation through Micro-Kjeldahl method. Total P by Ammonium molybdate-meta vandate yellow color method (Jackson 1973) and K was measured by flame photometer. Harvest index, nutrient harvest index and nutrient use efficiency were calculated by using the following formulas (Fageria *et al.* 1997):

Table 1 Initial soil properties of experimental field (Mean±SD)

Soil properties	Value	Soil properties	Value
Sand (%)	65.50±1.45	Organic carbon (g/kg)	1.30±0.02
Silt (%)	18.50±0.61	Available N (mg/kg)	30.68±1.10
Clay (%)	16.00±0.60	Olsen's P (mg/kg)	8.30±0.40
Textural class	Loam	Available K (mg/kg)	173.00±21.20
Bulk density (Mg/m^3)	1.59±0.01	Na^+ (ppm)	342.00±2.60
Porosity (%)	42.40±0.60	K^+(ppm)	3.10±0.02
Infiltration rate (mm/day)	2.10±0.2	Ca^{++} (mel^{-1})	3.60±0.21
pH_2 (1:2)	9.80±0.10	Mg^{++} (mel^{-1})	3.78±0.10
EC_2 (1:2) (dS/m)	1.47±0.12	CO_3^{--}(mel^{-1})	6.00±0.30
ESP	78.30±2.50	HCO_3^-(mel^{-1})	22.00±0.62

pH_2: soil and water suspension ratio of 1:2, EC_2: electrical conductivity (soil and water suspension ratio 1:2), ESP: exchangeable sodium percentage.

$$\text{Harvest index} = \frac{\text{Grain yields}}{\text{Biological yields}} \times 100$$

$$\text{Nutrient harvest index} = \frac{\text{Nutrient uptake by grain}}{\text{Nutrient uptake by grain and straw}} \times 100$$

$$\text{Nutrient use efficiency (\%)} = \frac{\text{Uptake in treated plot - uptake in control plot}}{\text{Fertilizer dose}} \times 100$$

The collected data were statistically analyzed using MSTAT-C version 2.1 developed by Russell (1994). In order to explore the economic feasibility of the study, the cost economics of all the treatments was worked out taking into account the variable cost and the returns calculated on the basis of prevailing market prices of the produce during the study period. Variable costs were calculated on the basis of quantity of gypsum, phosphogypsum, on-farm MSW compost, industrial processed MSW compost and pressmud applied to individual plot as per treatment. The prevailing market rates of gypsum, phosphogypsum, on-farm MSW compost, industrial processed MSW compost and pressmud applied once in the experiment during 2014-15 was ₹ 3702.6, 3999.76, 4099.72, 4999.36 and 1999.88/t, respectively. Other expenses including bunding and leveling at ₹ 3325/ha, leaching at ₹ 10664.44/ha, mixing of gypsum, phosphogypsum, MSW compost and pressmud at ₹ 1165.52/ha, and installation of tube well at ₹ 3264.00/ha. Costs of cultivation of rice and wheat crops were assumed identical for all the treatments. Gross returns of rice and wheat were calculated by multiplying the grain yield by their corresponding minimum support price for respective year (₹ 13600.00/t in 2014-15, ₹ 14701.60/t in 2015-16 for rice and ₹ 16252.00/t in 2014-15 and ₹ 16499.52/t in 2015-16 for wheat) and market price of rice straw was ₹ 2999.48/t, and wheat straw ₹ 5002.08/t during both the years. The gross margin was calculated by subtracting total variable cost from gross returns, and the benefit/cost ratio was calculated by dividing gross return by total variable cost. The values were calculated using Indian rupees (INR).

After two years of rice-wheat cropping system, surface soil samples (0-15 cm) were collected from each treatment. The soil samples were air dried in shade, ground to pass through a 2 mm sieve, and analyzed to monitor changes in soil properties following standard procedures.

RESULTS AND DISCUSSION

Agro-morphological characters

Crop growth attributed by plant height, panicle density, dry matter accumulation, leaf area development, and crop growth rate (CGR), were computed by the formulae given by Hunt (1982). The average plant height ranged from 104.0 cm to 118.4 cm. Maximum plant height in rice was recorded with treatment T_3 and minimum with T_7 however, there was no significant difference in plant height due to application of inorganic amendments alone or in combination with organic source of amendments (Table 2). Panicle density was recorded significantly higher in treatment T_3 over T_1, T_4, T_5, T_6 and T_8 treatments but it was statistically at par with T_2 and T_7 treatments. The dry matter accumulation differed significantly due to application of different treatments. Maximum dry matter (1.812 kg/m^2) was recorded with treatment T_3 and minimum (1.082 kg/m^2) with T_4 treatment. The treatment T_6 recorded highest CGR (0.94 g/day) of rice followed by T_2 and T_3. Leaf area index (LAI) of flag leaf recorded at panicle initiation stage significantly enhanced with T_3 and T_4 treatment over T_1 treatment. Treatment T_3 produced highest LAI (6.30) and the lowest recorded in T_6.

Data pertaining to yield and yield component as influenced by application of organic and inorganic amendments are presented in Table 3. The spikelets/panicle was recorded significantly higher (120.32) under in T_2 as compared to rest of treatments and lowest in T_4 treatment. The spikelet fertility was significantly affected with addition of organic amendments over the use of inorganic sources of amendments. Highest spikelet fertility (95.09%) was

Table 2 Effect of organic and inorganic amendments on crop growth attributes (mean of two years)

Treatment	Rice					Wheat				
	Plant height (cm)	Panicle density (m^2)	Dry matter (kg/m^2)	CGR (g/day)	LAI	Plant height (cm)	Spike density (m^2)	Dry matter (kg/m^2)	CGR (g/day)	LAI
T_1	105.77	336.00	1.696	0.82	5.63	88.83	387.90	0.589	4.83	2.34
T_2	115.93	389.10	1.367	0.93	5.22	96.12	343.90	0.645	5.87	2.18
T_3	118.37	432.00	1.812	0.91	6.30	86.76	414.70	0.779	3.91	2.52
T_4	112.66	330.00	1.082	0.61	6.15	86.29	388.15	0.688	4.49	2.41
T_5	109.40	359.10	1.493	0.69	4.63	72.49	343.65	0.636	3.28	2.01
T_6	113.99	345.00	1.392	0.94	4.36	74.95	394.10	0.610	8.29	1.89
T_7	103.97	387.90	1.641	0.78	5.21	83.79	401.00	0.743	4.54	2.34
T_8	106.55	325.80	1.419	0.77	5.43	82.11	374.30	0.720	5.44	2.21
LSD (P=0.05)	ns	12.79	0.051	0.03	0.10	ns	13.23	0.011	0.43	0.03

NS: Non significant, CGR: relative growth rate, LAI: leaf area index recorded in T_3 and the lowest (55.06%) in T_5. The 1000 grain weight was recorded significantly higher with combined application of organic and inorganic amendments over the sole application of inorganic amendments. Maximum 1000 grain weight was obtained in T_3 and minimum under T_8 treatment. Increment in 1000 grain weight of rice due to addition of organic sources was reported by Shivay and Singh (2003). Rice grain yield was recorded significantly higher (4.83 t/ha) under treatment T_3 as compared to other treatments but it was statistically at par with T_1 and T_7 treatments. Treatment T_2 significantly enhanced straw yield (13.70 t/ha) of rice over other treatments and it was statistically at par with T_3, T_5 and T_6 treatments in respect of straw yield of rice. The results showed that gypsum @ 25% GR may be saved by using MSW composts. Maximum harvest index (HI) and nitrogen harvest index (NHI) were recorded in T_1 and minimum with T_6 (22.58) and T_5 (49.76), respectively.

In case of wheat, plant height had no significant difference between the treatments but highest plant height was observed under T_2 treatment. Spike density between the treatments varied from 343.65/m^2 (T_5) to 414.70/m^2 (T_3). Highest spike density was observed in T_3 and lowest in T_5 treatment which had significant difference between the treatments. The dry matter accumulation was significantly higher in treatment T_3 over rest of the treatments (Table 2). Highest LAI was recorded with treatment T_3 but lowest in T_6 treatment. Grains/spike (38.89) was recorded significantly higher under treatment T_8 over rest of the treatments. However, treatment T_2 recorded significantly higher 1000 grain weight as compared to other treatments except treatment T_1. Moreover. both treatments T_1 and T_2 were statistically similar to each other in respect of 1000 grain weight of wheat. Similar results were reported by Araya *et al.* (2012). Highest wheat grain yield (2.37 t/ha) was recorded with T_4 and the lowest with T_5. Treatments T_2 and T_4 were at par with each other in respect of wheat grain yield, but significantly higher over T_1, T_3, T_5, T_6, T_7 and T_8 treatments, which indicates that application of on-farm MSW compost with reduced dose of phosphogypsum (25% GR), saved half dose of the phosphogypsum without any significant reduction in yield. Other treatment combinations showed inferiority to these two treatments (Table 3). Hossain and Sarker (2015) and Singh *et al.* (2017) reported significant increase in grain yield of rice and wheat due to synergistic effect of organic and inorganic amendments. The highest yield of rice and wheat in treatment T_3 and T_4 respectivey may be attributed to the significant reduction in soil pH, increased organic carbon content and decreased in ESP after application of combined use of organic and inorganic amendments in sodic soil. The positive impact of different treatments can also be visible in different management approaches and this can result in better services given by the soil (Parras-Alcántara *et al.* 2016, Galati *et al.* 2016).The highest harvest index and nitrogen harvest index in wheat were observed under T_4 and the minimum in treatment T_6.

Nutrient uptake

Integerated use of organic and inorganic amendments had significantly influenced the N uptake in grain and straw of rice and wheat. Maximum N uptake by rice grain and straw was recorded under treatment T_3. In case of wheat, the N uptake by grain (58.93 kg/ha) was significantly higher under T_4 treatment over rest of the treatments and the minimum (42.69 kg/ha) in T_1. Maximum N uptake (14.93 kg/ha) was recorded in T_2 which was at par with T_3 and T_4 but significantly higher over treatments T_1, T_5, T_6, T_7 and T_8. Maximum P uptake by rice grain (13.52 kg/ha) and wheat grain (5.21 kg/ha) was observed with treatments T_3 and T_4, respectively. Highest P uptake by rice straw (13.59 kg/ha) was also recorded in T_3 which was significantly higher over rest of the treatments however; there was no significant difference in P uptake by wheat straw among treatments. Potassium uptake by rice grain was non-significant but it was statistically significant in case of straw. Maximum K uptake (17.39 kg/ha) by rice grain was

Table 3 Effect of organic and inorganic amendments on yield components and yield of rice and wheat

Treatment	Rice							Wheat						
	Spikelets / panicle	Spikelet fertility (%)	1000-grain wt. (g)	Grain yield (t/ha)	Straw yield (t/ha)	HI (%)	NHI (%)	Grains / spike	1000-grain wt. (g)	Grain yield (t/ha)	Straw yield (t/ha)	HI (%)	NHI (%)
T_1	112.88	62.00	23.40	4.64	9.27	33.36	64.81	34.99	36.31	2.11	3.16	40.04	71.00
T_2	120.37	71.72	25.80	4.34	13.70	24.06	52.45	32.99	36.52	2.27	3.93	36.61	66.40
T_3	109.37	95.09	26.97	4.83	13.59	26.22	57.54	33.09	35.50	2.03	3.39	37.45	67.16
T_4	104.28	76.29	23.97	4.42	9.50	31.75	62.43	34.81	27.33	2.37	3.13	43.09	71.43
T_5	110.76	55.06	22.93	3.96	13.42	22.78	49.76	32.98	35.02	1.23	2.30	34.84	67.16
T_6	109.99	70.41	25.27	3.71	12.72	22.58	54.08	33.54	33.11	1.68	3.17	34.64	65.15
T_7	106.99	65.42	22.87	4.65	11.26	29.23	59.44	30.53	28.43	1.73	2.32	42.72	70.95
T_8	107.93	79.78	22.73	4.40	10.14	30.26	57.53	38.89	31.74	1.90	2.54	42.79	70.47
LSD (P=0.05)	6.73	3.64	1.12	0.30	1.13	2.21	3.21	3.12	0.65	0.24	0.43	2.61	2.26

LSD=Least significant difference, HI=Harvest index, NHI= nitrogen harvest index observed in T_3 and minimum with T_2 treatment. However, in wheat grain, maximum K uptake was recorded in T_4 which was significantly higher as compared to other treatments except T_3. The amount of nutrient uptake by crops depends on their yields and nutrient contents in grain and straw. In this study, highest grain yields in rice (4.83 t/ha) and wheat (2.37 t/ha) was observed in treatment T_3 and T_4 treatments respectively where, gypsum and phosphogypsum were used in conjunction with MSW compost. However, highest straw yields in rice and wheat were recorded in treatment T_3 and T_2, respectively. Nitrogen use efficiency (NUE) was significantly influenced due to different treatments applied to the crops. Maximum N use efficiency in rice (24.36%) was recorded with treatment T_3 followed by T_4. Similarly highest N-use efficiency in wheat was observed in T_4 treatment (Table 4).

Economics

In the first year of experimentation reclamation with different amendments, followed by cultivation of rice and wheat a small positive net return was obtained with treatment T_6 where reclamation cost was very less due to addition of very small quantity (12.5%) of inorganic amendment and only organic amendments were used for reclamation of sodic soil. However, net return was negative in all the remaining treatments.

Highest negative return was obtained in treatment T_8 followed by T_7 and T_1. This was obviously due to higher reclamation cost and less yields. During second year of experimentation of rice-wheat cropping system, the highest positive net return was observed in treatment T_3 followed by T_6 while it was negative in treatments T_1 and T_8. This showed that reclamation cost with addition of gypsum or phosphogypsum is not recovered even after second year of cultivation.

The positive B/C ratio during first year of reclamation followed by rice–wheat cropping system was obtained in only treatment T_6 (Fig 1). However, there was positive B/C ratio in all the treatments in second year of the experimentation. The highest B/C ratio was observed in T_6 treatment which was at par with T_3 treatment but significantly higher over rest of the treatments (Fig 1).

Soil properties

It is revealed that the bulk density of surface soil

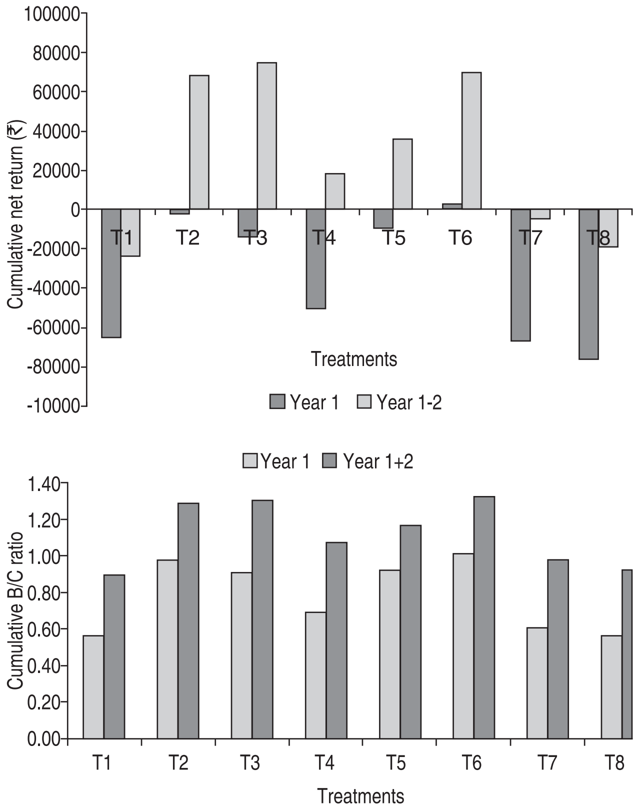

Fig 1 Cumulative net returns and benefit /cost ratio of rice-wheat cropping system over a two year period under organic and inorganic amendments of sodic soil.

Table 4 Effect of different sources of organic and inorganic amendments on nutrient uptake

Treatment	Rice							Wheat						
	Nitrogen uptake (kg/ha)		Phosphorus uptake (kg/ha)		Potassium uptake (kg/ha)		N use efficiency (%)	Nitrogen uptake (kg/ha)		Phosphorus uptake (kg/ha)		Potassium uptake (kg/ha)		N use efficiency (%)
	Grain	Straw	Grain	Straw	Grain	Straw		Grain	Straw	Grain	Straw	Grain	Straw	
T_1	42.69	23.17	6.03	4.63	12.53	129.78	-	27.85	11.376	2.74	0.63	5.49	42.98	
T_2	40.80	36.99	7.81	8.22	12.15	287.70	7.95	29.51	14.93	3.40	0.79	6.36	55.81	4.35
T_3	58.93	43.49	13.52	13.59	17.39	244.62	24.36	28.42	13.89	4.26	1.02	7.31	54.92	2.58
T_4	55.25	33.25	11.49	10.45	16.35	190.00	15.09	33.65	13.46	5.21	1.25	8.53	47.89	6.57
T_5	37.22	37.58	7.13	9.39	12.28	295.24	6.10	15.99	7.82	1.97	0.69	3.44	33.81	-12.8
T_6	40.44	34.34	7.79	10.18	12.61	190.80	6.00	21.33	11.41	3.19	0.63	5.04	47.55	-5.4
T_7	51.15	34.90	10.69	10.13	15.34	258.98	13.50	22.66	9.28	3.11	0.93	5.88	35.03	-6.11
T_8	45.32	33.46	11.44	10.14	13.64	223.08	6.00	25.46	10.67	3.99	1.02	6.27	38.86	-2.58
LSD (P=0.05)	3.12	2.54	ns	1.35	ns	21.12	-	2.13	2.32	ns	ns	1.23	3.26	

(0-5 cm) significantly reduced when organic sources of amendments were applied in conjunction with chemical amendments. Hussain *et al.* (2012) reported that application of amendments in the lesser quantities in combination with organics may be a good strategy to reclaim the sodic soils. Highest reduction in soil bulk density was recorded under treatment T_3 (gypsum @ 25% GR + on-farm MSW compost @10 t/ha) and lowest in T_1 (gypsum @ 50% GR). Nevertheless, 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). Infiltration rate increased from 4.10 mm/day to 18.20 mm/day. Highest infiltration rate was recorded with treatment T_4 where phosphogypsum @ 25% GR and on-farm MSW compost @10 t/ha was applied (Table 4). This might be due to enhancement of pore geometry and transmission pores by addition of organics (Singh *et al.* 2014).

It was observed that there was significant improvement in pH, EC, ESP, and organic carbon over the initial values (Fig 2). The soil pH ranged from 8.84 to 9.29 under different treatments. Maximum reduction in soil pH over the initial value was recorded in treatment T_3, whereas minimum in T_5. This could be due to addition of 10 t/ha MSW compost as organic source of amendment (Rai *et al.* 2010). Organic amendments decreased soil pH due to adsorption of H^+ by their specific negative surface areas.

The lowest EC (35 mS/m) was found in T_1 where only gypsum was applied @ 50% GR. This could be due to removal of Na^+ from the exchange complex. Furthermore, analysis shows that treatment T_3 has shown significant improvement in soil ESP and organic carbon content over the initial values. The highest organic carbon content (3.4 g/kg) was observed in T_3. Clark *et al.* (2007) has also reported significant improvement in soil organic carbon and ESP due to addition of organic matter in salt affected soils. The regression equations shown in Fig 3 clearly indicate the reclamation effect of MSW compost to reduce sodicity.

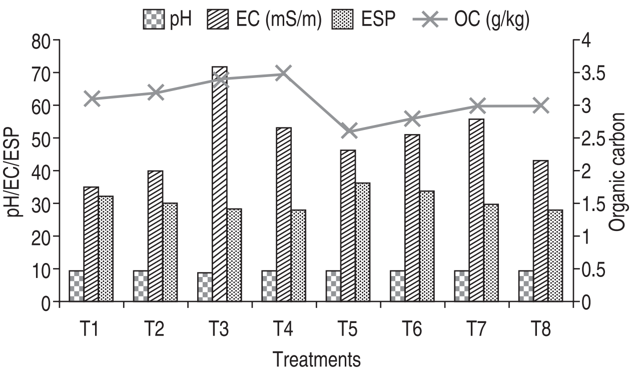

Fig 2 Effect of organic and inorganic amendments on soil properties after two years.

This is because of higher production of CO_2 and humic acid in MSW compost application, drops redox potential and the replacement of exchangable Na^+ ions with Ca^{2+} ions through leachdown to the root zone (Ansari 2008). Available N content varied from 135.9 to 165.2 kg/ha. Maximum available N (165.2 kg/ha) was recorded in treatment T_4 and minimum (135.9 kg/ha) with T_2. There was no significant difference between the treatments in this parameter but it increased significantly over the initial value. In present study, significant improvement in Na^+, K^+, Ca^{++}, Mg^{++}, Cl^-, CO_3^{--} and HCO_3^- was observed due to combined use of gypsum and on-farm MSW compost followed by cultivation of salt tolerant varieties of rice and wheat (Table 5). The superior results of addition of organic matter in conjunction with gypsum and phosphogypsum reduced adverse soil properties associated with sodic soils has also been reported by Nayak *et al.* (2009).

Based on the result of present study, it could be concluded that 10 t/ha MSW compost in combination with gypsum or phosphogypsum @ 25% GR is sufficient and equally effective to addition of gypsum or phosphogypsum @ 50 GR for reclaiming sodic soils and sustaining productivity of rice- wheat cropping system. This also indicated that about ₹ 29444.00/ha may be saved on account of reducing gypsum

Table 4 Effect of organic and inorganic amendments on soil physico-chemical properties after two years of rice-wheat cropping system

Treatment	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	LSD (P=0.05)
Bulk density (Mg/m^3)	1.57	1.53	1.41	1.46	1.48	1.52	1.48	1.41	0.03
Cumulative infiltration rate (mm/day)	11.15	13.20	17.21	18.20	15.42	15.20	18.00	17.22	1.32
Av. N (kg/ha)	146.34	135.89	148.80	165.16	150.52	150.52	148.43	146.34	ns
Na^+ (ppm)	283.75	289.86	229.81	232.67	279.56	296.16	288.66	259.28	23.20
K^+ (ppm)	3.14	2.74	2.44	3.56	2.45	3.21	4.37	3.21	ns
Ca^{++} (ppm)	20.00	30.00	23.20	26.00	20.00	23.20	23.20	23.20	0.06
Mg^{++} (ppm)	12.00	13.92	19.92	12.00	19.92	13.92	23.16	19.92	1.13
CO_3^{--}(meq/l)	2.33	1.33	2.33	2.00	2.66	3.00	3.00	2.00	0.24
HCO_3^-(meq/l)	1.50	2.83	1.50	2.16	1.66	1.83	1.33	1.83	1.12

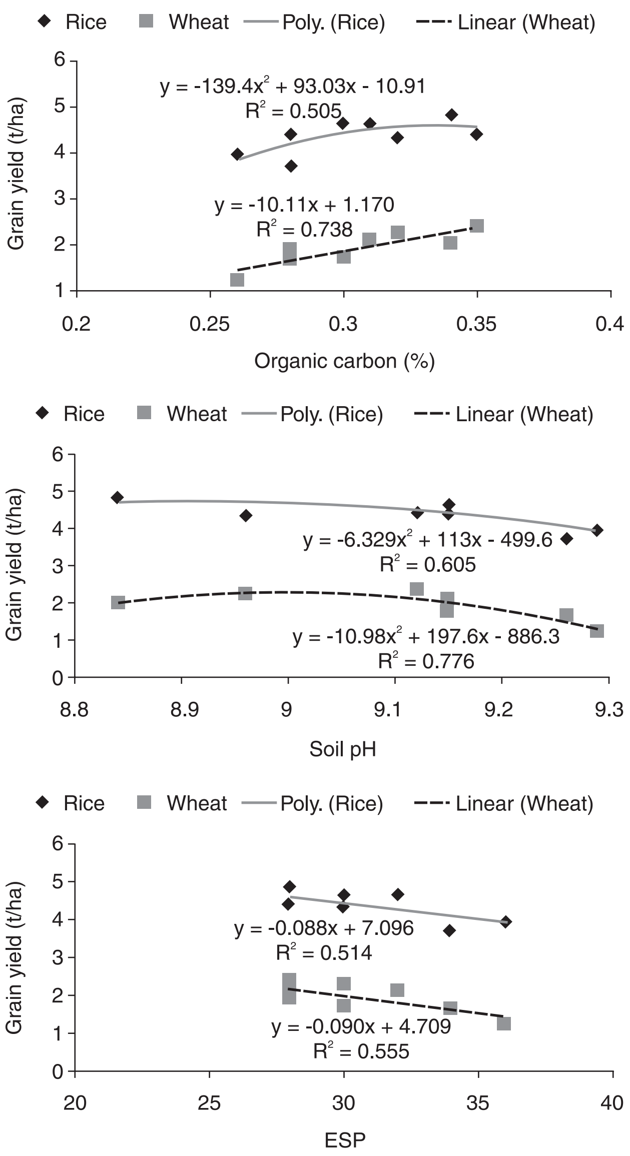

Fig 3 Correlation coefficients between soil organic carbon, pH and ESP with economic yield in rice and wheat crops.

dose at 25% GR by substituting with MSW compost and sustained crop productivity in degraded sodic soils.

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