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Assessment of the role of agricultural wastes in aggregate formation and their stability

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ABSTRACT

The purpose of this study was to evaluate the effects of three agricultural processing wastes (APWs) on aggregate formation and aggregate stability in a sandy loam textured soil (Typic Xerofluvent) in Antalya, Turkey. The effects of APW applications on aggregate formation and aggregate stability were observed for different aggregate size groups (>4; 4–2; 2–1; 1–0.5; 0.5–0.25; 0.25–0.050 and <0.050 mm). Sugar Beet Pulp (SBP), Apple Pomace (AP) and Cotton Gin Waste (CGW) were applied to soil as fresh material (dry weight basis 0, 10, 20 and 40 t ha^{-1}), and a greenhouse pot experiment was conducted using a completely randomized design with five replicates of each treatment. The study consisted of two periods. The first period (P1) consisted of a six-month incubation period (1st sample period). The second period (P2) is a six-month period and includes an eight-week green bean (*Phaseolus vulgaris* L.) growing process (2nd sample period). At the end of the first six months and fourteen months in total, aggregate formation and aggregate stability were determined and their correlation to different C sources was explained. At the end of the experiment, formation of aggregates was increased with increase in the application level of organic wastes in particular intermediate aggregates. Increase in the incubation time significantly enhanced the formation of particular macroaggregates. Soil aggregate stability of all aggregate sizes generally increased with the increasing in the level of implementation. In addition, incubation time effects on aggregate stability for macroaggregates were not significant, but significant for macro and microaggregates.

1. Introduction

Operating through various production models on a total area of approximately 26 million hectares, the agricultural sector significantly contributes to the Turkish economy. The animal and plant production areas of the agricultural sector produce considerable amounts of agricultural waste, which pose very serious environmental problems. Such wastes, which are usually burnt or disposed of in open dumps, threaten the environment. Besides, the disposal of wastes through such means results in the loss of plant nutrient resources and carbon. For example, the total annual amount of agricultural waste in Turkey is 50–65 Mtep (Başçetinçelik et al., 2005). This value corresponds to nearly double of Turkey's annual oil imports (Anonymous, 2013a).

Agricultural processing wastes have a high potential for agricultural use. As many organic matter rich wastes are generated via a multitude of industrial and food manufacturing processes, there is much exploration of the use of different types of unconventional organic waste materials for the joint purpose of waste disposal and soil conditioning, including stabilization against erosion (Graber et al., 2006). In Turkey, 2,486,088 tons of sugar beet pulp (Anonymous, 2013b), 43,000 tons of apple pulp (Canan, 2008) and 90,000–100,000 tons of cotton pulp (Alkaya, 2010) are produced and they play an important role in agricultural production.

The loss of soil organic matter (SOM) increases the possibility of erosion by wind and water, decreases overall soil quality or fertility, and ultimately reduces agricultural soil sustainability. Organic materials are important soil additives, particularly in semiarid regions (such as Turkey) where there is low input of organic materials. Use of organic matter in arid and semi-arid regions, where soil organic matter (SOM) content is rather low, will contribute to enrich the soil with SOM. The gradual and rapid decrease in SOM content in soils under intensive agriculture practices, especially in those having hot climates, may lead to the deterioration of their chemical and physical properties (Flaig et al., 1977).

Soil organic matter (SOM) or soil organic carbon (SOC) are known to play very important roles in the development of physical,

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chemical and biological soil characteristics. In addition, organic matter is one of the key components to good tilth. Cooperband (2002) stated that when a soil has plenty of spaces for air passage, holds water well without becoming too wet, is not compacted, and has a good physical structure for plant roots to grow and explore, we say it has good soil tilth.

Aggregate formation and stabilization of soil, along with soil organic matter (SOM) or soil organic carbon (SOC), are considered critical indicators for the health, quality and sustainable use of the soil. The analysis of soil aggregation is important in a variety of applications. Aggregate stability and size information may be used to evaluate or predict the effect of various agricultural techniques, such as tillage and organic matter additions, and erosion by wind and water (Nimmo and Perkins, 2002). Soil aggregate formation has an important role concerning seed–soil relation, hydraulic conductivity, root respiration and elongation, the diffusion of gases within the soil and plant growth. The degree of surface soil aggregation will determine how tightly the soil particles are held during rain or wind storms. Stable soil aggregates resist movement by wind or water because they are larger than primary particles of silt or clay. Soil pores created by aggregation also promote water infiltration, thereby reducing runoff and the likelihood that soil particles will be transported with the water (Cooperband, 2002).

The concept of aggregation as a process involving different organic binding agents at different scales was pioneered by Tisdall and Oades (1982). 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. Microaggregates are the structural units within the soil where SOM is predominantly stabilized in the long term and the balance between formation and breakdown of macroaggregates determines macroaggregate turnover, having an indirect effect on microaggregate formation (Six et al., 2004). Water-stable aggregates in soil prevent erosion, which is one of the main factors of soil degradation (Dinel et al., 1991). Water-stable aggregates of 2–20 μm size, in turn, consist of <2 μm particles, which are an association of living and dead bacterial cells and clay particles (Oades and Waters, 1991).

Agricultural management practices including crop rotation, residue management, and manure application, influence the amount of C entering an agroecosystem and subsequently affect soil organic carbon (SOC) stabilization and soil fertility (Stewart et al., 2008). In fact, most studies report a linear increase of aggregate stability and aggregate size with increasing levels of SOM or SOC. Addition of SOM effectively increases soil aggregate stability (Tisdall and Oades, 1982; Carter and Stewart, 1996). As the previous studies have shown, organic applications generally result in an increase in soil structural stability and aggregate formation (Ekwue, 1990; Haynes and Swift, 1990; Nelly, 2000). Kay and Angers (1999) reported that a minimum of 2% SOC was necessary to maintain structural stability and observed that if SOC content was between 1.2 and 1.5%, stability declined rapidly. Boix-Fayos et al. (2001) showed that a threshold of 3–3.5% SOC had to be attained to achieve increases in aggregate stability; no effects on aggregate stability were observed in soils below this threshold.

Different types of organic matter perform different functions at different times during the aggregate formation and stabilization. Differences in the composition of organic materials, such as C:N ratio, cellulose and lignin content, is an important factor in aggregate formation and stability. The effect of readily biodegradable substances on aggregates is quick and temporary. Glucose-like components acted strongly in aggregate formation for the first 2–3 weeks of the experiment after which the effect declined (Oades et al., 1989).

The objective of this paper was to evaluate the role of Sugar Beet Pulp (SBP), Apple Pomace (AP) and Cotton Gin Waste (CGW), as soil applications at different rates and periods, on soil aggregate formation and aggregate stability in a Typic Xerofluvent soil.

2. Materials and methods

2.1. Materials

Sandy loam textured soil was collected from 0 to 25 cm of A-Horizon of an alluvial (Typic Xerofluvent) plain of the Antalya region in south-western Turkey. This selected soil is one of the most widely distributed land area, and fluvial sediments are found near the river Aksu. The characteristics of soil were analyzed in samples that had been air-dried and passed through a 2-mm sieve. The results are given in Table 1.

Sugar Beet Pulp (SBP), Apple Pomace (AP) and Cotton Gin Waste (CGW) were obtained from sugar beet, apple and cotton processing companies in the Mediterranean Region. Analyzed general properties of the organic additives used are given in Table 2.

In the study, the green beans (*Phaseolus vulgaris* L.) were used as indicator plants, trade name GINA, in order to monitor the application of research results.

2.2. Methods

The study consists of two periods. The first period (P1) includes a six-month incubation period (1st sample period). The second period (P2) includes the second six months and an eight-week green bean (*P. vulgaris* L.) growing process (2nd sample period).

At the end of P1 and P2 soil samples were collected and the effects of agricultural processing wastes (APWs) on aggregate formation and stability were identified. The experiment was carried out in a completely randomized plot design with five replications and conducted under greenhouse conditions as a pot experiment. Ten (10 kg) kilograms of air-dried and sieved (4 mm) soil samples mixed with organic matter was placed in each pot. On a dry weight basis, four levels of APW (0, 10, 20 and 40 t ha^{-1}) were applied to soil in the pots (Table 3), and then incubated for fourteen months.

Table 1
Selected physicochemical properties of soil.

Properties	Values
pH (H_2O)	7.80
EC (dS m^{-1})	0.10
$CaCO_3$ (%)	48.69
Sand (2–0.05 mm) (%)	76.4
Silt (0.05–0.002 mm) (%)	4.6
Clay (<0.002 mm) (%)	19.0
Texture	Sandy loam
Field capacity (%)	11.72
Wilting point (%)	4.67
Available water (%)	7.05
Bulk density (Mg m^{-3})	1.67
CEC (cmol$_c$ kg^{-1})	12.29
OM (%)	0.92
Total N (%)	0.049
Exchangeable K (cmol$_c$ kg^{-1})	0.140
Exchangeable Ca (cmol$_c$ kg^{-1})	19.40
Exchangeable Mg (cmol$_c$ kg^{-1})	1.44
Exchangeable Na (cmol$_c$ kg^{-1})	0.16
Available P (mg kg^{-1})	10.52
Available Fe (mg kg^{-1})	9.21
Available Zn (mg kg^{-1})	1.70
Available Mn (mg kg^{-1})	7.11
Available Cu (mg kg^{-1})	1.10