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Near-saturated soil hydraulic properties as influenced by land use management systems in Koohrang region of central Zagros, Iran

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ABSTRACT

Soil management and land use *via* the effects on soil characteristics can indirectly change soil hydraulic properties. This study was conducted to investigate the impacts of different management and land uses on the near-saturated soil hydraulic properties in Koohrang region of central Zagros, Chaharmahal-va-Bakhtiari province, Iran. Major land uses in the area were pasture, dryland farming, irrigated farming and fallow. Unsaturated water infiltration was measured at the consecutive inlet matric suctions (h) of 2, 5, 10 and 15 cm using a tension infiltrometer at 100 locations (40 in pasture, 33 in dryland farming, 15 in irrigated farming and 12 in fallow). The infiltration data was modeled using Wooding's analytical method and best-fit values of Gardner's parameters of saturated hydraulic conductivity (K_s) and macroscopic capillary length (λ_c) were calculated. A completely random design was used in which soil texture and land use system were analyzed separately. The averages were compared by the least significant difference test at 5% of probability. The λ_c and unsaturated/saturated hydraulic conductivity [$K(h)$] values were not significantly affected by soil textural classes. However, the land use systems significantly affected soil hydraulic parameters ($K(h)$, steady-state flux, $q(h)$, and sorptivity, $S(h)$), and the differences became greater with decreasing h (towards saturation). The averaged $K(h)$, $q(h)$ and $S(h)$ values were lower in pasture soils when compared with the cultivated lands which were associated with lower organic matter and higher degree of compactness of pasture soils due to overgrazing. The λ_c was significantly greater in the fallow and pasture land uses than in dryland farming, and intermediate value belonged to the irrigated farming. For all of the land use systems, minimum values of $S(h)$ were observed at $h = 10$ cm. The $S(h)$ decrease with h decrease in the range 15–10 cm might be partially associated with swelling of smectite clays, reducing the size of soil pores. The dryland farming increased water infiltration and unsaturated hydraulic conductivity when compared to the other land uses. In this region, averages of soil hydraulic properties are mainly influenced by soil structure and management practices rather than by intrinsic soil properties like texture. A small change in degree of compactness in the swelling soils would significantly influence water infiltration and hydraulic properties, indicating structural susceptibility of the soils to management practices. Therefore, the degree of compactness (e.g. relative bulk density) could be considered as an important index of land use management.

1. Introduction

Near-saturated soil hydraulic properties are needed for studying and modeling water infiltration and contaminant transport processes in the vadose zone. Soil hydraulic properties consist of soil water retention and hydraulic conductivity functions (Hussen and Warrick, 1995). These properties are influenced by several factors including soil texture, structure, bulk density and organic carbon. Soil management and land use systems by affecting these attributes may change soil hydraulic properties (Zhou et al., 2008). Droogers and Bouma (1997) introduced *Genoform* and *Phenoform* for the discrimination of soils in terms of genesis and land use-soil management, respectively. *Genoform* soils are those that are less-affected by human (anthropogenic) activities (e.g. forest soils) and *Phenoform* soils are those which are affected by human activities (e.g. arable soils, pasture soils and urban soils). In general, surface soil properties are mainly influenced by land use. But subsurface/subsoil properties are dominantly governed by genetic processes and are independent of land use (Grossman et al., 2001). Li et al. (2010) found that land-use history not only determines soil attributes but also is a prevailing factor affecting spatial variability of soil hydraulic properties.

While there are many laboratory and field methods for determination of soil hydraulic properties, majority of the methods are time- and cost-consuming especially for the fine-textured soils (van Genuchten and Nielsen, 1985). Laboratory methods for determination of unsaturated hydraulic conductivity include steady-state procedures based on direct solution of Darcy's law such as long-column method (Corey, 2002) and crust method (Bouma et al., 1983), as well as transient procedures that involve some types of approximation or simplification of the Richards' equation, such as horizontal infiltration method (Bruce and Klute, 1956), hot-air method (Arya et al., 1975) and evaporation method

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(Wind, 1968). Field methods are more realistic than laboratory methods because they use larger soil volume and retain soil continuity versus depth (Ramos et al., 2006).

Development of *in situ* techniques to determine hydraulic properties of soils, particularly for assessing preferential flow pathways (Angulo-Jaramillo et al., 1997) under various management practices has received increasing attention in the recent years. Tension/disk infiltrometer was designed to measure and/or maintain the unsaturated flow of water into soil rapidly, accurately and easily; the extent of macropore flow is controlled by applying water to the soil surface at matric potentials less than zero (Kirkham, 2005). Tension/disk infiltrometer is a well-known standard device for measuring near-saturated soil hydraulic properties. The infiltration data could be used for predicting the contribution of soil pores with different sizes in overall water flow through the soil (Perroux and White, 1988; Watson and Luxmoore, 1986). The main advantage of this method compared to the others is the *in situ* measurement of soil hydraulic properties. This technique minimizes soil disturbance and allows investigating the dependency of soil hydraulic parameters on soil structure (Hussen and Warrick, 1993), plant roots and soil macropores (Clothier and White, 1981; Logsdon and Jaynes, 1993), agricultural activities (Mohanty et al., 1996), manure application (Miller et al., 2002), tillage practices (Sauer et al., 1990), land use change (Bodhinayake and Si, 2004), plant cover change (Holden et al., 2001) and climatic factors (Lin et al., 1998). Tension infiltrometer, a portable device with low amount of water required for infiltration trials (compared to pressure/ring infiltrometers), is suitable for characterization of spatial variation in soil hydraulic properties (Jarvis and Messing, 1995; Šimůnek and van Genuchten, 1996).

In agricultural lands, tillage is important to temporal and spatial variations of soil properties (Messing and Jarvis, 1993; Prieksat et al., 1994). Depending on climate, cropping history and soil management, saturated/unsaturated soil hydraulic conductivity can be greater (Buczko et al., 2006; Cameira et al., 2003), lower (Miller et al., 1998) or does not have significant difference (Ankeny et al., 1990) under no-till or minimum tillage compared to conventional tillage. There are diverse reports about the effect of tillage on water infiltration into the soil (Cameira et al., 2003; Xu and Mermoud, 2001). Generally saturated hydraulic conductivity (K_s) increases immediately after tillage, but it would decrease afterward due to settlement and consolidation of the soil (Angulo-Jaramillo et al., 1997; Azevendo et al., 1998; Bormann and Klaassen, 2008). Coquet et al. (2005) reported that tillage (especially by moldboard plow) could temporally increase saturated/unsaturated soil hydraulic conductivity due to creation of new macropores. Osborne et al. (1979) found that although soil porosity increased due to tillage but the number of micropores (0.5–50 μm) was significantly increased and little changes happened to the number of macropores (50–500 μm). Alletto and Coquet (2009) observed that only sampling time and position (row and interrow) were the factors affecting soil hydraulic conductivity at different matric suctions (h).

Different land use systems might alter several soil properties and processes. Shukla et al. (2003) reported that land use change could impact soil physical, chemical and biological properties. Studies by Tollnerm et al. (1990) and Broersma et al. (1995) showed that land use changes from natural and semi-natural vegetation to cultivated and grazed lands could affect soil bulk density, porosity and water storage, water infiltration, and water flow characteristics and surface runoff. Zimmermann et al. (2006) investigated soil hydraulic properties of forest, forested pasture, and pasture land uses using hood infiltrometer (a new type of tension infiltrometer) in Brazil and observed that water infiltrability and K_s (at soil surface and depth 20 cm) increased from pasture to forest land uses. Wahren et al. (2009) found that K_s and field capacity were 2 to 4 times greater in forest lands than those in cultivated lands. Mohanty et al. (1996) reported high variation in near-saturated hydraulic conductivity due to heterogeneous distribution of soil macropores and the effect of air entrapment in soil pores. Zhou et al. (2008) observed that land use effect was significant at h of 0, 1, 2, 3 and 12 cm in October but was not significant at any h value in May. They believed that an important variable responsible for temporal variability of soil hydraulic conductivity was initial water content. Soil hydraulic conductivity was greater in forest compared to other land uses, which was associated with the higher organic matter content (i.e. macropores and structural stability), lower bulk density and low disturbance by anthropogenic activities in forest soils (Zhou et al., 2008). Literature review showed that the effect of land use on soil hydraulic properties depends on climate, soil type, land management and tillage. Therefore, the site-specific impact of land uses on soil hydraulic properties is vital to be studied for better understanding of soil management sustainability and land hydrology.

In Iran, soil erosion rate (i.e. 25 Mg per hectare per year) is four times greater than its average in the world (Abbaszadeh Afshar et al., 2010; Jalalian et al., 1996). A high rate of land use change from pasture to dryland farming (i.e. 400 m^2 per second) is reported (Abbaszadeh Afshar et al., 2010). Hilly regions of Zagros Mountains in western Iran are dominantly covered by soft marl deposits and cultivation for over 50 years has caused severe soil erosion and diminished soil quality (Abbaszadeh Afshar et al., 2010). Overgrazing is also a serious problem in the pastures. Previous studies on land use impacts focused mostly on soil physical and chemical properties, and few researches have investigated the effects on soil hydraulic properties. Almost all of *in situ* infiltration experiments and hydraulic conductivity measurements were done in saturated condition. Nael et al. (2004) found no significant differences between the protected and disturbed sites for infiltration rate in central Iran. In contrast, K_s and organic matter (OM) were significantly higher in the protected forest site. Haghighi et al. (2010) measured K_s by constant-head method and infiltration by double-ring pressure infiltrometer in different land uses and reported greater K_s and infiltration rate in pasture than in dryland farming. They also found that OM and bulk density were greater in pasture soils compared to dryland-farmed soils. However, we believed that even after rainfall and runoff generation, soil is not fully saturated (but near-saturated) because of air entrapment in soil pores, surface seal barrier for infiltration and non-equilibrium condition. It is, therefore, necessary to explore the effects of land use and soil management practices on near-saturated soil hydraulic functions, infiltration, and runoff at a watershed scale for better understanding of their impacts on soil sustainability and land hydrology. Therefore, this study was done in Koohrang region of central Zagros, Chaharmahal-va-Bakhtiari province, Iran to: i) develop a database of soil hydraulic properties, and ii) investigate the impact of land use change from pasture to cultivated lands on near-saturated soil hydraulic properties.

2. Materials and methods

2.1. Description of study area

The study was performed at the Koohrang mountainous region of central Zagros, Chaharmahal-va-Bakhtiari province, Iran (50°5′–50°28′ E; 32°13′–32°35′N) with an area of approximately 370 km^2. The Zagros Mountains are the largest mountain range in Iran. With a total length of 1,500 km, from northwestern Iran, and roughly correlating with Iran's western border, the Zagros range spans the whole length of the western and southwestern Iranian plateau. Koohrang region is an important basin located in central Zagros. The average latitude of the study area is 2360 m above the sea level with long-term annual precipitation (mostly snow) and temperature of 1440 mm and 9.4 °C, respectively. The monthly mean air temperature range from a high of 22 °C observed in July to a low of −5.1 °C noted in January. The average precipitation ranges from maximum of 317 mm in March to minimum of 1.1 mm in June, July, August and September resembling cold–wet winters and warm–dry summers category according to Köppen climate classification (www.chaharmahalmet.ir).