Pedosphere **27**(2): 328–337, 2017
doi:10.1016/S1002-0160(17)60320-5
ISSN 1002-0160/CN 32-1315/P

Published by Elsevier B.V. and Science Press

PEDOSPHERE

www.elsevier.com/locate/pedosphere

Changes in Soil Organic Carbon After Five Years of Biowaste Compost Application in a Mediterranean Vegetable Cropping System

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(Received December 25, 2015; revised December 28, 2016)

ABSTRACT

Biowaste compost can influence soil organic matter accumulation directly or indirectly. A 5-year experiment was conducted to assess the influence of biowaste compost on the process of soil aggregation and soil organic carbon (SOC) accumulation in a Mediterranean vegetable cropping system. The study involved four treatments: biowaste compost (COM), mineral NPK fertilizers (MIN), biowaste compost with half-dose N fertilizer (COMN), and unfertilized control (CK). The SOC stocks were increased in COM, COMN, and MIN by 20.2, 14.9, and 2.4 Mg ha^{-1} over CK, respectively. The SOC concentration was significantly related to mean weight diameter of aggregates (MWD) ($P < 0.05$, $R^2 = 0.798\,4$) when CK was excluded from regression analysis. Compared to CK, COM and COMN increased the SOC amount in macroaggregates (> 250 µm) by 2.7 and 0.6 g kg^{-1} soil, respectively, while MIN showed a loss of 0.4 g kg^{-1} soil. The SOC amount in free microaggregates (53–250 µm) increased by 0.9, 1.6, and 1.0 g kg^{-1} soil for COM, COMN, and MIN, respectively, while those in the free silt plus clay aggregates (< 53 µm) did not vary significantly. However, when separating SOC in particle-size fractions, we found that more stable organic carbon associated with mineral fraction < 53 µm (MOM-C) increased significantly by 3.4, 2.2, and 0.7 g kg^{-1} soil for COM, COMN, and MIN, respectively, over CK, while SOC amount in fine particulate organic matter (POM) fraction (53–250 µm) increased only by 0.3 g kg^{-1} soil for both COM and COMN, with no difference in coarse POM > 250 µm. Therefore, we consider that biowaste compost could be effective in improving soil structure and long-term C sequestration as more stable MOM-C.

Key Words: aggregates, carbon sequestration, mineral-associated organic matter, particle-size fraction, particulate organic matter, soil structure

Citation: Baiano S, Morra L. 2017. Changes in soil organic carbon after five years of biowaste compost application in a Mediterranean vegetable cropping system. *Pedosphere*. **27**(2): 328–337.

INTRODUCTION

Decreases in soil organic matter (SOM) contents, through the intensification of tillage and crop cycles, lead to soil structure deterioration (Gobin *et al*., 2011), and, more generally, to soil fertility loss (Puget *et al*., 2000). In Italy, 23% of agricultural lands have less than 1% soil organic carbon (SOC) in the 0–30 cm layer. According to the EU Soil Thematic Strategy, soil fertility can degrade below the SOC threshold of 2%, and 74% agricultural soils in Southern Europe suffer from soil fertility degradation due to low SOC (Jones *et al*., 2004).

The production of compost by source-separated municipal food waste (biowaste compost) has reached 1.2 million Mg in Italy and this amount represents a valuable source of organic carbon (C) to exploit in order to counteract the soil degradation triggered by the organic matter depletion (Ghermandi *et al*., 2011). As an alternative to incineration, biowaste compost can be used in agriculture to restore degraded soil and simultaneously reduce CO_2 emission by storing stable C in soils.

Biowaste compost can affect SOM accumulation directly through its application to soil or indirectly through altering crop growth and returning crop residues. The SOM accumulation can improve soil structure which in turn exerts a feedback on SOM stock and dynamics (Oades, 1988). The storage and long-term stabilization of organic C (OC) input by organic amendment, in fact, are determined by its relationship with soil particles and aggregates (Marschner *et al*., 2008; Kleber *et al*., 2011; Schmidt *et al*., 2011), which are the base units of soil structure. Therefore, a greater knowledge on how SOM can stabilize soil structure and how soil structure can provide a physical protection for SOM is fundamental for a correct and more profitable use of soil organic amendment.

The relationship between SOM and soil structure dynamics in soils where SOM is the main binding ag-

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ent, as in temperate soils, was described by Tisdall and Oades (1982) in a hierarchical model, according to which temporary, transient, and persistent pools of SOM are associated with macroaggregates (> 250 μm), free microaggregates (53–250 μm), and free silt plus clay aggregates (< 53 μm) (free-SC), respectively. According to further developments of the hierarchical model, the particulate organic matter (POM) has a key role as nucleation points for microaggregates and in the formation of macroaggregtes (Oades and Waters, 1991; Jastrow and Miller, 1997; Six *et al.*, 1998), while long-term C sequestration within aggregates is mainly as mineral-associated organic matter (MOM) (Denef *et al.*, 2004). According to hierarchical model, macroaggregates contain more labile and less highly processed SOM than microaggregates (Elliott, 1986). However, because microaggregates are formed within macroaggregates (Oades, 1984; Angers *et al.*, 1997; Six *et al.*, 2002), the macroaggregation is in any case the first step for long-term sequestration of fresh OC input.

On the basis of these considerations, as suggested by Carter *et al.* (2002), the characterization of organic matter storage in temperate soils would be mainly a function of three pools experimentally obtainable by physical fractionation: MOM, POM, and the organic matter residing in stable aggregates.

Previous studies carried out in Mediterranean area showed that the application of compost at 45 Mg ha^{-1} dry weight resulted in the lowest C conversion efficiency in soil compared to the other two compost application doses of 15 and 30 Mg ha^{-1} dry weight (Pagano *et al.*, 2008; Morra *et al.*, 2010). The integration of N fertilizers to the lowest dose of compost (15 t ha^{-1}) appeared to have variable effects on the C conversion efficiency. The repeated application of compost, complying to the restrictive limits for trace elements fixed by Italian Legislative Decree No. 75/2010, did not increase total heavy metals in soil, their bioavailability, and overall, their uptake in plants (Baldantoni *et al.*, 2010; Baldantoni *et al.*, 2013). The effects of biowaste compost application on SOM pools of different turnover time, however, are not well documented in Mediterranean area.

A sandy-loam soil with low content of SOC in a Mediterranean agro-ecosystem devoted to vegetable crops was used to investigate the effects of long-term biowaste compost amendment on the mean weight diameter (MWD) and distribution of water-stable aggregates, as well as total SOC storage and SOC distribution in water-stable aggregates and particle-size fractions.

MATERIALS AND METHODS

Site description

Soil samples were taken from a Mediterranean open field vegetable cropping system in the Experimental Farm of Council for Agricultural Research and Analysis of Agricultural Economics (CREA) in Scafati, Campania Region, Italy (40°44′33″ N, 14°30′28″ E, 9 m above sea level). The soil was classified as a Vitric Andosol Calcaric according to World Reference Base classification, and had a sandy loam texture with sand, silt, and clay contents of 465, 508, and 44 g kg^{-1}, respectively. The soil had 11 g kg^{-1} SOC, 1.25 Mg m^{-3} bulk density, and a pH (H_2O) of 8.4. Information on the main agronomic management of the vegetable cropping system of the study site is shown in Table I.

Experimental description

The biowaste compost used, obtained from the organic fraction separately collected from municipal solid wastes, was produced in a composting plant in Perugia, Italy. Its chemical, physical, and microbiological characteristics complied with the threshold values fixed in the Italian Legislative Decree No. 75/2010; accordingly it can be commercialised as a soil improver for agriculture. Basic biowaste compost properties were as follows (dry matter basis): dry matter, 70%; pH, 7.9; OC, 280 g kg^{-1}; humic and fulvic acids, 142 g kg^{-1}; total N (TN), 21 g kg^{-1}; organic N, 90% of TN; and C/N ratio, 13.3.

This study was carried out from May 2007 to April 2012. There were four fertilizer treatments consisting of biowaste compost (dry matter basis) amendment of 30 Mg ha^{-1} during the first three years and 15 Mg ha^{-1} from the fourth year (COM), mineral NPK fertilization (MIN), biowaste compost (dry matter basis) amendment of 15 Mg ha^{-1} integrated with half of the mineral N supplied in MIN (COMN), and an unfertilized control (CK). The OC inputs from biowaste compost and/or crop residues for each treatment are shown in Table II.

For MIN, fertilizer N at 140 kg N ha^{-1} and 100 kg N ha^{-1} was applied to eggplant (*Solanum melongena* L.) and endive (*Cichorium endivia* L.) cultivated from May 2007 to March 2010, respectively. Eggplant received 40% of the whole dose in pre-transplant as Entec® (26% N) (ammonium sulphonitrate + 3,4-dimethylpyrazole phosphate (an inhibitor of nitrification)), and the remaining part of fertilizer N was applied through fertigation during crop growth as ammonium nitrate (34%). With regarding to endive, the