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# Changing soil hydraulic properties and water repellency in a pomegranate orchard irrigated with saline water by applying polyacrylamide

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ABSTRACT

Soil wettability and water repellency are important physical properties which greatly affect soil-water relations. This study was conducted to investigate the effects of polyacrylamide (PAM) on soil water repellency and wettability in a pomegranate orchard drip irrigated with saline water in Isfahan Province, central Iran. The experiment was a randomized complete block design conducted within each "durations of drip irrigation" (considered as the environment) including control (uncultivated), and 8 and 15 years old trees under drip irrigation system (DIS). PAM concentrations were 0 (control), 10 and 20 mg $l^{-1}$ arranged in each block at three replications. The PAM (solubilized in saline water with electrical conductivity of 6.2 dS $m^{-1}$) with the mentioned concentrations was applied once during the irrigation time. A week after applying the PAM, soil samples were taken from 0 to 0.3, 0.3–0.6 and 0.6–0.9 m depths under the emitters. Water repellency index (WRI) and soil-water contact angle ($\beta$) were determined using intrinsic sorptivity method by measuring the water and ethanol sorptivities in all soil samples. Increasing the duration of irrigation with saline water increased electrical conductivity ($EC_e$), concentrations of ($Ca^{2+}+Mg^{2+}$) and $Na^+$, and sodium adsorption ratio (SAR) of the saturated extract in the 0–0.3 m soil layer under the emitters. Increasing the duration of irrigation also increased WRI and $\beta$, and decreased water infiltration, especially in the 0–0.3 m soil layer, presumably through enhancing effects of long-term use of saline water on surface tension of water, soil aggregate stability, physical protection of organic matter in soil and stability of hydrophobic coatings. PAM application significantly reduced soil water repellency and increased soil water sorptivity. In the 0–0.3 m, 8 and 15 years of drip irrigation increased the WRI by 56 and 134 percent, respectively, compared with the control. PAM application at rates of 10 and 20 mg $l^{-1}$ decreased WRI by 27 and 40 percent, respectively, when compared with the control. Application of 20 mg $l^{-1}$ of PAM could completely ameliorate the degradative effects of drip irrigation with saline water for 8 years, whereas amelioration in the 15-year treatment remained incomplete.



## 1. Introduction

Iran is located in an arid and semi-arid region where more than 70% of surface water is consumed in agriculture. Thus, finding the most efficient method(s) of irrigation is essential. In drip irrigation system (DIS), water infiltrates into the soil through dripper under control. In recent years, Iranian farmers have shifted to use this method because of the reduced quantity and quality of subsurface water resources. It has been found that geometric dimensions of the wetted soil volume under dippers are significantly influenced by the discharge rate, the duration of irrigation and soil hydraulic properties (Bustamante, 1996; Schwartzman and Zur, 1986). In long-term irrigation periods, dripper flow and duration of irrigation have been monitored, and adjusted if necessary, but soil hydraulic properties have rarely been evaluated. Soil hydraulic properties would vary with space and time (i.e., spatiotemporal variability) and also show management-related variability (Van Es et al., 1999). In long-term periods, the DIS can affect soil hydraulic properties, e.g. it reduces hydraulic conductivity and porosity of the soil volume wetted under dipper; these changes are not usually favorable for plant growth. The DIS not only might destroy soil structure due to several cycles of wetting and drying but also could increase the

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salinity and/or sodicity of the soil under dippers (Mubarek et al., 2009a,b; Zeng et al., 2013; Currie, 2006).

Soil wettability and water repellency are important physical properties which affect soil-water relations. Soil water repellency (SWR) characterizes the resistance of soil against water absorption for different time periods. The SWR is originated from hydrophobic organic compounds covering the surfaces of soil particles. Natural sources of SWR are the organic compounds released by plant roots and leaves, which include resins, waxes, fatty acids and cutins (Doerr et al., 2000; Hallett, 2008; Hosseini et al., 2015a). Severe soil hydrophobicity might cause water stress to plants and could reduce the quality of production (Doerr et al., 2000). However, sub-critical water repellency would positively affect soil structural stability and physical protection of organic matter in soil (Hallett, 2008; Hosseini et al., 2015a,b). The SWR is affected by several soil and environmental factors.

Spatial distribution of SWR indicates no geographical and climatic dependence. In fact, SWR occurs in humid and arid/semi-arid climates (Dekker et al., 2005; Aelamanesh et al., 2014; Hosseini et al., 2015a). The SWR is not limited to any specific soil type. Although sandy soils are prone to water repellency, SWR is also reported in loamy, clay peaty and peaty clay soils (McGhie and Posner, 1980; Dekker and Ritsema, 1996a,b). The SWR has been studied in many countries; majority of the studies have examined the effect of organic matter on SWR (Doerr and Thomas, 2000). The SWR usually decreases with an increase in soil water content (Hallett, 2008); after a heavy rainfall, SWR reduces or disappears (Dekker and Ritsema, 1994).

The SWR studies in olive orchards with various ages and locations showed that regardless of soil texture and structure, the soils would increasingly become hydrophobic with time after tree plantation. It was found that the soils under mature trees were more hydrophobic than the soils under young trees and both of them were less wettable relative to uncultivated soil (Bughici and Wallash, 2016).

Irrigation water quality can affect the SWR in drip irrigation system. Highest SWR is usually observed near the wetting front in this system (Lehrsch and Sojka, 2011). Small increase in the electrolyte concentration has a great effect on the soil-water contact angle ($\beta$), and small changes in the $\beta$ may have a large impact on infiltration. Generally, a slight change in salinity may strongly affect the dynamics of soil water distribution (Leelamanie and Karube, 2013). Increase in soil water repellency under saline conditions might be attributed to the increment in surface tension of water with an increase in electrolyte concentration (Holthusen et al., 2012; Leelamanie and Karube 2013), restriction of the hydrophobic coatings to the outer surfaces of aggregates due to $Ca^{+2}$-induced aggregation, and the physical protection of organic matter inside the stable aggregates (Aelamanesh et al., 2014; Hosseini et al., 2015a,b). Dorostkar et al. (2016) applied four soil salinity levels ($EC_e$) of 1, 5, 10, and 15 dS $m^{-1}$ and showed that the water repellency index increased with salinity increment, ranging from 2.4 to 10.5.

Surfactants not only can reduce SWR and increase soil wettability, but can also increase the soil structural stability. In recent years, there is an intensive use of surfactants in arable soils (Feng et al., 2002; Lehrsch et al., 2012). Surfactants, which are used to improve the soil permeability and water retention, are usually expensive (Mitra et al., 2006). Due to the high value of water, use of surfactants in the agriculture is becoming attractive (Miller and Letey, 1975; Miller et al., 1975). Scheunert and Korte (1985) found that low concentrations of surfactants (e.g., 10 mg $l^{-1}$) can displace the hydrophobic organic compounds that coat the soil particles. In addition, the surfactants are effective in reducing the surface tension of water, and consequently can improve water infiltration into the soil matrix (Fernández Cirelli et al., 2008; Laha et al., 2009).

Linear, straight-chain forms of polyacrylamide (PAM) are used as industrial flocculants for separation of solids from aqueous suspensions. Anionic water-soluble forms of PAM are frequently used as *soil conditioners* (Sojka et al., 2006; Davidson et al., 2009). The favorable effects of anionic PAM on soil properties have recently been reviewed by Sojka et al. (2006). The PAM has positive effects on soil aggregation, structure stability and pore continuity, and as a consequence would decrease the runoff and soil erosion (Mamedov et al., 2010). PAM mainly consists of $-NH_2$ and $-COOH$ functional groups; they influence the soil aggregation due to their adsorption ability, creating bridges between soil particles and changing soil wettability (Janczuk et al., 1991). Davidson et al. (2009) studied highly burned soils in the United National Forest of Utah State. They measured erosion, soil hydrophobicity, vegetation covers and bare ground for four years. The results showed that fire-induced hydrophobic soils were improved by applying PAM at the rate of 6 kg $ha^{-1}$; in the second year, water droplet penetration time (WDPT) decreased after PAM application by about 80% relative to control. Janczuk et al. (1991) investigated the influence of PAM on the surface free energy. They showed that surface free energy and various solid surface properties (i.e., wettability) were strongly correlated.

The positive impacts of PAM on soil properties have been investigated in surface, sprinkler and furrow irrigation (Sojka et al., 2006). However, there is little information about the PAM effects on soil water repellency in drip irrigation system. Therefore, this study was conducted to investigate the PAM effects on variability of soil water repellency and wettability in DIS with saline water in pomegranate orchard. The results would be important because any changes in the soil properties under the drippers will be effective on geometry of the wetted soil volume under dippers, irrigation efficiency, and growth and health of plants.

## 2. Materials and methods

### 2.1. Experimental site and design

The study was carried out in a 3-ha pomegranate orchard (21°32′6“N, 48°51′18“E and 1825 m a.s.l.), located in the Mahyar plain in Isfahan Province, central Iran. The climate of the study area is BWk according to the agro-climatic classification of Köppen-Geiger (Peel et al., 2007), defined as an arid and cold climate with annual precipitation and mean temperature of 144 mm and 14°C, respectively.

The trees were of various ages, corresponding to different durations of implementing drip irrigation system (DIS). The soil series was coarse loamy, carbonatic, thermic Typic Haplogypsids (Soil Survey Staff, 2010); the soil type was similar among the different treatments such that the main treatment was tree age (i.e., time of DIS initiation). Young and mature pomegranate trees, 8 and 15 years old, respectively, were selected for this experiment. The orchard has been irrigated with saline water with electrical conductivity (EC) of 6.2 dS $m^{-1}$. Other chemical properties of the irrigation water were determined: pH of 7.5, SAR of 4.96, and $Na^+$, and ($Ca^{2+}+Mg^{2+}$), HCO3−, $Cl^-$ and $SO4^{2-}$concentrations of 23.0, 43.0, 5.6, 45.0 and 17.7 meq $l^{-1}$, respectively.

Given that the trees with different ages were planted in different sections of the orchard, a true randomization was not possible between the uncultivated and 8 and 15 years treatments (Fig. 1). Therefore, PAM concentrations were arranged according to a randomized complete block design with three replications in each “durations of DIS irrigation” as the environment. PAM concentrations were applied in plots with dimension of 3 m × 5 m, and tree spacing of 3 m (Fig. 1). Durations of DIS consisted of control (uncultivated), 8 and 15 years, and PAM concentrations consisted