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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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ABSTRACT

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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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