Catena 160 (2018) 32–40

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Changes of phosphorus fractions in saline soil amended with municipal solid waste compost and mineral fertilizers in a mustard-pearl millet cropping system

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A R T I C L E I N F O

Keywords:
Municipal solid waste compost
P fractions
Phosphatase activity
Salinity
Yield

A B S T R A C T

Salinity affects phosphorus (P) fractionation and its availability in soil and thereby crop growth as well as yields. Therefore understanding of P transformation and availability in soil with use of different sources of P is crucial to adopt appropriate P management practices for improving productivity of saline soils. A field experiment comprising of four treatments replicated thrice was conducted for three consecutive years during 2012–15. Treatments consisted of control (Ct), recommended dose of N-P-K fertilizers at 60-30-30 kg ha^{-1} (RDF-100%), municipal solid waste compost at 16 Mg ha^{-1} (MSWC-16) and MSWC at 8 Mg ha^{-1} + RDF-50% (MSWC-8 + RDF-50%) laid out in randomized complete block design. Among different phosphorous fractions across the years; saloid-P (S-P), iron-P (Fe-P), calcium-P (Ca-P) and occluded-P (Occ-P) increased markedly after 2012–13 with continuous increase in subsequent years in all treatments compared to Ct. However, MSWC-8 + RDF-50% produced significant increase in all P fractions, including Olsen-P, total-P (Pt) and inorganic-P (Pi), except S-P as compared to RDF-100%. Whereas, all P fractions progressively declined in Ct from 2012–13 to 2015, indicating continuous removal by mustard (*Brassica juncea*) and pearl millet (*Pennisetumglaucum*). MSWC-8 + RDF-50% also recorded 16 and 22% higher organic-P (Po) and alkaline phosphatase activity (ALPA), respectively during 2015 over 2012–13 in corresponding treatment. Soil organic carbon (SOC) increased with RDF-100% over Ct across the years as well as within year; however, the highest SOC (5.7 g kg^{-1}) was observed with MSWC-8 + RDF-50%. Mean soil salinity (electrical conductivity; EC) decreased by 38 and 25% with MSWC-8 + RDF-50% and MSWC-16, respectively relative to Ct (4.8 dSm^{-1}). Relatively better P availability and lower soil EC with MSWC-8 + RDF-50% and resulted significantly higher mean (of three year) grain yield of mustard (2.38 Mg ha^{-1}) and pearl millet (2.44 Mg ha^{-1}) over RDF-100%. Nevertheless, RDF-100% produced 11 and 15% higher mean grain yield of mustard and pearl millet, respectively than Ct. MSWC-8 + RDF-50% also resulted in higher P uptake by grain of both crops as compared to RDF-100%. Our results highlighted that integrated use of organic amendment (MSWC-8) and mineral fertilizers (RDF-50%) is beneficial option for improving P availability and crop yields under saline conditions.

1. Introduction

Soil salinity is a serious threat to global agriculture because it is responsible for decreased agro-ecosystems productivity (Lakhdar et al., 2009). About 20% of the world's cultivated area and nearly 50% of the irrigated croplands are affected by soil salinity (Zhu, 2001). In India, soils covering 6.73 Mha are salt-affected, with sodic soils comprising 3.77 Mha (Sharma et al., 2015). Use of poor quality water for irrigation and inadequate drainage systems have resulted in rising groundwater levels, which have the potential to trigger salt accumulation in the soil profile and have a negative effect on crop production (Qadir et al., 2009). Salinity inhibits plant growth through more negative osmotic potential of the soil solution, specific ion toxicity and ion imbalance, which further reduce nutrient uptake (Marschner, 2012). Soil salinity also affects yield and crop quality (Dong et al., 2008). Meena et al. (2016) also reported that low productivity of saline soils is not only due to salt toxicity or damage caused by excess amounts of soluble salts but also arising from the lack of available mineral nutrients especially N

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http://dx.doi.org/10.1016/j.catena.2017.09.002
Received 14 July 2017; Received in revised form 23 August 2017; Accepted 6 September 2017
Available online 12 September 2017

and P and organic matter.

Phosphorus (P) is the second major essential plant nutrient required for crop growth and productivity. Available P status in saline soils is highly variable and low due to displaced exchangeable Ca and changed ionic composition of the soil solution thus influencing the extraction of soil phosphorus (Olsen et al., 1960). Release of nutrients especially N, P, K, Ca, Mg and Mn from root zone soil and loss to the ground water have been reported during leaching of saline soils (Khattak and Jarrel, 1989). Soil inorganic P (Pi) is the preferred source for plant uptake, hence knowledge of the different P fractions in saline soils is essential to understand P availability. The assessment of better availability to plant, inorganic P (Pi) fractionation is an effective approach to understand soil P availability and inter-conversion among Pi fractions from different P pools (Shen et al., 2004). Soil Pi represents the dominant component of total P (Pt) and is considered to be the major contributor of P to the growing plants (Shen et al., 2004). Inorganic P constitutes, iron bound P (Fe-P), aluminium bound P (Al-P), calcium bound P (Ca-P), and P present within the matrices of P retaining components (occluded P). Khanna and Datta (1968) reported that the share of Pi in the total P content varies from 54 to 84% in Indian soils. Olsen-P is an indicator for estimating soil P availability to growing plants (Chang and Jackson, 1957).

Organic P (Po) is mainly bound in organic matter or manures. These have to undergo mineralization to release inorganic P prior to plant uptake. Soil biological activities and enzyme production related to Po hydrolysis affect mineralization of organic matter and subsequent release of P in soil solution (Magid et al., 1996). The phosphatase and phytase enzymes are hypothesized to hydrolyze the carbon-oxygen-phosphorous (C—O—P) ester bonds during mineralization of organic P (Meena and Biswas, 2014). Phosphatase activities have been regarded also as an important factor in maintaining and controlling mineralization rate of soil Po as well as a good indicator of P deficiency (Vance et al., 2003). Whereas alkaline phosphomonoesterases are responsible for hydrolyzing a range of low-molecular-weight P compounds (He and Honeycutt, 2001). These observations suggest the logic to assume that the enzymes play important roles in P cycle between soils and plant nutrition (Sharpley, 1999).

Bioavailability of applied P in soils is directly dependent upon the labiality of P in the waste materials (He et al., 2006). Recently municipal solid waste (MSW) has gained importance as an organic amendment for restoring the fertility of saline soils (Muhammad et al., 2007; Meena et al., 2016). Composting of MSW is considered as an important recycling tool to avoid environmental and health issues associated with its land filling. It is seen as a relatively low cost and sustainable method of diverting organic waste materials including MSW from landfills while creating a quality product that is suitable for enhancing productivity of salt-affected soils (Meena et al., 2016). As such the primary goals of sustainable MSW management are to protect human health and environment and to conserve resources. In addition to the primary goals, adoption of socially acceptable practices also prevents export of waste related problems (Brunner, 2013). The World Bank studies indicated that ~70% of global increase in urban MSW comes from developing countries facing the greatest challenges. The projected rise from present 1.3 to 2.2 billion tonnes per year by 2025, is predicted to raise the annual global management costs from $205 to $375 billion (World Bank, 2012). MSW from Indian cities is estimated to have 40–60% organic matter, high moisture contents and low calorific values ranging between 800 and 1200 kcal kg^{-1} (Rawat et al., 2013). The amount of MSW generation in India is expected to increase, from 0.4 kg day^{-1} $person^{-1}$ with annual total of ~42 Mt (Asnani, 2004), many fold in the near future as the country strives to attain the status of industrialized nation by 2020 (CPCB, 2004; Sharma and Shah, 2005).

Organic amendments not only influence soil fertility directly, but can also improve composition and activity of soil microorganisms (Crecchio et al., 2004). Also the combined use of municipal solid waste compost (MSWC) and mineral fertilizers has been observed to increase soil P status and biological activity in saline soil (Mkhabela and Warman, 2005; Meena et al., 2016). In addition to provide a new organic amendment for saline as well as normal soils as a possible alternative for costly chemical fertilizers, composting of MSW has also attracted attention in order to reduce the volume to be disposed in landfill (Muhammad et al., 2007). Alone use of mineral fertilizers provide P to growing plants very quickly, because of more water soluble P content, but there may be chance of precipitation, fixation and leaching lose whereas, organic fertilizers act as slow release P. Aforesaid facts suggest that integrated use of MSWC and mineral fertilizers is an essential for maintaining the optimum P levels in saline soil for plant growth and crop productivity. However, very little systematic information is available about P fractions in saline soils amended with organic amendments (MSWC) and mineral fertilizers (MF) in mustard-pearl millet cropping system. Therefore, the present study was carried out to (i) determine the effects of MSWC and mineral fertilizers on P fractions, (ii) yields and P uptake by mustard and pearl millet in saline soil and (iii) to assess the changes in soil salinity as influenced by MSWC with and without MF under mustard pearl millet cropping system. We hypothesized that application of organic amendments would increase P fractions and productivity of saline soil by alleviating the negative effect of salinity.

2. Methods and materials

2.1. Municipal solid waste compost (MSWC)

The MSWC was collected from Municipal Corporation of Delhi, New Delhi, during each growing season of mustard and pearl millet. It originated from fruit and vegetable peels, waste from the paper industry, food waste, sweepings, cardboard and waste papers. MSWC from Municipal Corporation of Delhi, India is commercially available for application in agriculture as organic fertilizer and soil conditioner in normal as well as salt-affected soils.

2.2. Chemical analysis of MSWC

Total N in compost was determined by digesting the sample with H_2SO_4 using a digestion mixture (K_2SO_4:$CuSO_4$::10:1) in a micro-Kjeldahl method (Bremner and Mulvaney, 1982). For estimation of total P and K content, samples were digested with di-acid mixture (HNO_3:$HClO_4$::9:4).Total phosphorus contents in the acid digest were determined using spectrophotometer after developing vanadomolybdo–phosphate yellow colour complex as described by Jackson (1973) and potassium was determined by flame photometer (Jackson, 1973). Total C content was determined by ignition method (Jackson, 1973). Micronutrient cations (Fe, Mn, Cu and Zn) and heavy metals (Ni, Pb and Cd) concentrations were determined by AAS (Ayten, 2004).The cation exchange capacity (CEC) was determined as per the procedure of Jackson (1973). Chemical properties of MSWC are presented in Table 1.

2.3. Experimental site and soil

The present field experiment, on combined use of MSWC and mineral fertilizers in mustard - pearl millet cropping system, was conducted on ICAR-Central Soil Salinity Research Institute (CSSRI), Karnal research farm located at village Nain (29°19′7.09″ to 29°19′10.0″ N latitude and 76°47′30.0″ to 76°48′0.0″ E longitude) district Panipat (Haryana), India during October 2012 to October 2015. The soil of experimental site is sandy loam and climate is semi-arid subtropical with hot summers (May–June) and cold winters (December–January). Initial soil samples were collected at surface soil (0–15 cm depth). The main physico-chemical and biological properties of the pre-experimental soil were: texture sandy loam with sand (0.2–0.02 mm) 56.4%, silt (0.02–0.002 mm) 25% and clay (< 0.002 mm) 18.6% (Bouyoucos, 1962); electrical conductivity (EC_w 1:2, soil:water) 7.2 dSm^{-1}; CEC

Table 1
Characteristics of municipal solid waste compost.

Parameters	MSWC (mean ± SD)
Moisture %	8.45 ± 0.20
pH_w (1:5)	8.21 ± 0.29
EC_w (dSm^{-1})	3.40 ± 0.26
CEC [cmol(p+) kg^{-1} compost]	200 ± 11.0
Total C (%)	30.1 ± 0.56
Total N (%)	0.86 ± 0.1
C/N	35.1 ± 0.4
Total P (%)	0.37 ± 0.12
Total K (%)	0.90 ± 0.02
Total Fe (%)	0.75 ± 0.28
Total Mn (mg kg^{-1})	303.5 ± 119.2
Total Zn (mg kg^{-1})	514.5 ± 88.1
Total Cu (mg kg^{-1})	348.8 ± 138.5
Heavy metals	
Total Ni (mg kg^{-1})	37.8 ± 8.1
Total Pb (mg kg^{-1})	57.2 ± 5.0
Total Cd (mg kg^{-1})	Trace

SD, standard deviation.

11.68 cmol (p^+) kg^{-1} soil (Jackson, 1973); organic C 1.9 g kg^{-1} (Walkley and Black, 1934); 0.5 M $NaHCO_3$-extractable P 8.0 mg kg^{-1} (Olsen et al., 1954) and alkaline phosphatase activity 79.2 µg PNP g^{-1} soil 24 h^{-1} (Tabatabai and Bremner, 1969); phosphorus fractions, saloid-P (8.5 mg kg^{-1}), iron-P (7.3 mg kg^{-1}), calcium-P (246 mg kg^{-1}), and occluded-P (12.3 mg kg^{-1}) were determined by Peterson and Corey (1966). Total P (430 mg kg^{-1}), organic P (130 mg kg^{-1}) and total inorganic P (300 mg kg^{-1}) was determined by Walker and Adams (1958).

2.4. Field experiment

Performances of MSWC with and without mineral fertilizers were evaluated in the mustard–pearl millet cropping system. Four treatments comprised of (1) control; without compost and mineral fertilizers (Ct); (2) 100% recommended dose of 60, 30 and 30 kg ha^{-1} N, P and K, respectively through mineral fertilizers, (RDF-100%); (3) municipal solid waste compost (dry weight basis) at the rate of 16 Mg ha^{-1} (MSWC-16) and (4) MSWC at the rate of 8 Mg ha^{-1} + 50% of RDF (MSWC-8 + RDF-50%). The experiment was laid out in a randomized block design with three replications in plots of size 5.0 m × 5.0 m. The doses of compost and mineral fertilizers were based on nutrients content in compost and fertilizers as well as crop requirement. The purpose of combined use of MSWC + RDF was to maintain balanced nutrient supply to growing crops.

Mustard and pearl millet were sown in October and July and harvested in March and October, respectively during 2012–13, 2013–14 and 2014–15. The row to row spacing was 45 cm for both crops. Mustard variety CS-52 was salt tolerant whereas pearl millet variety Proagro 9444 was not. Ground water of experimental site was highly saline in nature (16 to 20 EC dSm^{-1}), which was not suitable for irrigation, and soil was also saline. Mustard was irrigated using rain water (EC 1–2 dSm^{-1}) harvested during rainy season (July–September) in a farm pond. Pearl millet was totally dependent on monsoon rain. Both crops were cultivated adopting recommended agronomic practices for respective crops. Recommended dose of NPK mineral fertilizers applied to mustard and pearl millet was: 60-30-30. Fertilizer used for supplying N, P and K were urea, diammonium phosphate (DAP) and muriate of potash (MOP), respectively. Half of the total N and full quantities of municipal solid waste compost (MSWC), P and K were applied as basal in each crop. Remaining half of N was applied at 35–40 days after sowing of mustard and 20–25 days after sowing of pearl millet.

2.5. Soil analysis

The plot-wise soil samples were collected from surface soil (0–15 cm) after the harvest of each crop. About 100 g of moist soil samples collected from each plot were kept in a refrigerator at 4 °C immediately after collection from field and subsequently used for alkaline phosphatase activity. Post-harvest soil samples were air-dried, ground to pass through a 2-mm sieve using a wooden pestle and mortar and analyzed for various inorganic P fractions (modified P fractionation scheme of Peterson and Corey, 1966), Olsen-P (Olsen et al., 1954), electrical conductivity (EC), soil pH (Jackson, 1973) and soil organic carbon (Walkley and Black, 1934).

Total P (Pt), inorganic P (Pi) and organic P (Po) was determined by Walker and Adams (1958) method. For the estimation of Pt content in soil, 1.0 g sample was weighed in silica crucible and ignited in a muffle furnace at 550 °C for 1 h. After cooling, the ignited soil was transferred to 100 mL conical flask and extracted with 50 mL of 1 N H_2SO_4 by shaking for 16 h on a platform type shaker. Pi content was determined by extracting unignited soil samples (1.0 g) in similar manner as Pt. Phosphorus content in the extracts of ignited (Pt) and unignited (Pi) were measured by ascorbic acid method. The amount of Po in soil was calculated as follow:

Organic P (Po) = P content in ignited soil (Pt) − P in unignited soil (Pi). Soil P was sequentially fractionated into various inorganic fractions by modified P fractionation scheme of Peterson and Corey (1966).

2.6. Plant analysis

Mustard and pearl millet crops were harvested manually in months of March and early October, respectively and yield was recorded every year. For analysis of P content in grains of two crops, samples were digested in di-acid (HNO_3:$HClO_4$::9:4) after developing vanadomolybdo–phosphate yellow colour (Jackson, 1973).

2.7. Percentage P recovery

The percentage recovery of P was computed as per the equation given below:

$$\text{Percentage of P recovery (\%)} = \frac{U_f - U_c}{A} \times 100$$

where, U_f = uptake of P in fertilized treatment; U_c = uptake of P in control treatment; and A = amount of P applied.

2.8. Statistical analysis

Analysis of variance was applied to each data set to assess the effects of treatments and years using SSCNARS Portal online data analysis, IASRI (2016) (http://www.iasri.res.in/sscnars/2016). The design used for statistical analysis included sources of variation due to year (Y), treatments (T) and interactions of Y × T. Multiple comparisons of means were based on the least significant differences (LSD) with a probability level p = 0.05.

3. Results

3.1. Changes in Olsen-P

Olsen-P was significantly affected by interaction between treatments (T) × years (Y) (Table 2). In control (Ct), there was continuous decrease over the years but the decline happened to be remarkable only during 2013 (5.4 mg kg^{-1}). However, Olsen-P increased gradually in all other treatments in subsequent years since start of the experiment. Treatment receiving MSWC-8 + RDF-50% recorded significantly higher concentration of this fraction during 2015 compared to 2012–13 and 2013, thereafter no significant differences were detected in

Table 2
Year wise changes in Olsen-P, total-P (Pt) and inorganic-P (Pi) as affected by treatment (T) and year (Y).

Treatment (T)	Year (Y)					
	2012–13	2013	2013–14	2014	2014–15	2015
Olsen-P (mg kg^{-1})						
Ct	6.3	5.4	5.1	4.8	4.5	4.2
RDF-100%	11.6	11.9	14.3	14.9	15.5	15.8
MSWC-16	11.9	12.4	14.9	15.5	16.2	16.8
MSWC-8 + RDF-50%	15.2	15.9	17.0	17.3	18.0	18.8
LSD (p = 0.05) T × Y2.2						
Pt (mg kg^{-1})						
Ct	415	390	358	352	348	346
RDF-100%	427	437	448	453	456	463
MSWC-16	467	487	496	508	517	526
MSWC-8 + RDF-50%	473	490	501	508	518	525
LSD (p = 0.05) T × Y13.4						
Pi (mg kg^{-1})						
Ct	293	273	263	258	256	255
RDF-100%	303	309	311	314	316	319
MSWC-16	312	334	342	345	348	353
MSWC-8 + RDF-50%	343	347	355	360	368	372
LSD (p = 0.05) T × Y9.3						

Ct: without compost and mineral fertilizers; RDF-100%: (recommended dose of NPK fertilizers were 60–30–30 kg ha^{-1}, respectively.); MSWC-16 (Municipal solid waste compost at 16 Mg ha^{-1}); MSWC-8 + RDF-50%: (MSWC at 8 Mg ha^{-1} + RDF of NPK 30-15-15 kg ha^{-1}, respectively).

subsequent years. In MSWC-16, Olsen-P increased consistently after first growing season of mustard (2012 – 13) however, increment was significant only during 2013–14. MSWC-8 + RDF-50% had significantly higher Olsen-P relative to RDF-100% in each year. Application of RDF-100% resulted significantly higher Olsen-P during 2013–14 as compared to 2012–13 and 2013, after that no significant variations were observed in subsequent years. MSWC-8 + RDF-50% and MSWC-16 had 24 and 40% higher Olsen-P, respectively during 2015 compared to 2012–13 in respective treatments (Table 2).

3.2. Changes in total P (Pt) and inorganic P (Pi)

Total-P (Pt) considerably increased after first growing season of mustard (2012–13) in all treatments compared to Ct (Table 2). Pt significantly decreased in Ct (346 mg kg^{-1}) during 2015 compared to 2012–13 and 2013 but thereafter no significant variations were observed in the following years. Over the years, the plots receiving MSWC-8 + RDF-50% had significantly higher Pt than RDF-100%, however it remained statistically similar to MSWC-16. Continuous use of MSWC-8 + RDF-50% significantly increased Pt 11% during 2015 as compared to 2012–13 in respective treatment. But RDF-100% produced significant increase in Pt during 2013–14, however, only gradual increase was observed in subsequent years.

Inorganic-P (Pi) was significantly affected by interaction between T × Y. Concentration of Pi increased gradually over the years in plots receiving RDF-100% but no significant variations were noticed among the years except 2012–13 and 2013 (Table 2). MSWC-16 and RDF-100% had 13 and 5% higher Pi, respectively, during 2015 as compared to 2012–13 in corresponding treatments. Over all, MSWC-8 + RDF-50% performed significantly better than RDF-100% over the years.

3.3. Sequential P fractionations (S-P, Fe-P, Ca-P and Occ-P)

Observations revealed that inorganic P fractions were significantly affected by T × Y (Table 3). Integration of MSWC-8 with RDF-50% increased all P fractions in saline soil across years. In Ct, saloid P (S-P) declined gradually but significantly (5.6 mg kg^{-1}) in 2015 as compared to initial value of 7.5 mg kg^{-1} observed in 2012–13. Application of MSWC-16 resulted in significantly higher build-up of S-P during 2015 compared to first three crops (2012–13 to 2013–14) thereafter no significant variations were observed in the following years. S-P greatly increased in all treatments after first growing season of mustard (2012–13) compared to Ct and continuously increased in subsequent years. In 2015, MSWC-8 + RDF-50% had significantly higher S-P (27.0 mg kg^{-1}) than other treatments across the years; however it was statistically at par to 2014–15. With use of RDF-100%, S-P increased by 43% during 2015 over 2012–13 in respective treatment.

Table 3
Year wise changes in saloid-P (S-P), iron-P (Fe-P), calcium-P (Ca-P) and occluded-P (Occ-P) as affected by treatments (T) and years (Y).

Treatment (T)	Year (Y)					
	2012–13	2013	2013–14	2014	2014–15	2015
S-P (mg kg^{-1})						
Ct	7.5	6.8	6.5	6.0	5.7	5.6
RDF-100%	12.1	15.0	15.8	16.5	17.1	17.3
MSWC-16	10.8	16.0	18.1	19.6	20.0	20.3
MSWC-8 + RDF-50%	15.0	19.8	21.3	25.0	26.0	27.0
LSD (p = 0.05) T × Y1.3						
Fe-P (mg kg^{-1})						
Ct	6.7	6.1	5.8	5.3	5.1	4.8
RDF-100%	12.6	13.8	14.1	14.7	15.0	16.0
MSWC-16	12.3	14.2	15.5	16.1	16.4	17.0
MSWC-8 + RDF-50%	17.3	20.9	21.9	22.5	22.7	23.5
LSD (p = 0.05) T × Y1.1						
Ca-P (mg kg^{-1})						
Ct	234	211	200	196	194	191
RDF-100%	265	270	283	288	290	295
MSWC-16	287	300	308	313	316	319
MSWC-8 + RDF-50%	313	318	322	325	329	331
LSD (p = 0.05) T × Y11.3						
Occ-P (mg kg^{-1})						
Ct	11.6	10.8	10.0	9.2	8.3	7.2
RDF-100%	21.3	25.0	26.7	29. 2	30.0	31.1
MSWC-16	22.8	29.6	32.1	34.2	35.8	36.5
MSWC-8 + RDF-50%	29.7	37.6	39.6	41.7	44.2	45.3
LSD (p = 0.05) T × Y4.1						

Ct: without compost and mineral fertilizers; RDF-100%: (recommended dose of NPK fertilizers were 60-30-30 kg ha^{-1}, respectively.); MSWC-16 (municipal solid waste compost at 16 Mg ha^{-1}); MSWC-8 + RDF-50%: (MSWC at 8 Mg ha^{-1} + RDF of NPK 30-15-15 kg ha^{-1}, respectively).

Plots receiving MSWC either alone or in combination with RDF recorded significantly higher Fe-P compared to Ct over the years (Table 3). Likewise RDF-100% had significantly higher Fe-P than Ct over the years as well as within year. However, MSWC-16 had greatly increased Fe-P in 2013, but after that increment was only gradual. In case of Ct, though Fe-P decreased gradually in subsequent years from start of experiment in 2012–13 and 2013 but reached significance only in 2015. Adoption of MSWC-8 + RDF-50% resulted insignificantly higher Fe-P than RDF-100% across the years and within years.

Ca-P was significantly affected by interaction between T × Y (Table 3). It increased over the years after 2012–13 in all the treatments in comparison to Ct. However, repeated use of MSWC-16 resulted in accumulation of the highest amount of Ca-P relative to RDF-100%. In treatment MSWC-8 + RDF-50%, Ca-P varied from 313 to 331 mg kg^{-1} across the 3 year experiment (Table 3).

Occ-P was significantly affected by treatment and year interaction (T × Y). Application of different treatment combinations caused significant variations in Occ-P in soil across the years. Though, Occ-P was increased gradually in subsequent years in all treatments except Ct but the increase was significant only during 2013. Over the years, continuous use of RDF-100% recorded higher Occ-P in soil than Ct. Soil treated with RDF-100% had 46% higher Occ-P in 2015 compared to 2012–13 in respective treatment. (Table 3). MSWC-8 + RDF-50%, was significantly increased in Occ-P during 2015 as compared to 2012–13,

Table 4
Year wise changes in organic-P (Po) and alkaline phosphatase activity (ALPA) as affected by treatments (T) and years (Y).

Treatment (T)	Year (Y)					
	2012–13	2013	2013–14	2014	2014–15	2015
Po (mg kg^{-1})						
Ct	122	117	95	94	92	91
RDF-100%	124	128	138	138	141	144
MSWC-16	151	153	154	163	168	173
MSWC-8 + RDF-50%	133	143	146	148	150	154
LSD (p = 0.05) T × Y15.7						
ALPA (µg PNP g^{-1} soil 24 h^{-1})						
Ct	82	80	72	71	70	68
RDF-100%	86	102	113	117	119	121
MSWC-16	131	138	149	157	159	164
MSWC-8 + RDF-50%	154	162	175	179	184	188
LSD (p = 0.05) T × Y12.3						

Ct: without compost and mineral fertilizers; RDF-100%: (recommended dose of NPK fertilizers were 60-30-30 kg ha^{-1}, respectively.); MSWC-16 (municipal solid waste compost at 16 Mg ha^{-1}); MSWC-8 + RDF-50%: (MSWC at 8 Mg ha^{-1} + RDF of NPK 30-15-15 kg ha^{-1}, respectively).

but differences were non-significant over that of 2013 and 2013–14.

3.4. Organic P (Po) and alkaline phosphatase activity (ALPA)

Treatment and year had significant interaction (T × Y) effect on Po (Table 4). Though, Po decreased continuously in Ct, during three consecutive years of experimentation, but significant decline was observed over the years compared to 2012–13 and 2013 (Table 4). Treatments receiving MSWC-16 had 15% higher Po during 2015 compared to 2012–13 in respective treatment. There was no significant variation in Po with MSWC-8 + RDF-50% over the years except 2012–13. However, the maximum Po was recorded in treatment MSWC-16 during each year as compared to other treatments.

MSWC-8 + RDF-50% had significantly more amount of ALPA in 2015 in comparison to 2012–13 and 2013–14, but thereafter it was statistically similar in following years (Table 4). In Ct, ALPA had significantly decreased (20%) during 2015 relative to 2012–13. Treatment receiving RDF-100% had remarkably higher in ALPA during 2012–13 and 2013, but there was only gradual increase in subsequent years. MSWC-8 + RDF-50% had 22% higher ALPA during 2015 than 2012–13 in respective treatment.

3.5. Changes in soil organic carbon (SOC)

SOC was also influenced significantly by interaction between T × Y (Fig. 1). Results indicated that combined addition of MSWC-8 + RDF-50% had significantly increased in SOC relative to RDF-100% across the 3 year experiment (Fig. 1). SOC in RDF-100% increased gradually from 1st year itself *i.e.* in all subsequent years after 2012–13. MSWC-16 and RDF-100% resulted in statistically similar effect on SOC during 2012–13 to 2013; thereafter, MSWC-16 had significantly more SOC than RDF-100% in following years. In case of Ct, SOC decreased by 51% in 2015 compared to 2012–13, though no significant differences were detected over the years. As such we observed the highest amount of SOC during 2015 in all treatments except Ct across the years.

3.6. Salt dynamics (EC)

Soil electrical conductivity (EC) was also affected significantly by Y and T, while no interaction between Y × T was detected (Fig. 2). In all treatments, soil EC decreased after first crop, but the rate of decrease was higher with organic amendment as compared to Ct. Three year mean salt concentration was significantly reduced under MSWC-8 + RDF-50% than Ct followed by alone use of MSWC-16. There was no significant difference between Ct and RDF-100%. MSWC-16 had 25% reduction in mean salt concentration than Ct (Fig.2). However, the highest reduction (38%) in mean salt concentration was recorded with MSWC-8 + RDF-50% relative to Ct. As per our observations, decline in soil EC was gradually in 2013 after that significant in the following years.

3.7. Mean grain and straw yield of mustard and pearl millet

Grain and straw yields of mustard and pearl millet were significantly affected by treatments while, no significant interactions were observed between treatments and years (T × Y) with respect to grain or straw yield of the crops (Table 5). Combined use of organic amendment and mineral fertilizers produced significantly higher (mean of three year) grain yield of mustard and pearl millet than RDF-100% (Table 5). The highest grain yield of mustard (2.38 Mg ha^{-1}) and pearl millet (2.44 Mg ha^{-1}) was reported under MSWC-8 + RDF-50% than other treatments. Integrated use of MSWC-8 + RDF-50% produced 16 and 14% higher grain yield of mustard and pearl millet, respectively than RDF-100%. Alone use of organic amendment, MSWC-16 produced 9 and 7% higher grain yields of mustard and pearl millet, respectively as compared to RDF-100%. Whereas RDF-100% recorded 11 and 15%, respectively more grain yield mustard and pearl millet grain yield,

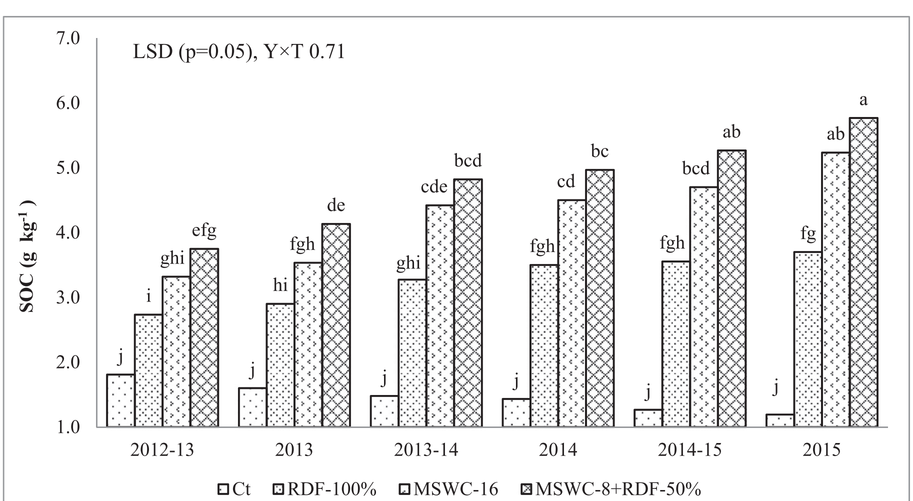

Fig. 1. Changes in soil organic carbon (SOC) as affected by treatments (T) and years (Y).
Ct: without compost and mineral fertilizers; RDF-100%: (recommended dose of NPK fertilizers were 60-30-30 kg ha^{-1}, respectively.); MSWC-16 (municipal solid waste compost at 16 Mg ha^{-1}); MSWC-8 + RDF-50%: (MSWC at 8 Mg ha^{-1} + RDF of NPK 30-15-15 kg ha^{-1}, respectively).
T: treatments, Y: years.
Different lowercase letters indicate significant difference (p = 0.05) among treatments and years.

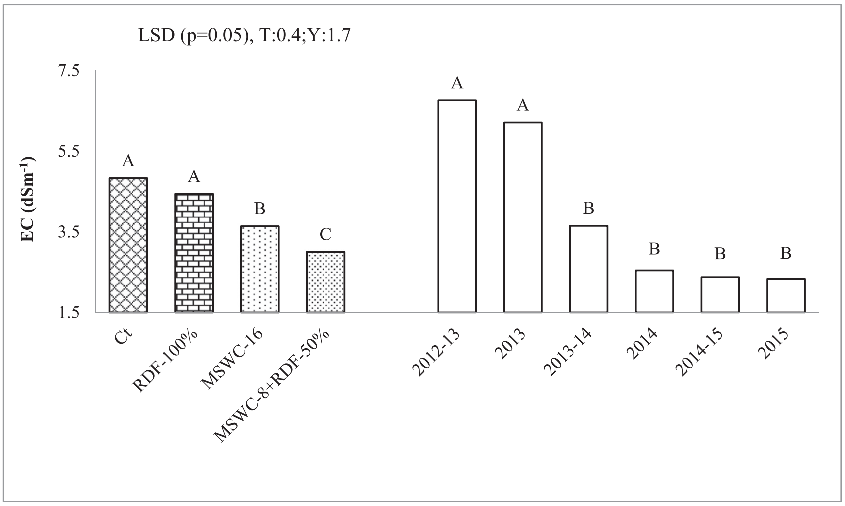

Fig. 2. Three year mean soil EC (dSm^{-1}) as influenced by MSWC and mineral fertilizers with data pooled over three year.
Ct: without compost and mineral fertilizers; RDF-100%: (recommended dose of NPK fertilizers were 60-30-30 kg ha^{-1}, respectively.); MSWC-16 (municipal solid waste compost at 16 Mg ha^{-1}); MSWC-8 + RDF-50%: (MSWC at 8 Mg ha^{-1} + RDF of NPK 30-15-15 kg ha^{-1}, respectively).
Different capital letters indicate statistically significant differences (p = 0.05) between treatments (T) and years (Y) based on the means of three year.

Table 5
Three year mean of grain and straw yields (Mg ha^{-1}) of mustard and pearl millet as affected by MSWC and mineral fertilizers.

Factors	Mustard		Pearl millet	
	Grain	Straw	Grain	Straw
Treatment (T)				
Ct	1.84C[a]	4.51D	1.86C	7.21B
RDF-100%	2.04BC	5.32C	2.14B	7.50AB
MSWC-16	2.22AB	5.71B	2.29AB	7.61AB
MSWC-8 + RDF-50%	2.38A	6.10A	2.44A	8.01A
Year (Y)				
2012–13	2.01	5.36	2.10	7.38
2013–14	2.21	5.55	2.27	7.50
2014–15	2.14	5.36	2.18	7.77
LSD (p = 0.05)				
Treatment (T)	0.15	0.51	0.16	0.42
Year (Y)	ns	ns	ns	ns
T × Y	ns	ns	ns	ns

Ct: without compost and mineral fertilizers; RDF-100%: (recommended dose of NPK fertilizers were 60-30-30 kg ha^{-1}, respectively.); MSWC-16 (municipal solid waste compost at 16 Mg ha^{-1}); MSWC-8 + RDF-50%: (MSWC at 8 Mg ha^{-1} + RDF of NPK 30-15-15 kg ha^{-1}, respectively).
[a] Different capital letters within column indicate statistically significant differences (p = 0.05) between treatments (T) and years (Y) based on the means of three year.

respectively than Ct.

RDF-100% had produced 27% higher mean (of three year) straw yield of mustard than Ct (Table 5). Though, straw yield of both crops was significantly higher with MSWC-8 + RDF-50% than Ct, whereas straw yield of pearl millet was statistically at par among the treatments except Ct. RDF-100% resulted 17 and 4% higher straw yield of mustard and pearl millet, respectively than Ct. However, MSWC-16 recorded significantly higher mustard straw yield (5.7 Mg ha^{-1}) as compared to RDF-100%.

3.8. Mean P uptake and P recovery (%) by grain of mustard and pearl millet

Mean P uptake by grain of mustard and pearl millet was significantly higher with MSWC-16 as compared to Ct, however it was statistically at par with RDF-100% (Fig. 3). Significantly higher P uptake by grain of both crops was observed under MSWC-8 + RDF-50% than Ct. Soil treated with MSWC-8 + RDF-50% had 35 and 19% higher P uptake by grains of mustard and pearl millet, respectively relative to RDF-100%.

Data pertaining to P recovery in grain revealed that the highest recovery of 14.8 and 11.6% was noticed by mustard and pearl millet, respectively under RDF-100% (Fig. 4). P recovery by grain of both crops under RDF-100% was significantly higher relative to alone use of MSWC-16. Likewise combined use of MSWC-8 + RDF-50% also recorded higher P recovery by grains of both crops as compared to alone use of MSWC-16.

4. Discussion

4.1. Changes in Olsen-P

In general, addition of P through either mineral fertilizers (RDF) or organic amendment (MSWC) and their combined use improved its availability with time to crops. Significantly higher Olsen-P was observed under MSWC-16 during 2015 as compared to 2012–13 and 2013. These observations suggested that availability of P (Olsen-P) was associated with mineralization of compost and increased with time in the following years. Similar increase was observed in soil fertility including Olsen-P with long-term use of organic inputs (Singh et al., 2004), and even conversion of unavailable soil phosphates into available (Olsen-P) form with release of humic acid during decomposition of organic matter added with 1% of compost application (Muhammad et al., 2007). In saline conditions, MSWC-8 + RDF-50% recorded higher Olsen-P as compared to RDF-100% over the years. Earlier also, soil salinity and sodicity have been observed to affect P dynamics due to changes in its sorbent surfaces due to increase in poorly crystalline Fe oxides, and changes in silicate clays, Na/Ca ratio and sulphate concentrations (Dominguez et al., 2001; Meena and Biswas, 2014; Meena et al., 2016). Likewise integration of organic amendment and mineral fertilizers has been observed to enhance P mineralization from organic amendments and its availability to plants for longer time in comparison to water-soluble P in fertilizer (Biswas and Narayanasamy, 2006). Therefore, as such over the years, integrated use of organic amendment along with mineral fertilizers proved better in terms of Olsen-P in saline soil as well as normal soils.

4.2. Total P (Pt) and inorganic P (Pi)

Over the years, both total P (Pt) and inorganic P (Pi) significantly increased with MSWC-16 alone and combination of MSWC-8 + RDF-50% in comparison to RDF-100%. It was mainly due to relatively more and consistent supply of the two fractions with application of organic amendments than mineral fertilizers alone (Meena and Biswas, 2014). Increase in total organic carbon (TOC) and enzymatic activities with additions of organic matter have been observed to affect different chemical processes including P dynamics. Hamdi et al. (2007) have also

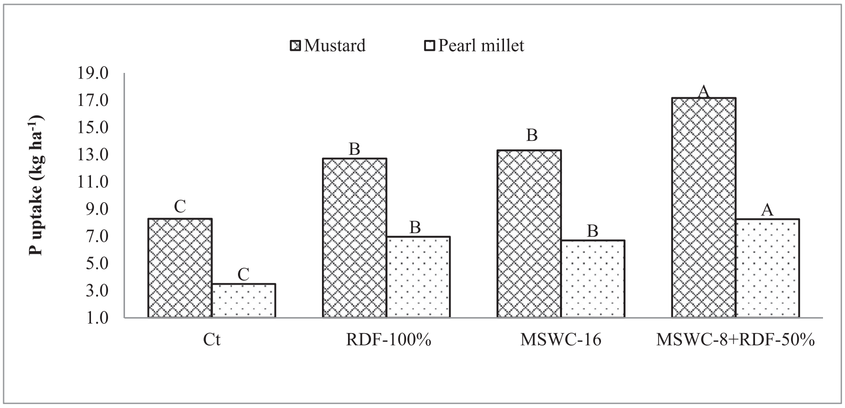

Fig. 3. Grain P uptake by mustard and pearl millet as affected by MSWC and mineral fertilizers, with data pooled over three year.
Ct: without compost and mineral fertilizers; RDF-100%: (Recommended dose of NPK fertilizers were 60-30-30kg ha^{-1}, respectively.); MSWC-16 (municipal solid waste compost at 16 Mg ha^{-1}); MSWC-8 + RDF-50%: (MSWC at 8 Mg ha^{-1} + RDF of NPK 30-15-15 kg ha^{-1}, respectively).
Different capital letters indicate statistically significant differences ($p = 0.05$) between treatments in three year means of P uptake.

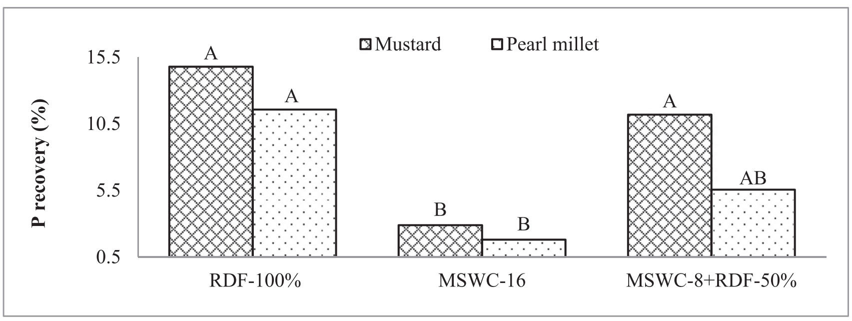

Fig. 4. P recovery (%) by grain of mustard and pearl millet as affected by MSWC and mineral fertilizers.
Ct: without compost and mineral fertilizers; RDF-100%: (recommended dose of NPK fertilizers were 60-30-30 kg ha^{-1}, respectively.); MSWC-16 (municipal solid waste compost at 16 Mg ha^{-1}); MSWC-8 + RDF-50%: (MSWC at 8 Mg ha^{-1} + RDF of NPK 30-15-15 kg ha^{-1}, respectively).
Different capital letters indicate significant differences ($p = 0.05$) between treatments in three year means of P recovery.

reported higher total P in soils applied with sewage sludge compost and decaying rice straw than that of without composts. Continued depletion of P by intensive cropping over the years, despite zero addition, had resulted in lower levels of Pt in Ct as compared to RDF-100%. Higher acid and alkaline phosphatase activities observed in soils amended with rock phosphate enriched composts increasing total, inorganic and water soluble P (Biswas and Narayanasamy, 2006) and relatively more inorganic P in soils amended with rock phosphate and waste mica enriched composts (Meena and Biswas, 2014) than that of un treated soil also substantiated with our findings. In Ct, total-P decreased by > 20% during 2015 as compared to 2012–13. The highest Pi content was maintained throughout three years, in soil amended with MSWC-8 + RDF-50%. These observations suggest that integrated use of organic and inorganic sources of P is more beneficial for sustainable crop production.

4.3. Sequential P fractions (S-P, Fe-P, Ca-P and Occ-P)

Inorganic P fractionation is an effective approach to understand soil inorganic P inter-conversions among different P pools (Gu and Qin, 1997). Though P availability in soils depends on several factors, the occurrence and abundance of metal cations that are prone to precipitate with P ions in the soil solution but in general, saloid P (S-P) is considered the most important P fraction for plant growth. However, in saline soils, Ca-P is considered as the most dominant source of P, whereas, Fe-P was less effective and Occ-P not effective for crop growth (Jiang and Gu, 1989). Hinsinger (2001) observed that in neutral to alkaline soils, P ions precipitate as dicalcium or octacalcium phosphates, hydroxyl apatite, and eventually least soluble apatites. We observed that all P fractions increased after first growing season of mustard (2012–13) in all treatments compared to Ct. Soil treated with MSWC-8 + RDF-50% also increased all P fractions in 2013 relative to RDF-100%. But in case of Ct, all P fractions gradually declined after first crop (2012–13) with significant decrease during 2015. Continuous addition of P through use of MSWC and RDF either alone or in combination increased different P fractions. In corroboration to our findings, increased inorganic P fractions in MSWC, mineral fertilizer and their integration treatments except Ct, Song et al. (2007) concluded that annual applications of chemical fertilizers and animal manure increased both labile as well as non-labile P pools in soils under the natural agro ecosystems. Nevertheless, without any P addition in Ct, continuous uptake by crops caused progressive depletion of all P fractions in soil solution as also observed earlier by Meena and Biswas (2014). Hence, results of our study indicate that integration of organic and inorganic sources of P improved P solubilization, minimized P precipitation in soil and thus helped in increasing its availability to crops.

4.4. Organic P (Po) and alkaline phosphatase activity (ALPA)

Due to low organic matter and lesser intensive investigations on organic P (Po) than inorganic P fraction, there is inadequate understanding on behaviour of Po in saline soils. Hence, contribution of Po towards meeting the P needs of the growing plants is often underestimated. In our study, Po content in soil under MSWC-16 increased by 15% during 2015 compared to 2012–13 in respective treatment and these were significantly higher than RDF-100% across the years. This might be due to the fact that Po added through MSWC was mainly in organic pool, which mineralized slowly with time (Lee et al., 2004; Singh et al., 2004) and remained available to crop plants (Meena and Biswas, 2014).

Alkaline phosphatase (ALPA) plays an important role in transformation of Po to inorganic forms that are essential for plant growth (Tabatabai, 1994). Here also MSWC either alone or in combination with RDF recorded significantly highest ALPA, across the years as well as within year, than RDF-100%. In Ct, ALPA significantly declined during 2015 in comparison to 2012–13. Juma and Tabatabai (1988) ascribed the increase in ALPA to stimulating effect of organic amendments which was absent under intensive mustard-pearl millet cropping system in Ct (Meena et al., 2016).

4.5. Soil organic carbon (SOC)

It is well known that organic matter plays a key role in the soil system and is an important regulator of numerous environmental constraints especially, soil salinity (Tejada et al., 2006). Combined use of RDF-50% and MSWC-8 increased SOC content than Ct, it was obviously due to greater biomass incorporated through compost (Meena et al., 2016; Moharana et al., 2012). SOC was significantly influenced with MSWC-8 + RDF-50% than RDF-100% over the years, due to integration of organic amendment and mineral fertilizers which enhanced organic carbon mineralization. There was low concentration of SOC during initial year of MSWC application; however, it gradually increased in subsequent years. It might be due to the fact that initially the organic material is degraded in small fractions and made available to plants and soil microorganisms (Hadas et al., 1996). Although chemical nature of MSWC governs the rate at which it is decomposed to SOC by the microbial community (Hahn and Quideau, 2013), but results of our study clearly showed that MSWC-8 along with RDF-50% performed better in saline soil than other treatments.

4.6. Salt dynamics

The magnitude of changes in salt concentration (EC; measured in terms of electrical conductance) was more with MSWC either alone or in combination of RDF. However, EC in Ct was initially higher but decreased gradually in the following years due to irrigation with good quality water (pond water) which leached down the soluble salts from surface soil to below root zone (Grattan and Oster, 2003). Combined use of MSWC and RDF had significant impact on decreasing mean salt concentration than Ct. This was mainly due to organic amendment decreased bulk density, and enhanced soil porosity and aeration, as a result, an improvement in salt leaching (Khaleel et al., 1981). The lowest decrease in salinity was observed with RDF and highest being with MSWC-8 + RDF-50% throughout the three years experiment, indicated that MSWC plus mineral fertilizers had improved soil physical properties. Our findings clearly indicate that remarkable reduction in salt concentration with integrated use of organic amendment and mineral fertilizers in comparison to other treatments. This was mainly due to improved organic carbon of soil as a consequence of decomposition of more mass of organic matter was added through MSWC, which improved soil structure and permeability thus enhanced salt leaching, reducing surface evaporation and inhibition of salt accumulation in surface soils (Raychev et al., 2001).

4.7. Grain and straw yield

Mean (of three year) grain yields of mustard and pearl millet were significantly higher with MSWC-8 + RDF-50% relative to RDF-100%. It can be explained that integration of organic amendment plus mineral fertilizers probably attributed to better synchrony of balanced nutrients supply which was not by mineral fertilizers alone (Yadav et al., 2000). Further, the greatest increase in grain as well as straw yields of both crops was observed with MSWC-8 + RDF-50% followed by MSWC-16. This was mainly due to the beneficial effects of compost on biological and physical conditions of soil (Meena et al., 2016; Moharana et al., 2012). Similar results of improved soil physical condition due to addition of organic amendments resulting in better crop performance were also reported by Hati et al. (2006) and Gopinath et al. (2008).

4.8. P uptake and recovery by grain of mustard and pearl millet

MSWC-8 + RDF-50% showed significantly more mean P uptake by grain of mustard and pearl millet relative to other treatments. This was mainly due to combined use of organic source of P and mineral fertilizers, continuously replenished soil solution P more effectively than alone use of MSWC-16 and RDF-100%. Soil treated with MSWC-16 had significant impact on P uptake by grains of both the crops than Ct, because of organic amendment in saline soil not only provided P but also improved soil biological activities which enhanced P uptake by crops as reported earlier by Lakhdar et al. (2008).

It is evident from the present study that the highest P recovery (%) by mustard and pearl millet grains was obtained in RDF-100% than MSWC-16. It was mainly due to the fact that chemical fertilizers had more water soluble P than organic amendment (MSWC). P recovery was higher under MSWC-8 + RDF-50%, because integration of these materials supplied P for longer period than RDF-100%. Results also suggest that the beneficial effect of organic amendment in mobilizing the native reserves of P for its exploitation by plants. Similarly, favourable effects of combined use of organic and inorganic source on the native phosphate or labile P in soils have also been reported by Mandal and Khan (1972).

5. Conclusions

Integrated use of MSWC-8 + RDF-50% had significantly improved Olsen-P, total P and inorganic P than Ct across the years. Organic amendment along with mineral fertilizers resulted higher concentration of inorganic P fractions, S-P, Fe-P, Ca-P and Occ-P as compared to alone use of MSWC-16 and RDF-100% over the years. MSWC-8 + RDF-50% maintained higher organic-P (154 mg kg^{-1}) and alkaline phosphatase activity (188 μg PNP g^{-1} soil 24 h^{-1}) than RDF-100% and Ct during 2015. Combined use of organic amendment along with mineral fertilizers resulted significantly higher grain yield of mustard and pearl millet than alone use of MSWC and RDF. Significantly higher grain P uptake by mustard and pearl millet was observed with MSWC-8 + RDF-50% than all treatments. SOC was more influenced with organic amendment rather than RDF-100% over the years. Soil salinity (mean of three year) was significantly lower under organic amendment plus mineral fertilizers followed by alone use of MSWC in comparison to RDF-100%. Our findings demonstrate that integration of organic amendment and mineral fertilizers improved P status of saline soil and maintained lower salinity throughout the experiment. However, organic amendments do not completely overcome the adverse effect of salinity but continuous use of compost improves chemical and biological properties of saline soil. Therefore, compost can provide better P availability to crops in saline soils.

Acknowledgments

The authors thank the Director, ICAR-Central Soil Salinity Research Institute (NRMACSSRISIL201200300844), Karnal, Haryana, India, for financing this work and Head, Division of Soil and Crop Management, ICAR-Central Soil Salinity Research Institute, Karnal, Haryana, India, for excellent technical assistance.

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