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The role of organic/bio–fertilizer amendment on aggregate stability and organic carbon content in different aggregate scales

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ABSTRACT

This study investigated the effects of different organic and bio–fertilizer (alone or in combination) applications on aggregate stability and organic carbon (OC) content in macro (2–1 mm) and micro (0.25–0.050 mm) aggregate sizes of clay loam (Typic Xerofluvent) textured soil. In addition, correlation between OC content and aggregate stability was determined. The study was conducted as a pot experiment under greenhouse conditions and was arranged in a completely randomized design with three replications. The treatments were: control (no fertilizer) (C), inorganic fertilizer (15:15:15 compound fertilizer + ammonium nitrate, 33% N) (F), mycorrhizal fungi (*Glomus* spp.) (M), microalgae (*Chlorella* spp.) (A), bacteria (*Bacillus megaterium* KBA–10 + *Pantoea agglomerans* RK–134 + *Pseudomonas fluorescens* FDG–37) (BMF), bacteria (*Bacillus subtilis* PA1 + *Paenibacillus azotofixans* PA2) (BCP), vermicompost (V), vermicompost + mycorrhizal fungi (VM), vermicompost + microalgae (VA), vermicompost + bacteria (VBMF) and vermicompost + bacteria (VBCP) applied in 90 days incubation period. At the end of the 90-day incubation period, organic and bio–fertilizer amendments had an increasing impact on aggregate stability and OC content in macro– and micro– aggregate scale. Especially, bio–fertilizers in combination with vermicompost mostly had stronger effects on stability and OC content of aggregates of both size classes in comparison with control and bio–fertilizer treatments alone. In addition, significant ($p < 0.05$) and positive correlations were observed between stability and OC contents of macro (2–1 mm) and micro (0.25–0.050 mm) aggregates size classes in each treatment.

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1. Introduction

In order to enhance the productive capacity and sustainable use of soils, it is important know the physical, chemical and biological properties of the soil and manage the soil taking into account these properties. Applications that improve soil physical, chemical and, especially, biological properties have significant roles in increasing soil fertility.

Good growth of plants in the soil environment is associated with the physical characteristics of the soil. Thus, it is important to use materials of organic and biological origin, in order to improve the soil's physical properties and ensure its sustainable use. Soil structural development, which is one of the physical properties of the soil, is very important in terms of soil–plant–water relationships and soil conservation. Positive or negative changes in soil fertility parameters are significantly related to biological factors in soil ecosystem. Soil health is a state of a soil meeting its range of ecosystem functions as appropriate to its environment. Soil health depends on soil biodiversity, and it can be improved via different organically or biological soil additives. In addition, soil health is closely associated with plant and environmental health, and food safety and quality (Parr et al., 1992; Halvorson et al., 1997; Nielsen and Winding, 2002). On the other hand, a soil that has a high level of organic matter, aggregate stability and biological activity and in which plant roots can move and water can be infiltrated on the surface easily is characterized as a fertile soil (Lewandowski and Zumwinkle, 1999).

An aggregate is a group of primary particles that cohere to each other more strongly than to other surrounding soil particles (Kemper and Rosenau, 1986). Soil aggregates are classified into three groups by size: (i) clay aggregates smaller than 2 μm (ii) micro-aggregates ranging between 2 and 250 μm (iii) macro-aggregates larger than 250 μm (Tisdall and Oades, 1982). In addition, large aggregates (>2000 μm) were hypothesized to be held together by a fine network of roots and hyphae in soils with high SOC content (>2%), while 20–250 μm aggregates consist of 2–20 μm particles, bonded together by various organic and inorganic cements. Water–stable aggregates of 2–20 μm size, in turn, consist

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of <2 μm particles, which are an association of living and dead bacterial cells and clay particles (Tisdall and Oades, 1982). As pointed out by Bronick and Lal (2005), soil aggregates are a main component of soil structure, which is a term used to describe the size, shape and arrangement of solids and pores, hence affecting pore continuity, water holding capacity and infiltration (Leifheit et al., 2014). Soil structural stability refers to the resistance of soil to structural rearrangement of pores and particles when exposed to different stresses (e.g. soil tillage, trampling/compaction, and irrigation) (Krull et al., 2003).

Bio–fertilizer is defined as a substance containing living microorganisms which, when applied to seed, plant surfaces or soil, colonizes the rhizosphere or the interior of the plant and promotes growth by increasing the supply or availability of primary nutrients to the host plant (Vessey, 2003). There are various studies investigating the effects of bio–fertilizer applications on aggregate stability and organic carbon content of soils (Bossuyt et al., 2001; Ambriz et al., 2010; Ganesh et al., 2011; Graf and Frei, 2013). Different results have been obtained in many different studies concerning the effects of bio–fertilizer applications on soil aggregates. Generally, it is assumed that arbuscular mycorrhizal fungi (AMF) and other fungi have an effect on the formation and stabilization of macro-aggregates (>250 μm), and bacteria, polysaccharides and organo–mineral complexes have an effect on micro-aggregates (<250 μm) (Rillig and Mummey, 2006; Leifheit et al., 2014). For example, mycorrhizal fungi contribute to soil structure by (1) growth of external hyphae into the soil to create a skeletal structure that holds soil particles together; (2) creation by external hyphae of conditions that are conducive for the formation of micro-aggregates; (3) enmeshment of micro aggregates by external hyphae and roots to form macro aggregates; and (4) directly tapping carbon resources of the plant to the soils (Miller and Jastrow, 2000). It is reported that this direct access influenced the formation of soil aggregates, because soil carbon is crucial to form organic materials necessary to cement soil particles (Mahdi et al., 2010). In addition, AM fungi produce glomalin (12–45 mg cm^{-3}), a specific soil protein, whose biochemical nature is still unknown. Glomalin is quantified by measuring several glomalin related soil protein (GRSP) pools (Rillig, 2004). Glomalin has a longer residence time in soil than hyphae, allowing for a long persistent contribution to soil aggregate stabilization. The residence time for hyphae is considered to vary from days to months (Staddon et al., 2003) and for glomalin from 6 to 42 years (Rillig et al., 2001). Glomalin is considered to stably glue hyphae to soil. The mechanism is the formation of a 'sticky' string-bag of hyphae which leads to the stability of aggregates (Mahdi et al., 2010).

Some researchers noted that there is a significant relationship between the organic carbon threshold value and soil productivity parameters. There are several studies showing that organic material applications mostly increase the organic carbon content of soils significantly (Yu et al., 2012; Zhou et al., 2013; Zhang et al., 2014), and also studies with different findings regarding the effects of bio-fertilizer applications on the organic carbon content of soils (Jakobsen and Rosendahl, 1990; Caravaca et al., 2002; Huang et al., 2013). Organic matter is one of three soil components that are crucial for its physicochemical properties, such as its sorptive and buffer abilities as well as its biodiversity and biological activity. Specific organic matter fractions differ in mobility. The dissolved organic matter is the most mobile fraction of organic matter. Dissolved organic matter is the product of the transformation and decomposition of carbon compounds that are built into soil organic material. The content, production, and consumption of dissolved organic matter are closely related to soil microbial activity. Microbial activity not only contributes to an increase of dissolved organic substances but also affects the chemical composition of dissolved organic matter (Dębska et al., 2016). On the other hand, Howard and Howard (1990), who estimated that the threshold value for most soils was at 2% SOC (equivalent to 3.4% SOM), below which most soils are prone to structural destabilization and crop yields, are reduced.

The objective of this paper is to evaluate the effects of bio–fertilizers with different contents and vermicompost applications on aggregate stability and organic carbon content in macro- and micro-aggregate scale, and the relationships between organic carbon and aggregate stability in a clay loam soil (Typic Xerofluvent) where maize is cultivated in a conventional agricultural system.

2. Material and methods

2.1. Material

Clay loam textured soil samples was collected, in disturbed from between the 0 and 30 cm depth of the A–Horizon of an alluvial (Typic Xerofluvent) (Soil Survey Staff, 2010) plain of the Antalya region (30°52′30″ and 30°53′45″ E; 36°52′30″ and 36°55′50″ N) in the southwest Turkey. This selected soil group (subgroup) is one of the most commonly found soils in the region, and fluvial sediments are found near the river Aksu. Maize is cultivated conventionally in the area where the soil samples were taken. The characteristics of the soil samples were analyzed with samples that had been air–dried and passed through a 2–mm sieve. The results are presented in Table 1.

As bio–fertilizers, BM–Megafluve, BM–Coton–Plus, Shubhodaya, Emek Microbial Liquid Fertilizer were used along with Green–PIK, an organic fertilizer vermicompost obtained from worms (*Eisenia fetida*). The vermicompost is the end product produced by a "Staratel" earthworm population in the process of treating/enriching especially prepared cattle manure compost. These fertilizers were procured from different commercial companies. BM-Megafluve, BM–Coton–Plus and Emek microbial liquid fertilizers are produced and sold in Turkey under the name; soil improvers and used by farmers. Some properties and contents of the organic and biologic additives as provided by their manufacturers are given in Tables 2 and 3.

Table 1
Some physicochemical properties of soil samples taken from land before setting the experiment.

Properties	Values
pH (1:2.5)	7.49
EC (dS m^{-1})	0.36
$CaCO_3$ (%)	32.67
Sand (2–0.05 mm) (%)	22.92
Silt (0.05–0.002 mm) (%)	44.36
Clay (<0.002 mm) (%)	32.72
Texture	Clay Loam
Field capacity (%)	28.71
Wilting point (%)	16.30
Available water (%)	12.41
Bulk density (g cm^{-3})	1.21
CEC (meq 100 g^{-1})	17.03
OM (%)	1.65
Total N (%)	0.10
Exchangeable K ($cmol_c$ kg^{-1})	0.420
Exchangeable Ca ($cmol_c$ kg^{-1})	23.93
Exchangeable Mg ($cmol_c$ kg^{-1})	1.65
Exchangeable Na ($cmol_c$ kg^{-1})	0.042
Available P (mg kg^{-1})	13.95
Available Fe (mg kg^{-1})	13.20
Available Zn (mg kg^{-1})	0.26
Available Mn (mg kg^{-1})	14.58
Available Cu (mg kg^{-1})	2.07

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