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The impact of organic amendments on soil hydrology, structure and microbial respiration in semiarid lands

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ABSTRACT

Few studies have considered the effect of organic amendments on soil microbial activity and its contributions to hydraulic conductivity under field conditions in semiarid region soils with different textures and degrees of aggregate stability. This study was performed to investigate the relationship between selected soil properties and hydraulic conductivity in response to different types and application rates of organic amendments. For this purpose, urban municipal solid waste (MSW) compost and alfalfa residue (AR) were applied at different rates of 0 (control), 10 Mg ha^{-1} and 30 Mg ha^{-1} to clay loam and loamy sand soils under field conditions. Results show that after two years, MSW-treated soils had lower soil organic carbon (SOC) compared to those treated with AR due to higher CO_2 emissions from the soils treated with MSW. Higher microbial respiration and mineralization quotient (qmC) in the MSW-treated soils resulted in higher levels of water stable aggregates (WSA > 0.25 mm) and more macro-pore fraction, leading to greater hydraulic conductivity, with larger increases at the higher rate of application (i.e. 30 Mg ha^{-1}). Relative to the control treatment, the application of MSW caused greater increases in microbial respiration in the clay loam soil than in the loamy sand soil, whereas the reverse was found for AR. Apart from soil texture, aggregate size was found to play an important role in controlling the carbon stock and microbial respiration of soils and consequently hydraulic conductivity. The macro-pore fraction was more sensitive than the micro-pore fraction to the application of organic amendments. Correlation analysis indicated that during the reclamation process higher levels of microbial respiration, SOC, water stable aggregates and macro-pore fraction were associated with greater soil hydraulic conductivity.

1. Introduction

Hydraulic conductivity is one of the most important soil physical properties controlling infiltration rates in agricultural lands and the migration of pollutants from contaminated sites to groundwater (Mazaheri and Mahmoodabadi, 2012; Bayabil et al., 2015). Soil hydraulic conductivity is mainly affected by its structural (Zhou et al., 2008; Moncada et al., 2014; Schwen et al., 2014) and chemical characteristics (Ahmad et al., 2015; Shi et al., 2015). Reduced aggregate stability and lowered hydraulic conductivity can be responsible for severe soil erosion and other forms of land degradation (Mainuri and Owino, 2013; Mahmoodabadi and Cerdà, 2013; Arjmand Sajjadi and Mahmoodabadi, 2015a,b) and is clearly dependent on vegetation cover (Cassinari et al., 2015; De Boever et al., 2014; Ola et al., 2015). In most agricultural areas, soil organic carbon (SOC) enhances hydraulic conductivity by improving aggregate stability and porosity (Le Bissonnais et al., 2007; Mahmoodabadi and Ahmadbeygi, 2013; Eibisch et al., 2015). In fact, soil management practices that encourage the addition of organic matter to the soil profoundly enhance aggregate stability and hydraulic conductivity (Mainuri and Owino, 2013; Batjes, 2014; Weyers and Spokas, 2014) and therefore, are important in limiting land degradation due to runoff generation and soil erosion (Cerdà and Doerr, 2007; Fialho and Zinn, 2014; Mahmoodabadi et al., 2014a,b; Yuan et al., 2015).

Soil organic carbon decline in many agroecosystems occurs as a result of oxidation and erosion (Ferreras et al., 2006; Brevik et al., 2015). Since most soils of arid and semiarid regions are low in organic carbon (Zamani and Mahmoodabadi, 2013; Cerdà et al., 2014; Tejada and Benítez, 2014), the application of organic amendments, such as animal manure, crop residues, and municipal solid waste (MSW) compost provides a management strategy to compensate for the depletion of SOC in these soils (Bronick and Lal, 2005; Mahmoodabadi et al., 2013). Previous studies demonstrated positive changes in several soil physical, chemical and biological properties after the addition of organic amendments to the soil (Ferreras et al., 2006; Brevik, 2012; Yazdanpanah and Mahmoodabadi, 2013; Eibisch et al., 2015). In a sandy silty loam soil, Albiach et al. (2001) found significant increases in SOC after applying ovine manure, MSW and sewage sludge at a rate of 24 Mg ha^{-1}. Ferreras et al. (2006) reported a significant correlation

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between soil aggregate stability and organic matter concentration after 6 months of amendment incorporation. Daraghmeh et al. (2008) demonstrated that temporal variation in infiltration characteristics was closely associated with temporal variations in aggregate stability, indicating the role of structural stability on infiltration. Land management and vegetation type are key factors in soil structure quality and aggregate stability (Cerdà, 1998, 2000; Brevik, 2013; Vanlauwe et al., 2015; Wick et al., 2015).

Good soil structure is important for the sustainable production of agricultural lands and for the preservation of environmental quality (Peng et al., 2004; An et al., 2013; van Leeuwen et al., 2015). Aggregate stability is used as an indicator of soil structure (Six et al., 2000; Moncada et al., 2014), which influences several aspects of soil behavior, such as hydraulic conductivity, water infiltration and soil erosion (Le Bissonnais et al., 2007; An et al., 2013; Sirjani and Mahmoodabadi, 2014). The application of organic amendments reduces the adverse effects of soil compaction and improves transport properties of soil gases and water (Brevik, 2009; Kuncoro et al., 2014) by affecting both biological processes (Beare et al., 2009) and pore characteristics (Mangalassery et al., 2013; Kuncoro et al., 2014). The hydraulic conductivity of soil is highly governed by the macroporosity and the continuity and connectivity of the macro-pore network (Buczko et al., 2006). Kim et al. (2010) found that macroporosity as a soil property correlated most closely with the hydraulic conductivity.

Under arid climate conditions, plant residue removal decreases soil organic carbon, leading to aggregate instability and hydraulic conductivity reduction (Yu et al., 2014). Due to insufficient livestock production, the addition of other organic sources such as crop residues and MSW to the soil appears to be an alternative strategy for soil improvement (Hueso-González et al., 2015). In this study, alfalfa (*Medicago sativa* L.) residue was used as an organic amendment, which plays an important role in sustainable cropping systems (Thorup-Kristensen et al., 2003) and enhances SOC and nutrient stocks and improves soil quality attributes (Bell et al., 2012). However, the effect of alfalfa residue and MSW on the hydrology, structural stability and microbial respiration of soils of our region with different degrees of aggregate stability has not been a subject of any investigation up to now. Therefore, the aims of the present study were 1) to compare the effect of two types of organic amendments including alfalfa residue (AR) and urban MSW compost applied at different rates on the hydraulic conductivity of two different cropland soils, and 2) to investigate the relationships between soil microbial respiration, carbon storage, aggregate stability and porosity fractions (i.e. total, macro-and micro-pores) and the hydraulic conductivity in response to different types and application rates of organic amendments under field conditions.

2. Materials and methods

2.1. Experimental sites description

This study was performed in two different experimental fields both located in a semiarid region of Kerman province, central Iran (latitude of 30° 14′ N and longitude of 57° 06′ E). The first experimental field has clay loam soils and the second field loamy sand soils established on aeolian deposits, hereafter called “clay loam soil” and “loamy sand soil”, respectively. Long-term mean precipitation in the area is 140 mm per annum, about 75% of which falls during the winter and spring, and the average annual temperature is 16.5 °C. During the experiment, the mean annual precipitation was 131.6 mm, and the mean temperature was 17.3 °C. Both experimental fields had been under agricultural cropping for more than 10 years, with a conventional management. Irrigation was performed with water that had an electrical conductivity (EC) of 1.1 dS m^{-1} and sodium adsorption ratio (SAR) of 0.73. Prior to the beginning of the experiment, the fields were rested under fallow conditions for 2 years and were not fertilized to make them more homogeneous. Some selected properties of the studied soils before the application of amendments are presented in Table 1.

2.2. Application of organic amendments

Two different organic amendments, urban municipal solid waste (MSW) compost and alfalfa residue (AR), were applied. The urban MSW compost was obtained from the organic solid waste of Kerman Municipality and alfalfa residue was provided as mature hay from an agricultural field in the region. After air drying, the electrical conductivity (EC) and pH of the organic amendments were measured 24 h after 1 h shaking of 1 g samples in vials with 5 ml of distilled water. The amounts of organic carbon and total nitrogen were measured by the Walkley and Black (1934) and Kjeldahl methods, respectively (Pansu and Gautheyrou, 2006). The measured chemical composition of amendments is presented in Table 2. The experiment was performed in a randomized complete block design with five treatments each at three replicates on the two separate fields. For each field (soil texture), 15 experimental plots of 3 m × 5 m were established, so that 30 plots were prepared. Treatments were: (1) control, without any amendment application (C); (2) municipal solid waste at a rate of 10 Mg ha^{-1} (MSW10); (3) municipal solid waste at a rate of 30 Mg ha^{-1} (MSW30); (4) alfalfa residue at a rate of 10 Mg ha^{-1} (AR10), and (5) alfalfa residue at a rate of 30 Mg ha^{-1} (AR30). The selected rates of organic amendments were applied on the basis of dry matter (Ferreras et al., 2006; Ojeda et al., 2008; Celik et al., 2004). The cured amendments were passed through a 5 mm mesh screen before being applied to the soils (Aggelides and Londra, 2000). In August 2011, the organic amendments were spread uniformly on the surface of specified plots and then were incorporated manually into the top 15 cm layer of the soil. Similar procedures were followed for the two fields. During the experiment, which lasted for two years, no crop was planted and no fertilizer was added to the soils.

2.3. Measurement of soil properties

Twenty four months after the application of amendments, soil samples were taken after mixing four subsamples from each plot at depths of 0–15 cm. The air dried soil samples were crushed to pass through a 2 mm sieve and selected soil properties measured. Soil microbial respiration was measured on fresh soil samples (Benbouali et al., 2013). The saturated hydraulic conductivity was measured by the constant head method in undisturbed soil samples with a length of 10 cm and a diameter of 8 cm (Aggelides and Londra, 2000). Soil organic carbon was measured as described by Walkley and Black (1934). To study the effect of organic amendments on biological activity, soil microbial respiration was measured by the incubation-alkaline absorption method at 75% of water holding capacity and 25 °C over 7 days (Ferreras et al., 2006; Yazdanpanah et al., 2013). To compare the decomposability of organic amendments, the mineralization quotient (qmC) was

Table 1
Some physical and chemical properties of the soils used in the experiment.

Soil property	Loamy sand	Clay loam
Clay (<0.002 mm) (%)	5.8	31.0
Silt (0.05–0.002 mm) (%)	10.0	40.8
Sand (2–0.05 mm) (%)	84.2	28.2
MWD[a] (mm)	0.18	0.27
Bulk density (Mg m^{-3})	1.76	1.53
EC[b] (dS m^{-1})	0.28	2.45
pH	6.8	7.2
OC[c] (g kg^{-1})	1.33	2.9
$CaCO_3$ (%)	16.2	21.5

[a] MWD: mean weight diameter.
[b] EC: electrical conductivity.
[c] OC: organic carbon.