Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 6, No. 5, p. 409-417, 2015
http://www.innspub.net

INNSPUB
RESEARCH PAPER
OPEN ACCESS

Soil aggregate size distribution, stability and carbon content as affected by various levels of municipal solid waste compost

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Article published on May 28, 2015

Key words: Aggregate Size Distribution, Mean Weight Diameter, Aggregate Associated Carbon, Aggregate Stability, Municipal solid waste compost.

Abstract

Abundance of stable soil aggregates is an important indicator of good soil structure for sustainable crop production. Application of municipal solid waste (MSW) compost, due to its higher proportion of stable carbon pools, which serves as persistent binding agent for stabilization of aggregates, may significantly improve soil aggregation. In order to evaluate the effects of varying levels of MSW compost upon the formation, stability and associated carbon content of soil aggregates, a field trial was executed for two years in the dryland Pothwar, Pakistan. The MSW compost was applied at four levels i.e. 0, 0.25, 0.50 and 1 % of soil organic carbon in a randomized complete block design. The MSW compost application affected the stability and carbon concentration of different aggregate size classes at the end of the experimental period although the effect on dry aggregates size distribution was less noticeable. The application of MSW compost at 0.5 % level significantly improved the MWD of wet aggregates and the carbon concentration of macro (2 – 4, 1 – 2, 0.5 – 1 and 0.25 – 0.5 mm) and micro aggregates (0.05 – 0.25 mm).

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Introduction

Soil structure is an important attribute of soil that affects several other properties such as water movement, aeration, penetration resistance etc. A good soil structure is indicated by the abundance of its stable aggregates. Formation of aggregates begins when the mineral particles of soil are joined together by the cementing action of soil organic matter (Six *et al.,* 2000). There is a range of organic carbon components such as microbial biomass carbon, polysaccharides and humic substances that account for the largest, most decomposed and stable part of soil organic matter (SOM), serve as persistent binding force for the stability of aggregates.

Stabilization of aggregates by organic matter (Six *et al.,* 2004) and interactions between aggregative factors and aggregate structures is well documented and it is quite clear that organic carbon acts as a central force for soil structure development. But it is also true that a range of organic carbon components exist such as microbial biomass carbon, polysaccharides and humic substances which influence the mechanisms of aggregate formation and stability. Humic substances account for the largest, most decomposed and stable fraction of soil organic matter (SOM) with chemically complex and ill-defined structure. It serves as a persistent binding agent for stabilization of aggregates. Materials having mature and stable carbonaceous compounds in their composition like MSW compost can serve as a good source for improvement in soil aggregation but the quantities of MSW compost are still to be evaluated for the rehabilitation or conservation of soil structure in dryland agriculture.

The composted products like municipal solid waste (MSW) compost can be a good substitute of farmyard manure for improvement of structural properties of soil (Bresson *et al.,* 2001). The present study was aimed to evaluate the influence of MSW compost applied at different levels on formation, stability and carbon contents of different aggregate size fractions (macro and micro) till two years after application.

Materials and methods

Field experiment

The field study was carried out under the subtropical dry land conditions of Pothwar, northern Punjab, Pakistan, and using fallow-wheat cropping system for two years (2012-13). The soil of experimental location was sandy clay loam, non-saline, calcareous and low in organic carbon (Table 1). The treatments involved application of municipal solid waste (MSW) compost at four levels i.e. 0, 0.25 (62 t ha^{-1}), 0.50 (124 t ha^{-1}) and 1 (248 t ha^{-1}) % of soil organic carbon (SOC) in a randomized complete block design with four replications. The concentration of different carbonaceous compounds and total organic carbon was appreciable in MSW compost (Table 2). The MSW compost application at different levels was carried out during fallow period of first experimental year on the basis of their organic carbon content. Wheat crop (Cv Chakwal 50) was sown as a test crop each year during November, and seed rate of 150 kg ha^{-1}, urea and diamonium phosphate (DAP) as sources of N and P respectively were applied.

Compost Analyses

Total organic carbon (TOC) in MSW compost was measured by wet digestion method (Nelson and Somers, 1982) with a little modification of reducing the sample weight to 0.25 g instead of 1 g, due to high amount of carbon present in the compost samples. Total polysaccharide contents (TPC) were extracted from 1g of compost samples by adding 20 mL distilled water, keeping at 80 °C for 24 hours and then centrifugation at ambient temperature for 25 minutes. The TPC contents of the supernatant were measured colorimetrically (Dubois, 1956). Microbial biomass carbon (MBC) was estimated by the fumigation extraction method using a 0.025 M solution of K_2SO_4 to extract relatively labile organic C from the fumigated and non-fumigated samples (Vance *et al.,* 1987). Organic carbon fractions were measured by extracting humic acid and fulvic acid with NaOH and HCl. The concentration of these fractions was estimated colorimetrically against carbon standards (Swift, 1996). Carbon recovery was calculated by subtracting humic substances (FA + HA) from TOC. The FA/HA ratio was also calculated.

Soil Analyses

The textural analysis of soil was carried out using hydrometer method (Gee and Bauder, 1986). Bulk density was measured using the cylinder method (Blake and Hartge, 1986). Soil moisture content was measured gravimetrically (Gardner *et al.*, 1991). Aggregate size distribution was determined by sieving 750 g of soil through sieves of 8, 4, 2, 1, 0.5, 0.25 and 0.05 mm sizes for 5 min (Chepil, 1962) using the sieve shaker (Octagon D200, Endecotts Limited, London). Aggregate stability was determined by wet sieving of each aggregate fraction obtained from dry sieving in wet sieving apparatus (Eijkelkamp Agrisearch Equipment, The Netherlands). Each aggregate fraction was sieved through sieves having equal mesh diameter as their own sieves. Aggregate stability percentage was calculated by Kemper's aggregate stability formula (Kemper and Koch, 1966).

$$\text{Aggregate stability (\%)} = \left(\frac{\text{weight of aggregates}>0.25\text{ mm} \quad \text{weight of sand}>0.25\text{ mm}}{\text{weight of sample} \quad \text{weight of sand}>0.25\text{ mm}}\right) \times 100$$

(1)

The carbon contents of the different aggregate size fractions after wet sieving and bulk soil was determined by wet digestion method (Walkley, 1947).

Statistical Analyses

Mean weight diameters of the separated dry aggregates and stable aggregates were calculated by using the equation:

$$\text{Mean weight diameter (mm)} = \frac{\sum_{i=1}^{n} \text{diWi}}{\text{Total Mass}} \qquad (2)$$

Where, n is the number of size fractions, d_i is the mean diameter of each size range and w_i is the weight of aggregates in that size range.

Data collected was subjected to two-way Analysis of Variance (ANOVA) using Randomized Complete Block Design (RCBD) taking levels and manures as factors. The means were separated by Least Significant Difference (LSD) test at 5 % level of significance (Steel *et al.,* 1997).

Results

Aggregate size distribution

The variation in distribution of different aggregate size classes by the changing levels of MSW compost was significant in the first year (2012) of application except 0.5 – 1 mm aggregates (Figure 1). In the first experimental year (2012), the amount of macro aggregates (4 – 8 and 2 – 4 mm) was significantly higher in control. The application of MSW compost at 1 % SOC level showed that weight of 1 -2 mm aggregates was improved with valuable significance. And the amount of 0.25 – 0.5 and 0.05 – 0.25 mm aggregates were found significantly higher in all levels as compared to control. The results of first experimental year show that improvement in aggregate formation at the expense of MSW compost levels was found only in smaller aggregate size classes. In the second experimental year, the variation of aggregate size distribution with levels of MSW compost was significant for two of the various aggregate size classes (2 – 4 mm and 0.05 – 0.25 mm). The plots with control and 0.5 % SOC levels have the highest amount of 2 – 4 mm and 0.05 – 0.25 mm aggregates, respectively. The results of both years clearly suggest that MSW compost has not significantly improved the formation of macro aggregates.

Aggregate stability

The variation in stability of different aggregate size classes by the varying levels of MSW compost was significant in the first year (2012) of application (Figure 2). In the first experimental year (2012), the stability of 4 – 8 mm aggregates was significantly improved by the application of MSW compost at 0.5 % SOC level. The application of MSW compost at 1 % and 0.25 % SOC levels improved the stability of 2 - 4 and 1 – 2 mm aggregates, respectively, with valuable significance. The aggregates sized as 0.5 – 1 and 0.25 – 0.5 mm were highly stable in control plots. The stability of micro aggregates (0.05 – 0.25 mm) was significantly higher by the application of all the levels of MSW compost as compared to control.

In the second experimental year (2013), the stability of all aggregate size classes varied significantly with the different levels of MSW compost except 0.25 – 0.5 mm aggregate size class. The application of MSW compost at 0.5 % SOC level significantly enhanced the stability of 4 – 8 and 1 – 2 mm (macro) aggregates. Considering the 2 – 4 mm aggregates, the 0.25 and 1 % levels both improved aggregate stability. Similarly, the SOC levels at 0.5 and 1 % improved the stability of 0.5 – 1 mm aggregates. The stability of micro aggregates (0.05 – 0.25 mm) was found higher with significance by the application 0.25 % SOC level of MSW compost.

Table 1. Characteristics of the experimental soil.

Characteristics	Values
Texture	Sandy clay loam
Sand (%)	56.0
Silt (%)	22.8
Clay (%)	21.2
EC (dS m^{-1})	0.53
Soil pH	7.87
Bulk Density (Mg m^{-3})	1.45
Total Organic Carbon (g $100g^{-1}$)	0.59

Table 2. Concentration of different carbonaceous compounds in the MSW Compost.

Components	Values
Humic acid (g kg^{-1})	14.1
Fulvic acid (g kg^{-1})	4.9
Total polysaccharides (mg kg^{-1})	2.06
Total organic carbon (g kg^{-1})	8.06
Microbial biomass carbon (g kg^{-1})	3.07

Mean weight diameters of dry and wet aggregates

The mean weight diameter (MWD) of dry and wet aggregates was significantly changed with MSW compost levels in both experimental years. In 2012, the MWD of dry aggregates was found significantly higher in control while MWD of wet aggregates increased with the application of MSW compost at 0.25 and 0.5 % SOC levels. In second experimental year, the application of MSW compost at 1 % SOC level and control both have significantly higher values for MWD of dry aggregates. While, the application of MSW compost at 0.5 % SOC level improved the MWD of wet aggregates with valuable significance.

Distribution of carbon within soil aggregates and bulk soil

The carbon concentration in different sized aggregates varied with the levels of MSW compost in all aggregate size classes (Figure 4) except 4 – 8, 2 – 4 and 0.5 – 1 mm aggregates in first experimental year (2012). The application of MSW compost at 0.25 and 0.5 % levels improved the aggregate associated carbon of 1 – 2 and 0.05 – 0.25 mm aggregates, while the carbon concentration of 0.25 – 0.5 mm aggregates was found significantly higher in control plot. In the second experimental year (2013), the effect of MSW compost levels on aggregate associated carbon was significant for all aggregate size classes except 4 – 8 mm. The application of MSW compost at 1 % SOC level significantly improved the carbon concentration of 2 – 4, 0.5 – 1 and 0.25 – 0.5 mm aggregates, while the improvement in carbon concentration of 1 – 2 and 0.05 – 0.25 mm aggregates was observed with the application of 0.5 % and 0.25 % SOC level.

Discussion

It is clearly evident that the MSW compost treatments enhanced the formation of micro aggregates but failed to improve the macro aggregation, over two years of time. On the other hand, the MSW compost dominantly improved macro aggregate stability and the stability of macro aggregates is correlated with soil organic matter content (Douglas and Goss, 1982). Aggregates larger than 0.25 mm diameter are considered as macro aggregates (Xiao *et al.,* 2007). The proportion of water-stable macro aggregates (>1 mm) showed large temporal variation and additional organic matter accumulation in the surface soil provided by compost additions which would lead to increased macro aggregation and be related to the accumulation of particulate organic matter (Angers and Caron, 1998). At the time of application MSW compost had appreciable amounts of humic acid (14.08 g kg^{-1}) and microbial biomass carbon (3.07 mg kg^{-1}). Higher microbial biomass carbon contents might have increased the microbial activity when applied in soil, and such conditions favors aggregate formation (Six *et al.,* 2004). Such substances are also important transient binding agents for soil particles, thus improved the aggregate stability when applied into the soil. Active carbon fractions like microbial biomass carbon and polysaccharides are more sensitive to the changes in soil quality as compared to whole soil organic matter (Allison *et al.,* 2008). Organic material addition improves the relative abundance of macro aggregates at the expense of other fractions and also results in higher C in macro aggregate fractions (Das *et al.,* 2014). The relationship between mean weight diameters and soil organic matter levels also showed a positive correlation (Sardo *et al.,* 2013). Aggregate stability is believed to be improved by TOC, biota, clay and carbonates which act as binding agents and as a central force in the stabilization of aggregates. Organic matter plays the fundamental role in processing soil particles to form aggregates and also by decreasing the amount of non-complexed clay available for cementation upon drying of aggregates (Schjønning *et al.,* 2012).

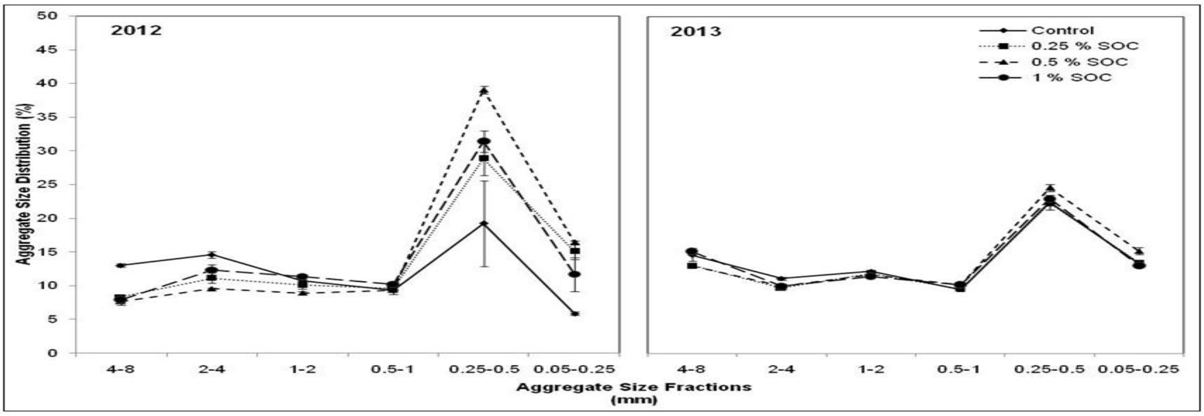

Fig. 1. Aggregate size distribution variation by the different levels of MSW compost in two years of experimental period.

These results suggest that the composted manures like MSW compost applied at higher levels improved the carbon distribution within different large sized aggregates in first year of application. The macro aggregate classes (2 – 4 mm, 1 – 2 mm, 0.5 – 1 mm and 0.25 – 0.5 mm) and micro aggregates (0.05 – 0.25 mm) improved their carbon contents significantly by the application of MSW compost at different levels in second year of application. And it can be deduced that the application of MSW compost helped to retain the carbon contents for longer time which suggests that composted products can play effective role in conserving the carbon within the soil aggregates.

The sequestration of carbon within soil aggregates is important for improvement in soil structural properties and the effect of different manure treatments on SOC in soil have been conducted to develop better ways for enhancing SOC (Banger *et al.,* 2009). The application of composted manures can improve soil aggregation and aggregate associated carbon (Rasool *et al.,* 2008).

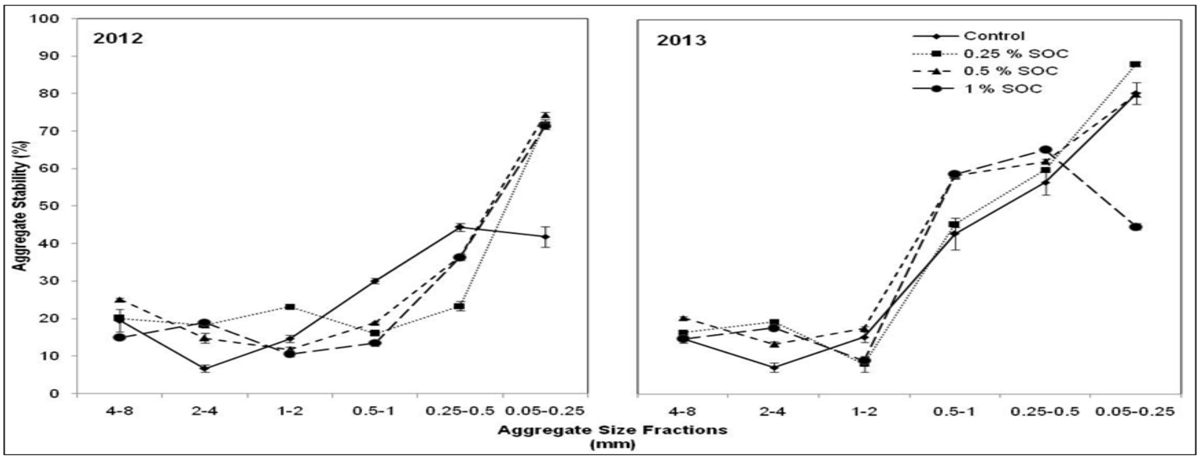

Fig. 2. Variation in stability of different aggregate size classes by the different levels of MSW compost in two years of experimental period.

Distribution of carbon within aggregates by manure application was increased with the aggregate size (Bhattacharyya *et al.,* 2009). Presence of stable carbon fractions can lead to an enhanced SOC buildup by increasing formation of macro aggregates. Organic manures accumulate within macro aggregates in the form of particulate organic matter (Kong *et al.,* 2005). However, in this case carbon accumulation in macro aggregates and in whole soil mainly depends on the organic carbon concentration in the aggregated silt + clay fractions as compared to the presence of stable or unstable POM within macro aggregates.

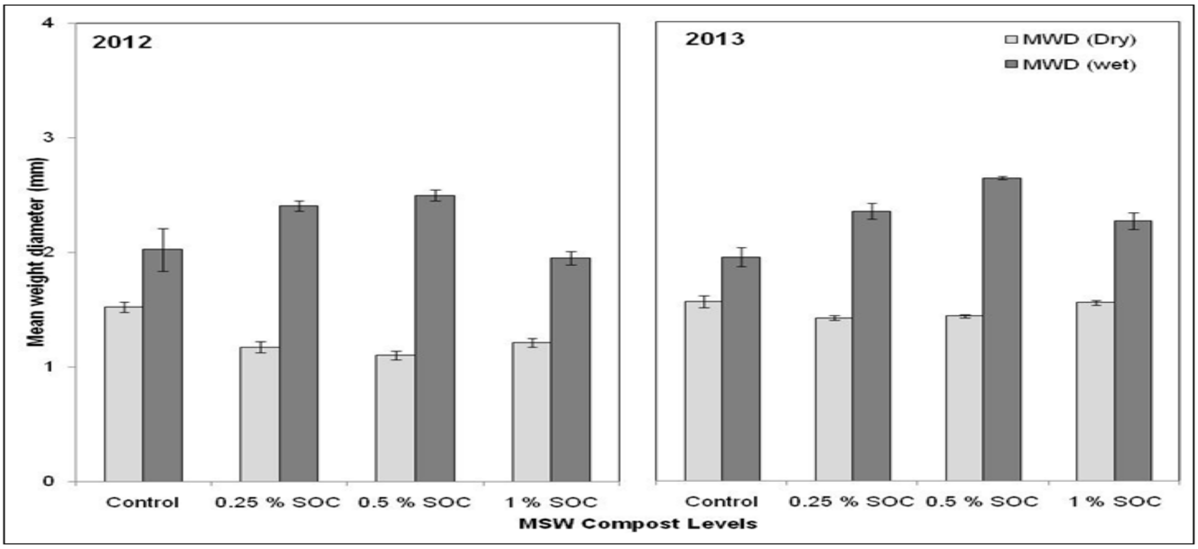

Fig. 3. Variation in mean weight diameters of dry and wet aggregates by the different levels of MSW compost in two years of experimental period.

MSW Compost application significantly increased carbon concentration in soil macro aggregates at the expense of micro aggregates and the aggregated silt + clay fraction. Compost application increases carbon concentration in all aggregate size fractions in loamy sand and sandy loam (Liao *et al.,* 2006). Silt and clay particles provide various sites for carbon through strong ligand exchange and polyvalent cation bridging and organic materials having high microbial activity enhances polysaccharide contents, which accumulate in aggregated silt + clay fractions (Jolivet *et al.,* 2006). Carbon concentration in the un aggregated fraction may not be stable, and can be greatly affected by management practices. The associated carbon in the micro aggregates (0.05 – 0.25 mm) is likely to play a key role in the formation of macro aggregates by increasing the carbon content. As discussed above, aggregates in the different treatments had significantly improved associated carbon concentrations in the aggregated silt + clay fraction and micro aggregates.

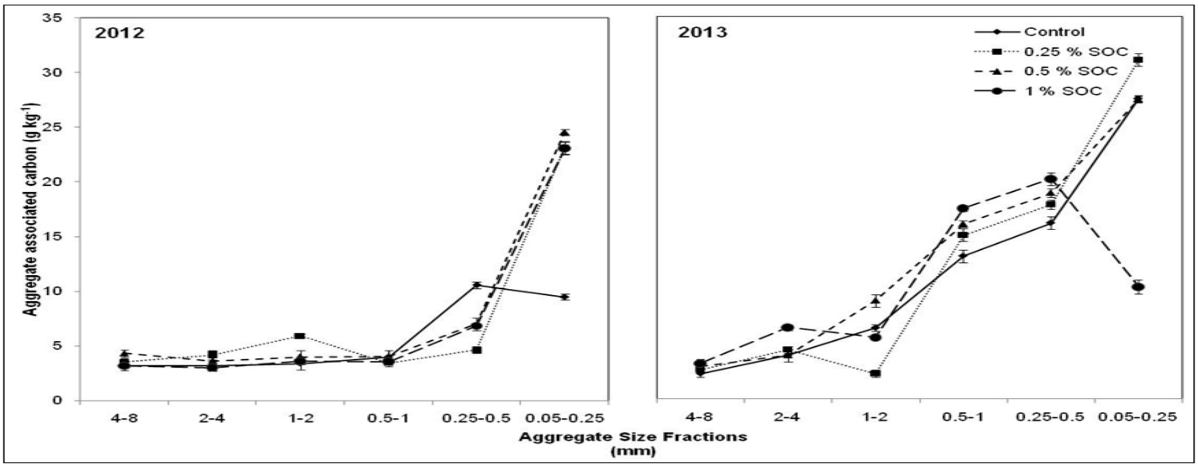

Fig. 4. Carbon concentration variation in various aggregate size classes by the different levels of MSW compost in two years of experimental period.

Conclusions

It is clearly evident that the MSW compost treatments enhanced the formation of micro aggregates but failed to improve the macro aggregation, over two years time. The stability of aggregates reflected by MWD was significantly improved with the application of MSW compost at 0.5 % SOC level. The accumulation of carbon in macro aggregates was mainly associated to an increase in carbon content of the micro aggregates. Thus the MSW compost can be an excellent source for carbon sequestration and rehabilitation of structurally degraded soils for shorter time period.

Acknowledgement

The financial assistance by Higher Education Commission (HEC), Pakistan is highly accredited.

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