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Water Repellency in Calcareous Soils Under Different Land Uses in Western Iran*[1]

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ABSTRACT

Soil wettability and water repellency, two important soil physical properties, play an important role in water retention and water conductivity in arid and semi-arid regions. To date, there is a lack of information on soil water repellency in calcareous soils of western Iran. In this study, soil water repellency and its affecting factors were studied using 20 soil series collected from Hamadan Province, western Iran. The effects of soil properties including organic carbon content (SOC), total nitrogen (TN), C:N ratio, texture, $CaCO_3$ content, and both fungal and bacterial activities on water repellency were investigated using air-dried, oven-dried and heated soil samples. Water repellency index (WRI) was determined using the short-time sorptivity (water/ethanol) method. To distinguish the actual effects of SOC, a set of soil samples were heated at 300 °C to remove SOC and then WRI was measured on the heated samples. Relative water repellency index (RWRI) was defined as the change of WRI due to heating relative to the oven-dry WRI value. Results of the WRI values showed that the soils were sub-critically water-repellent. Pasture soils had higher WRI values compared to tilled soils, resulting from high SOC and TN, and high activities of bacteria and fungi. It was observed that SOC, TN, fungal activity, and SOC:clay ratio had significant positive impacts on WRI. Strong positive correlations of RWRI with SOC, TN and fungal activity were also observed. Pedotransfer functions derived for predicting WRI showed that the WRI values had an increasing trend with the increases in fungal activity, salinity, alkalinity and fine clay content, but showed a decreasing trend with increasing bacterial activity.

Key Words: calcareous soils, pedotransfer functions, soil sorptivity, soil wettability, water repellency index

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Soil wettability and water repellency (hydrophobicity) have been considered as important physical properties of soil. Hydrophilic soils are soils that are quickly and easily wetted by water (Anderson *et al.*, 1995). Water-repellent soils are soils that show resistance against water infiltration (Dekker *et al.*, 2001). Soil wettability reflects the ability of a soil to absorb water and can be quantified by the rate and/or cumulative water that infiltrates into unsaturated soil. In arid and semi-arid regions, soil wettability and water repellency play an important role in water retention and water conduction in soil. These characteristics ultimately affect surface and sub-surface hydrological cycles, soil water and plant relations, and crop production (Doerr and Thomas, 2000). Until the late 1960s, there were a limited number of publications focused on soil water repellency. However, since 1980 the topic has received much more attention (DeBano, 1991). Soil water repellency has been studied in many countries including USA, Canada, Japan, Netherlands, UK, Portugal, Italy, Australia, New Zealand, Columbia, and numerous African states (Doerr and Thomas, 2000).

When water infiltration into soil or water absorption by soil is slow (*i.e.*, the soil-water contact angle, θ, is greater than 0° but lower than 90°), the soil water repellency is termed sub-critical (Tillman *et al.*, 1989). Sub-critical water repellency has been observed in many soils; however, a soil is actually water-repellent when the soil-water contact angle is greater than 90°, preventing water absorption by the soil for a period of time (Tillman *et al.*, 1989; Hallett *et al.*, 2001a,b). It is important to define the severity and persistence of soil water repellency. Severity determines to what degree hydrophobic substances are concentrated in the

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soils, while persistence indicates the stability of water repellency when the soil is in contact with water (Urbanek *et al.*, 2007). The severity of water repellency may diminish with long-time soil-water contact due to arrangement changes of the functional groups in hydrophobic organic compounds. Soil water repellency is also dependent on water content. Generally, its severity decreases with an increase in water content (Dekker and Ritsema, 1994). Dekker and Ritsema (1994) introduced the terms of potential and actual water repellencies, representing the highest degree of water repellency and the water repellency under the natural condition of soil, respectively.

It has been observed that water-repellent soils have lower water storage capacities and stay dry in the presence of water from hours to weeks (Doerr and Thomas, 2000). The major restriction of water-repellent soils is low water retention, which results in surface runoff, overland flow, fingering flow, river and streams, an unstable wetting front, and possibly severe erosion (Dekker *et al.*, 2001; Arber *et al.*, 2005). Transport of solutes through macropores (*i.e.*, preferential pathways) of these soils may result in the contamination of subsurface water resources (Jarvis *et al.*, 2008). However, even a low degree of water repellency and a low rate of water absorption by soil has a positive effect on soil structural stability due to moderate swelling and a reduction of air entrapment in the soil pores (*e.g.*, Piccolo and Mbagwu, 1999; Blanco-Canqui *et al.*, 2007), which may promote long-term carbon sequestration because the physically-protected organic materials in the aggregates would not be easily exposed to microbial decomposition (Urbanek *et al.*, 2007).

Soil water repellency can be quantified and measured using several methods including the well-known sorptivity method. Short-term water entry/infiltration into the soil is modeled using the Philip equation (Philip, 1957). In general, it is assumed that during the initial time of soil wetting (*i.e.*, 60–180 s), soil hydrophobicity and wettability will not be changed significantly. Tillman *et al.* (1989) introduced the sorptivity method to characterize soil sub-critical water repellency. Hallett and Young (1999) expanded the method for the use in the assessment of water repellency in soil aggregates. Water and ethanol are used for the test as ethanol is a fluid that can wet the entirety of the particles' surfaces, and therefore can characterize the soil pore structure. Soil water repellency index (WRI) can be calculated as the ratio of intrinsic sorptivity of ethanol to that of water in the soil. The WRI is an index quantifying the relative decrease of soil's sorptivity for water in relation to water-repellent compounds in the soil. If a soil is hydrophilic, WRI will be equal to 1 and if WRI is greater than 1 (particularly when greater than 1.95), the soil is hydrophobic (Tillman *et al.*, 1989; Hallett and Young, 1999).

Soil water repellency can be affected by many factors such as quantity and quality of soil organic matter (SOM), soil texture and structure, carbonate content, water content, wetting-drying cycles, soil heating and freezing, products of microorganisms (*i.e.*, fungi, bacteria and actinomycetes), and management practices (*i.e.*, land use, manure application, and chemical fertilizers) (Quyum, 2000). It is frequently reported that the high soil organic carbon (SOC) will intensify soil water repellency (Wallis and Horne, 1992). Organic materials that are washed of plant leaves (Roberts and Carbon, 1971), hydrophobic organic products of microbes (Bond, 1969), hydrophobic root exudates, waxes of leaf epidermis, resins and waxes of trees (Letey *et al.*, 1975; Hallett *et al.*, 2006) exhibit important influences on soil water repellency. In general, long-chain fatty acids, humic and fulvic acids and waxes (*i.e.*, esters) are usually responsible for soil water repellency (Roy and McGill, 2000). Piccolo and Mbagwu (1999) observed that humic substances in the form of humic-metal-clay complexes could increase the soil-water contact angle and surface tension of soil water, leading to an increase in soil water repellency. Soil water content could greatly influence the water repellency, and it has been found that water repellency decreases with the increase in soil water content in most soils (Tillman *et al.*, 1989; Dekker and Ritsema, 1994; Jasinska *et al.*, 2006). Critical water content is the lowest water content where a soil becomes hydrophobic. Therefore, seasonal wetting-drying cycles will enhance soil water repellency. It is frequently reported that coarse-textured soils are more susceptible to water repellency than fine-textured soils because small amounts of hydrophobic organic compounds are enough to cover the surfaces of their larger particles (DeBano, 1981). Compounds left after fire events such as forest fires also create severe water repellency conditions in soils and lead to a high potential for post-fire erosion (Lewis *et al.*, 2008). Snyman (2003) observed that the water infiltration into the soils of the unburnt rangeland was higher than that of the burnt rangeland.

Fungi, bacteria, and actinomycetes could affect soil water repellency. Hallett *et al.* (2006) reported that hydrophobic materials produced by fungi could substantially increase soil water repellency. Actinomycetes are able to decompose a variety of organic materials, particularly waxes, thereby decreasing soil water repellency (Roper, 2004). Hallett and Young (1999) found