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Changes in soil quality in response to short-term application of municipal sewage sludge in a typic haplustept under cowpea-wheat cropping system

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ABSTRACT

Recycling of sewage sludge as an organic amendment and source of macro- and micro-nutrient in agricultural fields can be a potential option for proper disposal of organic wastes. A field experiment was conducted at the experimental farm of Indian Agricultural Research Institute, New Delhi, to examine the short-term effect of municipal sewage sludge application on soil physical, chemical and biological properties of a sandy loam soil (typic haplustept) under cowpea-wheat cropping system. Control and four treatments adopted in this study were, 100%NPK (nitrogen, phosphorus and potassium), and three sludge applications i.e. equivalent to 5, 10, 15 t ha^{-1}. The results showed a positive effect of sewage sludge on different parameters. Bulk density was decreased by about 21% in surface layer, increased the mean weight diameter (MWD), porosity, dehydrogenase activity and microbial biomass carbon. A higher amount of aggregate associated organic carbon was associated with soil macro-aggregate (>0.25 mm) in comparison to micro-aggregate (<0.25 mm). Sewage sludge at 15 t ha^{-1} produced most prominent effect in the upper 15 cm soil layer. Considerable improvement in microbial biomass carbon, dehydrogenase activity and aggregate associated organic matter was observed particularly when higher amount of sludge was applied. Lower quantity of organic waste showed a beneficial trend but in a smaller extent.

1. Introduction

The increasing generation of organic wastes by livestock operations, industrial activity, and municipalities brings significant pressure on the waste disposal (Eghball and Gilley, 1999). The use of wastes in agriculture and for land reclamation is increasingly being identified as an important issue for both soil conservation and residual disposal. Sewage sludge (SS), a byproduct of treated wastewater are organic C-rich materials and represent a source of organic matter, N, P, and other nutrients, which, if properly managed, can be used to improve organic fertility in intensively cropped degraded soils (Albiach et al., 2001; Garcia-Gil et al., 2004), thus can reduce the needs for synthetic fertilizer (Angle, 1994). However, sewage sludge may also contain contaminants that may affect soil microbial communities and their processes that are fundamental to maintaining soil conditions and ecosystem functions. Efficient use of sewage-sludge therefore requires an individual assessment and any effects should be compared with natural variations due to climate and soil type (Debosz et al., 2002). Previous studies on sludge application have shown improvement in the soil physical (Griffiths et al., 2005) and chemical (Speir et al., 2004) status and generally facilitates microbial growth and activity (Debosz et al., 2002; Garcia-Gil et al., 2004). Several workers elsewhere also reported that application of sewage sludge improves soil physical properties such as bulk density, aggregate stability, water holding capacity, total porosity, and saturated hydraulic conductivity (Sort and Alcañiz, 1999; Aggelides and Londra, 2000). Sludge addition has also produced undesirable changes, such as decreases in pH, increases in salinity and heavy metal contents (Navas et al., 1998; Veeresh et al., 2003; Singh and Agrawal, 2008).

Over the long-term however, the accumulation of potentially toxic metals through repeated sludge additions could have a detrimental influence on soil microbial communities and their functions and thus threaten the long-term viability of sludge application to land. The observations made by different workers showed that long-term effects of sludge on the soil microbial biomass are varied (Fliebach et al., 1994; Defra, 2005).

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Table 1
Basic parameters of soil and sewage sludge.

Parameters	Soil	Sludge
Bulk density ($g\,cm^{-3}$)	1.67	–
EC ($dS\,m^{-1}$)	0.19	1.45
pH	8.4	6.4
Cation exchange capacity (meq $100\,g^{-1}$)	10.61	–
Sand (%)	65.5	–
Silt (%)	14.2	–
Clay (%)	20.3	–
Oxidisable organic C ($g\,kg^{-1}$)	3.91	70.4
Available N ($mg\,kg^{-1}$)	11.6	18,000
Available P ($g\,kg^{-1}$)	2.65	16,100
Available K ($g\,kg^{-1}$)	141.5	1830
DTPA–Fe ($mg\,kg^{-1}$)	14.53	9130
DTPA–Zn ($mg\,kg^{-1}$)	3.76	1853
DTPA–Mn ($mg\,kg^{-1}$)	2.41	555.3
DTPA–Cu ($mg\,kg^{-1}$)	2.07	173
DTPA–Pb ($mg\,kg^{-1}$)	0.056	78
Dehydrogenase activity (μg TPF $g^{-1}\,h^{-1}$)	10.4	13.7
MBC ($g\,kg^{-1}$)	0.44	3.23

The objective of the present study was to determine the short-term effect of sewage sludge on physical, chemical and biological properties of soil.

2. Materials and methods

2.1. Experimental site and design

A field experiment on “Nutrient Recycling Potential of Organic Wastes for Crop Productivity and Soil Health” is continuing since October, 2010 with different rate of sewage sludge in cow pea (*Vigna unguiculata*)–wheat (*Triticum aestivum* L.) rotation in the experimental farm of the Indian Agricultural Research Institute, New Delhi (28°37′N, 77°09′E, 228.7 m above mean sea level). The climate is semi-arid with mean annual rainfall of 750–800 mm, the distribution of which is unimodal with 75–80% rain occurring during the monsoon months (July–August). The soil (typic haplustept) is sandy loam in texture, mild alkaline in reaction (pH 8.4), low in soluble salt and organic matter content and 8–15% (v/v) in available soil water content (Table 1). The experiment was conducted in randomized block design and every treatments and control were replicated twice.

2.2. Treatment

The sewage sludge obtained during the rainy season August, 2010 was used as a source of nutrient for the crop. Four sludge treatment and control were taken for the study purpose. Field plots (3 m × 3 m) are either unammended (control and 100%NPK) or amended with sludge at a rate of 5, 10 and 15 t ha^{-1} on a dry weight basis in every year. In control neither fertilizer nor sewage sludge was applied. Application of 100%NPK means 120 kg nitrogen, 60 kg P_2O_5 and 40 kg K_2O per hectare. Sludge was applied yearly in the month of October and incorporated at 0–15 cm soil layer.

2.3. Bulk density, and size distribution of soil aggregate

Cylindrical cores (6 cm diameter, 5 cm height) were used to collect intact soil samples from 0–15 and 15–30 cm depths to measure bulk density of the soil (Blake and Hartge, 1986). Fresh soil cores were processed in the laboratory, weighed and then oven-dried at 105 °C till constant weight was obtained. Bulk densities of soil were calculated from the oven dry weight of soil cores and the volume of cores. Soil water content θ (%, v/v) at the time of sampling was determined from the difference of wet and dry bulk density.

Soil samples were prepared in the laboratory by carefully breaking larger clods (field moist soil) by hand into smaller segments along natural cleavage and then air-dried, passed through 8 mm sieve, and wet-sieved through a collection of sieves in the decreasing order of arrangement (4, 2, 1, 0.5, 0.25 and 0.1 mm size) following the procedure as laid out by Yoder (1936). During wet sieving, the set of sieves were oscillated vertically with an average speed of 30 cycles min^{-1} for 5 min, and the aggregates retained on each sieve were transferred to a set of pre-weighed beakers, oven-dried at 60 °C for 24 h and weighed. These six nested sieves were finally clubbed to two aggregate size classes namely, (>0.25 mm) macro-aggregates and micro-aggregates (<0.25 mm).

For obtaining the sand-free aggregates in each size class, the quantity of sand having diameter greater than the lower limit of each size class range were subtracted from the mass of total aggregates collected on each sieve (Kemper and Rosenau, 1986). The respective sand content was determined through dispersion of a sub-sample (~1.5–2 g) retained on each sieve using 0.1 mol L^{-1} NaOH (Whalen et al., 2003). The aggregate stability was expressed by:

Mean weight diameter (MWD) of water stable aggregates (Kemper and Roseneau, 1986)

as: MWD = Σ (xi wi)where xi = mean diameter of a given size fraction (mm) and wi = the proportion of soil aggregates in the respective size fraction ($g\,g^{-1}$).

2.4. Dehydrogenase activity and microbial biomass carbon (MBC)

Determination of dehydrogenase activity in soil was done by the method given by Klein et al. (1971). For this purpose 1 g of air dried soil sample was saturated with 0.2 ml of 3% triphenyl tetrazolium chloride (TTC) solution. After 24 h of incubation period at a temperature of 28 ± 0.5 °C, 10 ml of methanol was added and shaken vigorously. The clear pink colour supernatant was withdrawn after 6 h and absorbance was measured in spectrophotometer at 485 nm wavelength. The amount of triphenylformazan (TPF) formed in each samples were calculated from the standard curve drawn in range of 10 µg–90 µg TPF ml^{-1}. Dehydrogenase activity is expressed as µg TPF formed per g soil per hour.

Soil microbial biomass of freshly collected sample was measured by the substrate induced respiration (SIR) method (Anderson and Domsch, 1978; Smith et al., 1985) in which 0.5 ml of a 12 g glucose L^{-1} solution was added to moist soil equivalent to 10 g of oven dry soil and incubated for 3 h at 22 °C. Vials were covered for 2 h, flushed with moist air, septa capped and CO_2 in the head space measured by a gas chromatograph after 1 h incubation. The MBC was estimated by using the equation of Anderson and Domsch (1978);

$$x = 40.04y + 0.37$$

where x mg microbial biomass carbon 100 g $soil^{-1}$, y ml CO_2 100 g $soil^{-1}\,h^{-1}$.

2.5. Chemical analysis of soil and sewage sludge

Prior to analysis, soil samples were air-dried and passed through a 2 mm sieve. The principal chemical properties of soil and sludge samples were determined by standard methods (Sparks et al., 1996). In particular, the pH was measured on mixtures of sample: water = 1:2.5; the EC was measured on a 1:5 sample: water mixture; and the organic carbon content was determined by dichromate oxidation of the sample and subsequent titration with ferrous ammonium sulphate (Walkley and Black, 1934). Aggregates obtained from wet sieving were used for determination of aggregate associated organic carbon. The mineralisable N content was obtained by the Kjeldahl method followed by titration