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The changes in the physical and hydraulic properties of a loamy soil under irrigation with simpler-reclaimed wastewaters

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ABSTRACT

Soil physical properties (bulk density, particle density, total porosity, pore size distribution and aggregate stability) and hydraulic properties (water retention and infiltration) may be affected significantly from wastewater irrigation. In addition, environmental conditions may change the magnitude of these effects. Therefore, we examined the effects of irrigation with simpler-reclaimed wastewaters on the certain soil properties under cauliflower and red cabbage planting with two-year study in a semi-arid region with a cool climate. W1 (filtered wastewater), W2 (filtered and aerated wastewater) and W1-FW (mix of filtered wastewater with the freshwater at the ratio of 1:1 as volume) were the wastewater treatments. Control plots were irrigated with freshwater (FW) provided from groundwater.

Soil electrical conductivity and organic C content in wastewater irrigated plots were higher than the freshwater irrigated plots. Moreover, exchangeable sodium percentage was low in wastewater plots (<2.25%). Therefore, irrigation with especially W1 and W2 wastewaters markedly increased the aggregate stability. Particle density was not changed with wastewater applications. Although bulk density and porosity increased under the wastewater irrigation conditions, changes were not meaningful in terms of practical conditions. While available soil moisture increased with the increase of micropores, infiltration rate decreased with the decrease of macropores. This was probably because of the clogging of pores with suspended solids in wastewater. According to research findings, it was expressed that soil aggregation and available water content could be improved under irrigation with the mix of filtered wastewater and freshwater in a semi-arid region with a cool climate and the infiltration rate could also be protected.

1. Introduction

Treated or untreated urban wastewater has been used commonly for agricultural irrigation in arid and semi-arid regions of the world. According to the estimations, at least 20 million hectares of agricultural land worldwide is irrigated with treated and untreated wastewaters (Corcoran et al., 2010). Its use has increased recently because there are inadequate freshwater resources. While the population suffering from water scarcity is presently 11% of the total worldwide population, it is estimated that the population with inadequate water will be 38% in 2025 and 50% of the total worldwide population in 2050 (Jiménez and Asano, 2008).

Urban wastewater contains higher levels of organic matter, nutrients and pollutants (heavy metals and suspended solids) compared to freshwater. Although wastewater application provides positive effects on soil properties and crop productivity because of its high organic matter and macro and micronutrient contents, the pollutants in wastewater may cause some problems to soil and crops (Pescod, 1992). Wastewater compounds especially affect soil porosity and therefore hydrological properties (Coppola et al., 2004). Nadav et al. (2013) indicated that the physico-chemical properties of soils were altered with treated wastewater irrigation, because long-term wastewater application caused the accumulation of organic matter in soil. High organic matter in wastewater is cement for the improvement of soil aggregates. Therefore, lower bulk density and higher infiltration and water retention have been obtained under the wastewater irrigation conditions. However, suspended solids in wastewater negatively affect the soil porosity.

Many researches obtained lower bulk density or higher porosity values under wastewater irrigation (Mojiri, 2011; Mojid and Wyseure, 2013; Vogeler, 2009). Conversely, Mollahoseini (2013) determined higher bulk density values under wastewater irrigation. In addition, Wang et al. (2003) indicated that wastewater irrigation caused a slight increase in soil compaction. Especially high-suspended solid concentration in wastewater may increase the bulk density, while lower concentrations may not significantly affect it (Kunhikrishnan et al., 2012).

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Water retention, infiltration and hydraulic conductivity are among the soil hydraulic properties affected by soil porosity and pore size distribution (Gonçalves et al., 2010; Wang et al., 2003). Mojid and Wyseure (2013) determined enhanced saturated hydraulic conductivity and water retention capacity values in the wastewater irrigation conditions compared to freshwater irrigation. However, some researchers reported that wastewater application to soil may decrease the hydraulic conductivity and infiltration rate. Gharaibeh et al. (2007) observed that the infiltration rate of an area irrigated with wastewater for 2 and 5 years was reduced compared to a rain-fed area. Mollahoseini (2013) found that saturated hydraulic conductivity in the top soil layer of 20 cm decreased significantly with wastewater irrigation. Adhikari et al. (2012) indicated that soil hydraulic conductivity may decrease due to the accumulation of dispersed clay and suspended solid particles in the soil pores under saline/sodic wastewater application. Similarly, Gharaibeh et al. (2007) concluded that the presence of sodium in wastewater-irrigated soil can cause swelling and dispersion of soil particles. Especially, the wastewater containing high levels of sodium leads to soil structure deterioration (Qadir et al., 2010). In addition, Fernández-Cirelli et al. (2009) reported that deteriorated soil physical properties due to irrigation with waters having high sodicity and low salinity affect the water movement in soil. Microbiological activity may also decrease the infiltration rate (Bedbabis et al., 2014).

In the regions with a cool climate, soils are exposed to freeze–thaw cycles, especially in the spring period. Aggregation and therefore soil structure may be either positively or negatively affected by freeze–thaw cycles (Sahin et al., 2008). Therefore, the impacts of wastewater irrigation on main soil properties in agricultural areas under cool climate conditions may be different. Moreover, we observed that the studies examining the effects of wastewater irrigation on physical and hydraulic properties of soils in semi-arid regions with a cool climate are limited. Trials were carried out under irrigated conditions using plant material. Two Brassica vegetables were irrigated frequently due to the fact that low effective root depth (40 cm) was selected as plant material. These crops are also cool climate plants. Two plants in the same vegetable group were considered to offer more reliable results with more data about the irrigated soils.

The fresh water resources potential of Turkey is not sufficient considering the agricultural areas. Agriculture is the sector in which water is used the most with 73% (32×10^9 m^3) (SHW, 2013). Treated wastewater amount in Turkey in 2012 was 3.26×10^9 m^3. Proportion of the population served by wastewater treatment plants to the total population was 58% (TSI, 2014). Therefore, wastewaters are used in irrigation by applying simpler reclamation processes in water deficit regions which had no wastewater reclamation plant with sufficient number and capacity.

For the above-mentioned reasons, we examined the effects of simpler reclaimed wastewater irrigation applications by drip irrigation system, which decreases the crop contamination on the physical and hydraulic properties of soil, with the production of two Brassica vegetables in a semi-arid region with a cool climate compared to freshwater. The plants were only used to form the irrigation conditions. Therefore, additional evaluations for the determination of plant properties were not made.

2. Materials and methods

2.1. Experimental site and soil properties

The field experiments were conducted at the Agricultural Research Station of Ataturk University, Erzurum, Turkey (39.933°N, 41.236°E and the altitude of 1798 m a.s.l.). In the experimental region, the annual rainfall is 406.1 mm and the average annual temperature is 5.6 °C according to the long-term climatic data (1960–2012) (TSMS, 2013). The hottest and coldest months are July (19.3 °C average) and January (−9.4 °C average), respectively. Average air temperatures during December-March are below zero degrees. Erzurum region with high altitude has Dsc climate (D: snow, s: summer dry, c: cool summer) according to the Köppen–Geiger Climate Classification (Kottek et al., 2006).

Table 1
Monthly temperature, pan evaporation, and precipitation at the time of cauliflower and red cabbage cultivation.

Year	Month	Temperature, °C	Pan evaporation, mm	Precipitation, mm
2010	May[a]	11.7	32.5	1.1
	June	15.9	171.3	51.5
	July	19.5	220.1	59
	August	20.3	254.2	12.8
	September[b]	21	49.3	–
	September[c]	17.9	131.8	4
2011	June	14.6	174.5	52.7
	July	19.6	236.5	15
	August	19.4	259.4	16
	September[d]	14.9	86.7	2
	September[e]	14.2	151.7	15

[a] Calculated from data between 25 and 31 May.
[b] Calculated from data between 1 and 6 September.
[c] Calculated from data between 1 and 19 September.
[d] Calculated from data between 1 and 14 September.
[e] Calculated from data between 1 and 28 September.

Two Brassica vegetables (cauliflower and red cabbage) from cool climate crops produced in this region were selected as experimental plant material. The cauliflower growing period was from 25 May to 6 September in 2010 and from 1 June to 14 September in 2011, while the red cabbage growing period was from 25 May to 19 September in 2010 and from 1 June to 28 September in 2011. Monthly average temperature, total evaporation and precipitation values in the growing periods are given in Table 1. Evaporation and precipitation data was measured using a Class A pan and a pluviometer located in the experimental area, respectively. Temperature values were provided from the data of Erzurum meteorology station at approximately 5 km distance from the experimental area.

The soils of the region were Aridisol according to the US Soil Taxonomy (Soil Survey Staff, 1992). Basal properties of the experimental field soil prior to trial in 2010 are given in Table 2. The texture of trial field soil determined by the Bouyoucos hydrometer method was loam containing 27.45% clay, 33.55% silt and 39.0% sand in the top 40 cm soil profile based on the effective rooting depth of the crops (Demiralay, 1993). The available water holding capacity calculated from the difference between field capacity and wilting point was 55 mm (Cassel and Nielsen, 1986).

Table 2
Baseline soil properties of experimental field.

Parameter	Soil depth, cm	
	0–20	20–40
Texture	Clay loam	Loam
Clay, %	30.2	24.7
Silt, %	34.4	32.7
Sand, %	35.4	42.6
Bulk density, Mg m^{-3}	1.22	1.25
Field capacity, % of weight	31.7	28.1
Wilting point, % of weight	19.2	18.3
pH	7.70	7.37
EC, dS m^{-1}	2.12	2.75
Organic C, g kg^{-1}	4.81	4.81
$CaCO_3$, %	2.93	0.65