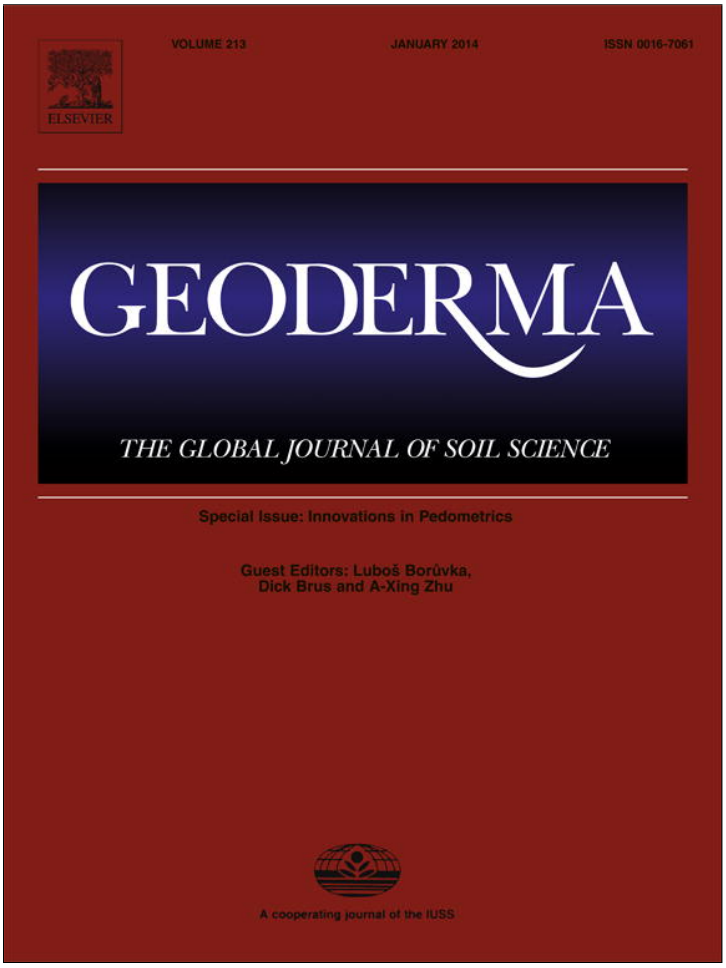
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Near-saturated soil hydraulic properties as influenced by land use management systems in Koohrang region of central Zagros, Iran

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A B S T R A C T

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).

2.2. Soils, land uses and sampling locations

The studied soils are mainly developed on carbonatic marl deposits of the Mesozoic Era, Cretaceous period (66–138 million years ago). The dominant clay mineral is smectite (Sharifi, 2011) and the major land uses are pasture (*Astragalus* sp. and *Bromus* sp), dryland farming, irrigated farming and fallow. Winter wheat (*Triticum aestivum*) is mostly cultivated in the dryland farming and alfalfa (*Medicago sativa*) is generally cultivated in the irrigated fields. The traditional tillage tools use cows for draft and result in a shallow/reduced tillage system, and this is the usual method of cultivation in the drylands. Conventional tillage (i.e. moldboard plowing and disking by MF285 tractors) has been used in the irrigated farming. The area is under intensive sheep overgrazing (i.e. four to eight times greater than pastures' capacity) during the late May to early September months. All of the cover crops (*Bromus* sp.) are consumed by livestock during the grazing. Soil erosion rate is reported severe (i.e. 30 Mg per hectare per year) in the region (Abbaszadeh Afshar et al., 2010), induced by improper land use change and inappropriate cultivation practices over a long time period. Jalalian et al. (1996) predicted using the MPCIAC model high erosion at rate of 13.72 Mg per hectare per year for steep lands in the Zagros under rainfed cropping.

Soils were sampled and the hydraulic properties measured at the end of the grazing period from late September to early October, 2011. Zhou et al. (2008) used five replicates per plot to study the impact of land use on soil hydraulic properties. They observed no significant differences between land uses perhaps due to spatial variability of soil hydraulic conductivity in plots. Therefore, we aimed to select sampling locations depending on the area of each land use. One hundred locations (Fig. 1) were used (40 in pasture, 33 in dryland farming, 15 in irrigated farming and 12 in the fallow system). The locations in combination with land uses were well scattered and are representative of the study area (Fig. 1).

2.3. Field soil measurements and modeling

Hydraulic properties of the surface soils were determined using a tension infiltrometer with 20 cm diameter disk (Soil Measurement Systems LLC, Tucson, Arizona). Unsaturated 3D water infiltration into the soils (initially dry) was measured at consecutive inlet (upper boundary) matric suctions (h) of 2, 5, 10 and 15 cm at all locations. To have a good contact between the disk and the soil, moist fine sand (0.10–0.25 mm) was gently placed on the soil surface. Then, the disk was placed on the soil surface and cumulative water infiltration (at the mentioned inlet h values) was monitored *versus* time with 20–30 s intervals, and then with 1 min intervals up to when the steady-state flux condition was reached. Required time to steady-state flux was reported to vary from 10 min (Ankeny et al., 1991) to 25 min (Logsdon and Jaynes, 1993) depending on soil condition and inlet h value. We assumed the steady-state flux condition when the infiltration at five equal-time intervals (e.g. 1 min) became constant. The required time for steady-state flux condition decreased with decreasing h value (i.e. towards saturation): it varied in the range 18–22 min for $h = 15$ cm and in the range 12–16 min for $h = 2$ cm. Measured steady-state flux (q) values at h of 15, 10, 5 and 2 cm were shown by q_{15}, q_{10}, q_5 and q_2, respectively. A soil sample (near to the disk place) was collected from the surface soil using Kopecky core samplers of 5 cm diameter and 5.1 cm height (i.e. 100 cm^3) to measure initial water content and bulk density (ρ_b). The final water content (corresponding to the lower inlet h value, 2 cm) was determined on a core sample taken from the soil under the disk immediately after the end of infiltration test. Gravimetric water content was determined by the oven method (at 105 °C for 48 h). Volumetric water content (θ) was then calculated using the gravimetric water content and ρ_b. A composite soil sample was also collected from the 0–5 cm layer near the infiltration test location and transported to the laboratory for routine physical and chemical measurements.

The infiltration data was analyzed using Wooding's analytical method as described below. For the early times, the infiltration data was modeled using single-term Philip (1969) model which only considers the effect of matric forces and one-dimensional infiltration:

$$I = St^{0.5} \quad (1)$$

where I is the cumulative volume of infiltrated water per disk area (L) and t is the time (T). Soil sorptivity (S, $LT^{-0.5}$) equals to the slope of relation between I *vs.* $t^{0.5}$ for the initial times. The infiltration data of the first 200 s at each inlet h were used for S calculation. The S values at h of 15, 10, 5 and 2 cm were symbolized by S_{15}, S_{10}, S_5 and S_2, respectively.

For the long period of times, Wooding (1968) proposed the following approximation of steady-state unconfined infiltration rate from a circular source on the soil surface:

$$q = K_{wet}\left[1 + \frac{4\lambda_c}{\pi r_0}\right] \quad (2)$$

where q is the steady-state infiltration rate (volume of water infiltration per disk area per unit time) (LT^{-1}), r_0 is radius of the disk (L), K_{wet} is the unsaturated hydraulic conductivity (LT^{-1}) corresponding to the inlet matric suction h_{wet} (L), and λ_c is the macroscopic capillary length (L) ($= \alpha^{-1}$, where α is the slope of $K(h)$ function (Eq. (3)) in the semi-logarithmic form). In Eq. (2), the first term on right hand represents water flow due to gravitational force and the second term stands for the effects of capillary forces and geometry of supply source (Hussen and Warrick, 1995; Kirkham, 2005). It was assumed that the K varies with h according to exponential model of Gardner (1958):

$$K(h) = K_s \exp\left(-\frac{h}{\lambda_c}\right) \quad (3)$$

where K_s is the saturated hydraulic conductivity (LT^{-1}) and h is the matric suction (L). Therefore, Wooding's analytical solution has two unknown parameters: $K(h)$ or K_s, and λ_c.

Saturated hydraulic conductivity (K_s), unsaturated hydraulic conductivity [$K(h)$], and macroscopic capillary length ($\lambda_c = \alpha^{-1}$, where α is the slope of $K(h)$ function (Eq. (3)) in the semi-logarithmic form) were first calculated using the multiple-head method (Ankeny et al.,

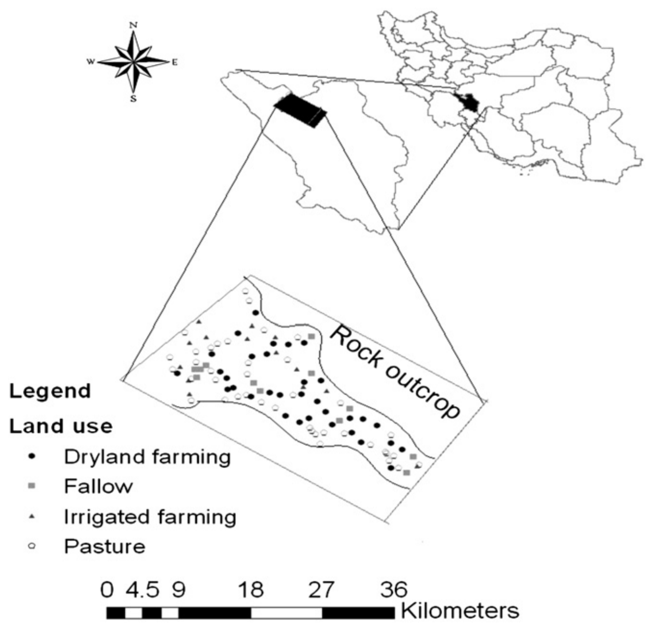

Fig. 1. Study area and soil sampling/measurement locations.

1991) at three sets of two consecutive h values of 15 and 10 cm, 10 and 5 cm, and 5 and 2 cm. The means of predicted parameters were used as the first approximations for the best-fit predictions. By substituting Eq. (3) in Eq. (2), the following equation is obtained (Ankeny et al., 1991; Kirkham, 2005):

$$q = K_s \exp\left(-\frac{h}{\lambda_c}\right)\left[1+\frac{4\lambda_c}{\pi r_0}\right] \tag{4}$$

Measurement of steady-state fluxes (q) for n values of h leads to n equations with K_s and λ_c as the unknown parameters. According to method of Ankeny et al. (1991), the q values of two consecutive matric suctions (h_1 and h_2), e.g. 15 and 10 cm were used. By using h_1 and h_2 values replaced for h, following equations are obtained (i.e., $n = 2$):

$$q_1 = K_s \exp\left(-\frac{h_1}{\lambda_c}\right)\left[1+\frac{4\lambda_c}{\pi r_0}\right] \tag{5}$$

and

$$q_2 = K_s \exp\left(-\frac{h_2}{\lambda_c}\right)\left[1+\frac{4\lambda_c}{\pi r_0}\right] \tag{6}$$

Dividing Eq. (6) by Eq. (5) and solving for λ_c yields (Ankeny et al., 1991; Hussen and Warrick, 1995; Kirkham, 2005):

$$\lambda_c = \frac{|h_2 - h_1|}{|\ln(q_2/q_1)|} \tag{7}$$

Because q_1 and q_2 were measured, and h_1 and h_2 were known, the λ_c was computed directly from Eq. (7). With λ_c known, we calculated the K_s from Eq. (5) or Eq. (6).

The best-fit values of K_s and λ_c were calculated using non-linear optimization technique of Microsoft Excel® Solver (Microsoft Office 2007) by minimizing the sum of squared errors (SSE), squared differences between measured and predicted values of steady-state water fluxes:

$$\text{SSE} = \sum \left(q_{\text{measured}} - q_{\text{predicted}}\right)^2 \tag{8}$$

where q_{measured} and $q_{\text{predicted}}$ are measured and predicted (by Eq. (4)) values of steady-state fluxes for n inlet h values (here $n = 4$). Once the best-fit values of λ_c and K_s were known, with substituting in Eq. (3), resulted in the $K(h)$ relationship. The $K(h)$ functions were used to calculate K at measured h values of 15, 10, 5 and 2 cm which were shown by K_{15}, K_{10}, K_5 and K_2, respectively.

2.4. Laboratory soil measurements and degree of compactness calculations

The composite disturbed soil samples were air-dried, ground to pass a 2-mm sieve and used for routine physical and chemical measurements. Particle size distribution and soil texture was determined using the pipette method (Gee and Bauder, 1986). Organic carbon content (OC) was determined using the wet-digestion method (Walkley and Black, 1934). Calcium carbonate content ($CaCO_3$) was measured using the back-titration method (Sims, 1996). Soluble sodium was determined with a flame photometer (Corning M 410), and soluble calcium and magnesium were measured by the EDTA-titration method in the saturated soil extract (Lanyon and Heald, 1982).

Soil bulk density (ρ_b) was determined using the core sampling method. The ρ_b is an important soil physical property that characterizes soil structure in general. It can easily be shown that ρ_b is not a perfect measure of the degree of compactness of soil. Specific value of ρ_b (e.g., 1.4 Mg m^{-3}) might be high in a fine-textured soil but might not be critical in a coarse-textured soil. Several studies have shown that ρ_b can not properly determine degree of compactness for e.g., plant root growth and crop yield (Håkansson and Lipiec, 2000; Kaufmann et al., 2010), and soil water availability to plants (Asgarzadeh et al., 2010, 2011). The main reason is the dependency of ρ_b on soil texture, mineralogy, particle shape and organic matter (Kaufmann et al., 2010; Reichert et al., 2009). In order to assess the degree of compactness irrespective of soil type (i.e. clay content), the relative bulk density ($\rho_{b\text{-rel}}$) as the ratio of ρ_b to a reference ρ_b ($\rho_{b\text{-ref}}$) was used:

$$\rho_{b\text{-rel}} = \frac{\rho_b}{\rho_{b\text{-ref}}} \tag{9}$$

where $\rho_{b\text{-ref}}$ was calculated depending on the clay content by (Dexter, 2004; Jones, 1983):

$$\rho_{b\text{-ref}}\left(\text{Mg m}^{-3}\right) = 1.985 - 0.00857\text{clay}\left(\text{kg } 100\text{kg}^{-1}\right) \tag{10}$$

It was found that $\rho_{b\text{-ref}}$ calculated using Eq. (10) has a strong correlation with natural ρ_b of the field soil (see Mosaddeghi et al., 2009). As a soil physical quality parameter, $\rho_{b\text{-rel}}$ might be better related to several physical soil functions such as water and air storage, mechanical impedance to root growth, and water availability to plants when compared to ρ_b (e.g. see Asgarzadeh et al., 2010, 2011).

Another index of soil packing is effective bulk density ($\rho_{b\text{-eff}}$) which was used by Abu-Hashim (2011) to characterize the degree of compactness in swelling and shrinking soils. The $\rho_{b\text{-eff}}$ was calculated using the following equation (Abu-Hashim, 2011; Kaufmann et al., 2010):

$$\rho_{b\text{-eff}}\left(\text{Mg m}^{-3}\right) = \rho_b\left(\text{Mg m}^{-3}\right) + 0.009\text{clay}\left(\text{kg } 100\text{kg}^{-1}\right) \tag{11}$$

Eq. (11) shows that clay content has a positive effect on the effective bulk density. The two indices of soil compactness (i.e. $\rho_{b\text{-rel}}$ and $\rho_{b\text{-eff}}$) were used to assess and interpret the impact of land use on water infiltration and soil hydraulic properties.

2.5. Statistical analyses

The data were analyzed using a completely random design with different land use systems as the main treatment. Statistical analyses were done using generalized linear model (GLM) procedure in SAS (version 9.0). The mean comparisons were performed using the least significant difference (LSD) test at $p < 0.05$. The impacts of land use on soil textural data, OM, $CaCO_3$, SAR, ρ_b, $\rho_{b\text{-rel}}$ and $\rho_{b\text{-eff}}$, and soil hydraulic properties including S_{15}, S_{10}, S_5, S_2, K_s, λ_c, q_{15}, q_{10}, q_5, q_2, K_{15}, K_{10}, K_5 and K_2 were assessed. In an additional analysis, the effect of soil textural class on hydraulic properties was investigated using a similar experimental design.

In order to identify the most important soil properties affecting soil hydraulic properties, sensitivity analysis was done in a neural network analysis by the StatSoft method (StatSoft Inc., 2004). Relative sensitivity coefficient (RSC) was calculated by dividing the total error of network when the variable was treated equal to zero by the total error of network when the actual values of the variable were used:

$$RSC = \frac{\dfrac{\sum_{i=1}^{N}(y_{is} - \hat{y}_{is})^2}{N}}{\dfrac{\sum_{i=1}^{n}(y_{it} - y)^2}{n}} \tag{12}$$

where y_{is} is the simulated output value using all the inputs, $\hat{y}_{is}$ is the simulated output value using all the inputs except an input (i.e. equal to zero), y_{it} is the simulated output for the *test dataset*, y is the measured output, N is the total number of data (i.e. 100) and n is the number of *test* *dataset* (i.e. 20). If RSC is greater than 1.0 then, the variable made an important contribution to the variability on the output.

3. Results and discussion

Out of the hundred soils (locations) three most dominant textures were silty clay loam (48), silty clay (38) silt loam (10). The remaining four soils were not included in the statistical analysis due to low number of samples (replications). Distribution of the 96 soils in the land uses were in this order: 40 in pasture, 31 in dryland farming, 15 in irrigated farming and 10 in fallow (Table 1). Particle fractions did not significantly differ between the land use systems (Table 1) indicating that the selected soils had good scatter of texture and were intrinsically similar among the land uses.

Additional statistical analysis showed that the averages of soil hydraulic properties including macroscopic capillary length (λ_c) and unsaturated/saturated hydraulic conductivity values were not significantly affected by soil textural class (Table 2). This indicates that on average soil hydraulic properties mainly varied with land use independent of soil texture in the region. As shown in Table 2, λ_c decreases with coarseness of the soil texture. However, no specific trend was observed for the $K(h)$ and K_s among the textural classes indicating that λ_c as a scaling parameter depends on soil texture more than K.

3.1. Soil physical and chemical properties as affected by land use

Summary results of statistics for the soil physical, chemical and hydraulic properties among the land uses are shown in Table 3. Almost all of coefficients of variation (CVs) for soil hydraulic parameters were greater than 36% showing a relatively high spatial variability according to Wilding (1985) categorization. However, somehow increasing trends were observed for the CV of hydraulic parameters (K, q and S) with decreasing h. The greatest values for CV of $K(h)$ were noted for K_s in all of land uses with the exception of pasture locations (Table 3). Accordingly, Moosavi and Sepaskhah (2012) reported the highest CV for K_s compared to other hydraulic conductivities, which was associated with the heterogeneity of large-sized soil pores. Perhaps the lower CV values for hydraulic parameters (K, q and S) near saturation in the pasture (Table 3) are related to the destruction of macropores due to overgrazing which reduces the size range of soil pores towards a uniform pore size distribution.

Another interesting trend was noticed for the soil hydraulic parameters [$K(h)$, $q(h)$ and $S(h)$] which greatly increased with h from 15 to 2 cm in dryland farming when compared to other land uses (Table 3). This shows the high frequency of macropores in the soils of dryland farming locations. This might be because of preservation and/or creation of soil macropores due to reduced tillage by traditional tools. It is surprising that the lowest increase in $K(h)$ with h from 15 to 2 cm belonged to the pasture field (Table 3). This is presumably related to soil compaction, structural damage and destruction of macropores due to overgrazing. Hu et al. (2009) observed that variation in $K(h)$ would be increased with decreasing h, but the CV of λ_c was an intermediate value in a range of land uses. They found that when h decreased from 3 cm to 0 the $K(h)$ increased less than two times which is smaller than those reported in the literature. This could be associated with the low frequency of macropores or weak connectivity/continuity of macropores in the studied soils. Data of Schwartz et al. (2003) showed that the $K(h)$ increased with h decrease from 15 cm to 0 by 10.1, 47 and 13 times respectively for the cropland, native grassland and re-established land uses. Jarvis and Messing (1995) determined the near-saturated hydraulic conductivity in six tilled soils of loamy sand to silty clay by a tension infiltrometer and observed that $K(h)$ variations with h in the range of 0–10 cm were greater in fine-textured soils (3–4 times) than in coarse-textured soils (about 2 times).

Table 1
Mean comparisons of surface soil sand, silt and clay percents between different land uses.[a]

Land use	Sand (50–2000 μm)	Silt (2–50 μm)	Clay (<2 μm)
	kg 100 kg^{-1}		
Dryland farming (31)[b]	7.94a	55.20a	36.86a
Fallow (10)	9.03a	55.74a	35.23a
Irrigated farming (15)	8.74a	54.66a	36.60a
Pasture (40)	6.52a	54.24a	39.24a

[a] Figures followed by similar letters in each column are not significantly different at $p < 0.05$ (LSD).
[b] Numbers in the parentheses stand for the number of soils (locations) in a land use.

Table 2
Mean comparisons of soil hydraulic properties including macroscopic capillary length (λ_c) and unsaturated/saturated hydraulic conductivity values as affected by soil textural class.[a]

Texture class	λ_c	K_{15}	K_{10}	K_5	K_2	K_s
	cm	mm h^{-1}				
Silty clay (38)[b]	7.22a	5.26a	11.11a	25.54a	44.32a	65.64a
Silty clay loam (48)	7.18a	5.92a	12.20a	26.78a	44.63a	64.03a
Silt loam (10)	6.65a	5.10a	11.06a	26.86a	49.08a	75.93a

[a] Figures followed by similar letters in each column are not significantly different at $p < 0.05$ (LSD); λ_c is macroscopic capillary length, and K_{15}, K_{10}, K_5, K_2 and K_s are hydraulic conductivities at matric suctions of 15, 10, 5, 2 and 0 cm, respectively.
[b] Numbers in the parentheses stand for the number of soils (locations) in a soil textural class.

The comparisons of land use impacts on selected soil physical and chemical properties, based on mean values, are shown in Table 4. Land use management significantly affected the soil OC in the order of: irrigated farming > pasture > fallow > dryland farming. Irrigated farming significantly increased soil OC mainly due to the manure applications and higher soil water availability to plants. Low OC of pasture soils might be due to the high erosion rate and low plant cover. Pastures are mainly covered by *Astragalus* sp. and *Bromus* sp., and almost all of *Bromus* sp. is consumed by the livestock during grazing. The amounts of litter and residues of *Astragalus* sp. with high C/N ratio, added to the soils are not considerable. Pasture conversion to dryland farming did not significantly reduce the OC (Table 4) because the average OC of pasture soils was not high, and some wheat residues were left after harvest in the dryland farming. Although it is frequently reported that continuous and intensive tillage would reduce the OC level in arable soils, but it seems that reduced tillage by traditional tools in addition to greater inputs of high-quality (with low C/N ratio) residues in the dryland farming of the region more or less preserved the soil OC level. This result is in agreement with the findings of Hajabbasi et al. (2001). However, it is generally believed that long-term soil manipulation in conventional tillage systems would decrease the OM and consequently water infiltration into the soil. This might be due lowered activity of soil mesofauna, destructed biopores, low aggregate stability, soil dispersion and crust formation (Schwartz et al., 2003).

Poor soil management and surface frosting due to low soil temperature during the winter minimize the water infiltration into the soil and create considerable surface runoff. Land use significantly affected the soil carbonate content in the order of: fallow > irrigated farming > dryland farming > pasture. The $CaCO_3$ content was significantly lower in the surface soils of pasture (Table 4) due to leaching and transport of $CaCO_3$ into the subsoil. It might be reasoned that soil inversion especially by moldboard plowing in irrigated farming brought the carbonatic B horizon into the surface. (Table 4). Soil erosion in the fallow soils with negligible cover might cause the exposure of carbonatic B horizon and increase the surface soil $CaCO_3$ content. The SAR values were in the order of: fallow > dryland farming > irrigated farming > pasture (Table 4).

Land use did not significantly affect the ρ_b, $\rho_{b\text{-eff}}$ and $\rho_{b\text{-rel}}$ (Table 4). However, the trends of $\rho_{b\text{-eff}}$ and $\rho_{b\text{-rel}}$ values, to some extent, could explain the $K(h)$ variations near saturation among the land uses

Table 3
Summary of statistics (maximum, minimum, average and coefficient of variations, CV) for the soil physical, chemical and hydraulic properties among the land uses.[a]

Property or Parameter	Irrigated farming				Dryland farming				Fallow				Pasture			
	Max	Min	Ave	CV	Max	Min	Ave	CV	Max	Min	Ave	CV	Max	Min	Ave	CV
K_{15} (mm h^{-1})	10.8	0.5	5.1	74.6	14.1	1.1	5.9	52.5	11.6	5.8	7.8	27.8	13.4	1.12	4.8	53.1
K_{10} (mm h^{-1})	20.3	2.9	10.6	64.1	33.0	4.6	13.6	51.6	22.2	8.5	15.2	32.6	21.6	4.35	9.6	39.9
K_5 (mm h^{-1})	38.1	11.5	24.8	43.4	77.8	15.4	33.6	54.1	54.9	11.8	31.0	46.1	34.8	6.87	19.9	33.9
K_2 (mm h^{-1})	74.9	15.2	44.3	46.9	138.3	21.0	61.1	63.0	99.4	14.4	48.4	55.9	67.4	8.53	31.8	39.0
K_s (mm h^{-1})	148.1	18.3	67.7	78.3	239.2	26.0	93.3	70.4	147.8	16.3	65.6	62.8	126.8	9.85	44.0	49.9
λ_c (cm^{-1})	10.8	2.8	6.7	38.0	12.5	2.8	6.2	37.6	15.4	5.0	8.8	41.5	16.9	3.17	7.5	40.4
q_{15} (mm h^{-1})	23.7	4.4	13.6	50.5	26.7	5.9	14.6	44.8	32.7	14.8	20.6	26.7	35.6	5.94	13.4	50.2
q_{10} (mm h^{-1})	38.6	7.4	21.5	43.0	62.4	8.9	26.6	44.9	44.5	20.8	30.6	29.6	47.5	8.94	19.2	47.3
q_5 (mm h^{-1})	77.2	20.8	40.9	36.6	130.6	23.6	55.8	43.7	83.1	32.7	56.9	33.7	80.2	16.32	35.4	40.2
q_2 (mm h^{-1})	112.8	32.7	72.1	46.4	228.7	47.5	104.9	47.8	166.3	44.5	95.3	41.8	109.9	23.76	61.6	34.1
S_{15} (mm h^{-1})	15.2	2.46	9.1	46.2	27.4	3.1	11.3	51.3	20.1	10.2	18.0	26.1	26.1	2.1	10.4	53.1
S_{10} (mm h^{-1})	15.9	3.7	8.7	43.9	24.5	3.7	10.8	47.7	23.5	8.2	14.5	40.1	18.4	2.8	7.7	47.0
S_5 (mm h^{-1})	28.4	7.2	14.5	38.5	44.6	7.7	20.7	46.9	33.6	11.1	20.8	33.6	30.8	5.5	12.2	42.3
S_2 (mm h^{-1})	34.1	10.1	21.8	45.8	80.9	13.4	34.9	50.8	50.0	13.7	30.6	41.1	34.2	7.6	19.6	35.32
Sand (kg 100 kg^{-1})	15.7	2.7	8.7	108.4	18.5	2.0	7.9	92.8	14.9	2.5	9.0	48.7	18.1	1.02	6.5	109.5
Silt (kg 100 kg^{-1})	73.0	41.1	54.6	19.8	78.7	41.8	55.2	17.4	60.6	44.8	55.7	9.5	82.0	40.73	54.2	16.5
Clay (kg 100 kg^{-1})	56.0	17.6	36.6	22.6	51.5	16.8	36.8	22.3	42.3	28.7	35.2	14.1	57.5	16.46	39.2	21.5
ρ_b (Mg m^{-3})	1.37	1.09	1.23	16.4	1.44	1.10	1.24	9.3	1.40	1.18	1.27	5.6	1.50	1.09	1.25	10.2
$\rho_{b\text{-eff}}$ (Mg m^{-3})	1.72	1.34	1.55	63.1	1.75	1.32	1.56	55.5	1.71	1.44	1.58	6.1	1.89	1.35	1.60	50.1
$\rho_{b\text{-rel}}$ (–)	0.87	0.68	0.78	2.1	0.92	0.66	0.78	23.1	0.88	0.72	0.80	7.1	0.99	0.69	0.80	16.7
$CaCO_3$ (kg 100 kg^{-1})	37.5	2.0	17.9	77.1	41.0	1.50	15.6	66.0	45.5	3.0	18.9	69.4	42.5	1.00	10.8	95.6
OC (kg 100 kg^{-1})	2.2	0.1	1.1	53.1	1.5	0.2	0.7	42.9	1.8	0.4	0.81	50.1	1.8	0.3	0.8	39.3
SAR (meq l^{-1})$^{0.5}$	3.6	0.8	1.7	42.7	4.5	0.9	1.8	46.9	5.0	0.9	2.18	61.2	2.1	0.9	1.5	21.4

[a] K_{15}, K_{10}, K_5, K_2 and K_s are hydraulic conductivities at matric suctions of 15, 10, 5, 2 and 0 cm, respectively; q_{15}, q_{10}, q_5 and q_2 are steady-state fluxes at matric suctions of 15, 10, 5 and 2 cm, respectively; S_{15}, S_{10}, S_5 and S_2 are soil sorptivities at matric suctions of 15, 10, 5 and 2 cm, respectively; ρ_b, $\rho_{b\text{-eff}}$ and $\rho_{b\text{-rel}}$ are bulk density, effective bulk density and relative bulk density, respectively; $CaCO_3$ is calcium carbonate calcium content and OC is organic carbon content; SAR is sodium adsorption ratio.

(Table 3). Sensitivity analysis in a neural network analysis (StatSoft Inc., 2004) identified $\rho_{b\text{-rel}}$ as the most important property affecting K_s in the region. Relative sensitivity coefficient (RSC) was 4.37 for the $\rho_{b\text{-rel}}$ but its values for the ρ_b and silt content were 1.41 and 2.13, respectively. The K_s was not sensitive to clay content (RSC < 1). Therefore, a small change in $\rho_{b\text{-eff}}$ or $\rho_{b\text{-rel}}$ corresponds to a large change in $K(h)$ indicating structural susceptibility of the soils to management practices. Since $\rho_{b\text{-eff}}$ or $\rho_{b\text{-rel}}$ calculate bulk density independent of soil texture, they might be considered as an input for derivation of pedotransfer functions and for studying the land use effect on soil properties. Fig. 2 shows the strong linear relation between $\rho_{b\text{-rel}}$ and $\rho_{b\text{-eff}}$ for the studied soils. It is implied that $\rho_{b\text{-rel}}$ and $\rho_{b\text{-eff}}$ could be interchangeably used to characterize the degree of compactness in the region.

The ρ_b values for the treatments were in the order of: fallow > pasture > dryland farming > irrigated farming. Some changes were observed in the orders of $\rho_{b\text{-eff}}$ and $\rho_{b\text{-rel}}$ values with land uses: pasture > fallow > irrigated farming > dryland farming, and pasture > fallow > dryland farming > irrigated farming, respectively (Table 4). In the dryland farming, traditional shallow tillage have loosened the soil and reduced ρ_b. In the irrigated farming, mostly perennial plants have been cultivated and the organic matter inputs might prevent excessive soil compaction. Relatively high degree of compactness in the fallow might be associated with the lack of short-term soil loosening by tillage.

The highest degree of compactness (i.e. $\rho_{b\text{-eff}}$ and $\rho_{b\text{-rel}}$) was observed in the pasture (Table 4) due to soil compaction by livestock overgrazing and non-loosened (no-tilled) state of the soils. It is believed that soils with low OM would be naturally compacted if not tilled. This behavior is known as *natural compaction* or *hard-setting* due to internal forces of the soil but not because of external mechanical stresses. This phenomenon happens in soils with low OM and/or weak structure (e.g. see Mosaddeghi et al., 2003; Mullins, 2000). However, Abu-Hashim (2011) reported that $\rho_{b\text{-eff}}$ is significantly greater in the agricultural soils compared to forest and grassland soils. Celik (2005) reported that soil OM and ρ_b were significantly decreased and increased, respectively, due to 12 years cultivation of pasture in the southern Mediterranean

Table 4
Mean comparisons of selected soil physical and chemical properties between different land uses.[a]

Land use	OC	$CaCO_3$	SAR	ρ_b	$\rho_{b\text{-eff}}$	$\rho_{b\text{-rel}}$
	kg 100 kg^{-1}		(meq l^{-1})$^{0.5}$	Mg m^{-3}		
Dryland farming	0.76b	15.62ab	1.85ab	1.24a	1.54a	0.785a
Fallow	0.80ab	18.90a	2.18ab	1.26a	1.58a	0.797a
Irrigated farming	1.12a	17.95a	1.79ab	1.23a	1.55a	0.780a
Pasture	0.83b	10.89b	1.50b	1.25a	1.60a	0.805a

[a] Figures followed by similar letters in each column are not significantly different at $p < 0.05$ (LSD); OC is organic carbon content, $CaCO_3$ is calcium carbonate content, SAR is sodium absorption ratio, and ρ_b, $\rho_{b\text{-eff}}$ and $\rho_{b\text{-rel}}$ are bulk density, effective bulk density and relative bulk density, respectively.

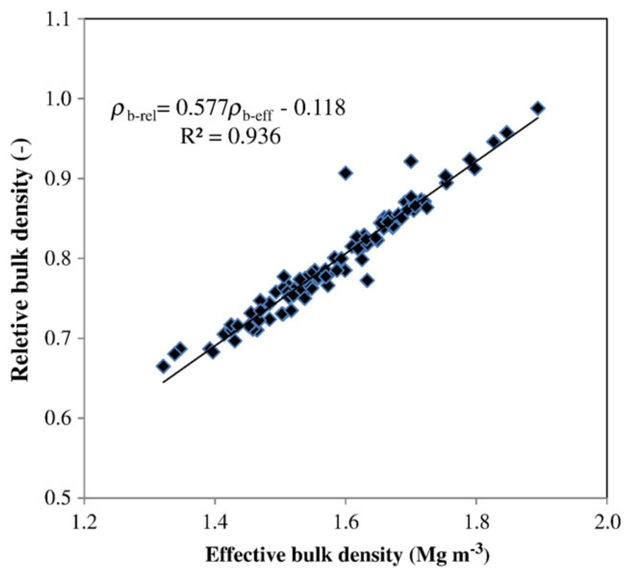

Fig. 2. Linear relation between relative bulk density ($\rho_{b\text{-rel}}$) and effective bulk density ($\rho_{b\text{-eff}}$) in the studied soils.

highland of Turkey. The high ρ_b in the arable soils was related to the weak structure and destruction of soil pore system. Similarly, Bodhinayake and Si (2004) found that soil OM and ρ_b were significantly lower and greater, respectively, in the arable lands compared to native and brome grasslands. Schwartz et al. (2003) observed that ρ_b values of the 1–4, 11–14 and 15–18 cm layers were not significantly different among cropland, native grassland and re-established land uses, but it was only greater in the 5–8 cm layer of cropland. Bormann and Klaassen (2008) reported that land use changes from forest to grassland and from grassland to cropland increased the ρ_b and consequently decreased hydraulic conductivity of the surface soil.

3.2. Soil hydraulic properties as affected by land use

Land use significantly affected the macroscopic capillary length (λ_c) and hydraulic conductivity (Table 5). This indicates that averages of soil hydraulic properties mainly varied with land use independent of soil texture in the region. The λ_c was significantly greater in the fallow and pasture land uses when compared with the dryland farming. Intermediate value of this parameter belonged to the irrigated farming which was not significantly different from other land uses (Table 5). This trend is interpretable by considering that λ_c is positively related to degree of compactness (Radcliffe and Šimůnek, 2010); the clay content (Table 1) and the degree of compactness (ρ_b, $\rho_{b\text{-eff}}$ and $\rho_{b\text{-rel}}$; Table 4) were greater in the pasture soils resulting in higher λ_c. With an increase in λ_c, the relative contribution of capillary forces vs. gravitational forces to infiltration would be increased (Radcliffe and Šimůnek, 2010). Gravitational water flow through the pasture soils is expected leading to preferential flows.

Towards the saturation (i.e. decreasing h), the differences in $K(h)$ became greater among the land uses (Table 5). The lowest values of $K(h)$ belonged to the pasture as a result of high degree of compactness (ρ_b, $\rho_{b\text{-eff}}$ and $\rho_{b\text{-rel}}$) in the pasture soils (see Table 4). At high h values, the $K(h)$ values of the fallow treatments were higher than those of the dryland farming but at low h values, the $K(h)$ of dryland farming was greater than other land uses (Table 5). This shows the high frequency of macropores in the soils of dryland farming locations and might be related to preservation and/or creation of soil macropores due to reduced tillage by traditional tools. Contrary to these findings, Abu-Hashim (2011) reported the following order for the K_s in different land uses: forest > grassland > agricultural soils. However, he reported greater variation for the K_s in agricultural soils compared to forest and grassland soils. Bodhinayake and Si (2004) observed considerable decrease in the $K(h)$ with increasing h in grasslands compared to arable lands. They also reported significant differences in the $K(h)$ among the land uses at low h values. Differences in the $K(h)$ at h of 22, 15 and 7 cm were not significant but the differences in the $K(h)$ at h of 3 cm became significant among different land uses (i.e. grassland soils > arable soils.) Schwartz et al. (2003) observed that the $K(h)$ values in cropland and native grassland were greater than those of re-established grassland at low h values. But at high h values, the $K(h)$ of cropland became higher than those in native and re-established grasslands. In contrast, Hu et al. (2009) found that land use did not influence the λ_c and only affected K_{15} significantly. Moret and Arrúe (2007) showed that during a 10–12 years no-till management, $K(h)$ was significantly lower than in reduced and conventional tillage systems presumably due to greater ρ_b in no-tilled soil. No significant difference was observed between reduced and conventional tillage systems. Evett et al. (1999) also reported that K_s was significantly greater under conventional tillage system (perhaps because of its lower ρ_b) compared to no-till system.

The $K(h)$ function of Gardner (1958) is drawn and compared among the land uses in Fig. 3. The slope of $K(h)$ function (i.e. α) in semi-logarithmic scale (i.e. log K vs. h) is equal to the inverse of macroscopic capillary length (i.e. $\lambda_c = \alpha^{-1}$). The $\alpha = \lambda_c^{-1}$ in dryland farming was greater than those in other land uses in the low h values (5 to 0 cm) as an indication of gravitational or macroporous flow pathways.

The effects of land use on unsaturated steady-state fluxes (q) at different h values are presented in Fig. 4. Obviously, q increased with a decrease in h under all land uses because of contribution of large soil pores to near-saturated water flow. Similar to $K(h)$, the differences among the land uses of $q(h)$ became greater when approaching the saturated state (Fig. 4). This might be related to heterogeneity of macropores and creation of macropores due to reduced tillage by traditional tools, resulting in greater near-saturated water infiltration under dryland farming. The lowest $q(h)$ values were recorded for the pasture (Fig. 4) which is associated with high degree of compactness (ρ_b, $\rho_{b\text{-eff}}$ and $\rho_{b\text{-rel}}$) in these soils (see Table 4). The highest variation of q within the h range was observed for dryland farming due to creation of heterogeneous pores by tillage. The lowest variation of q within the h range was recorded for pasture (Fig. 4) because of soil compaction during grazing which might have altered macropores to micropores (i.e. reduced size range of soil pores) towards a uniform pore size distribution. Abu-Hashim (2011) observed that infiltration rate was in following order for different land uses: forest > grassland > agricultural soils; which was associated with the greater OM content of forest soils. However, it is implied from his presentation of graphs that variation of the q was greater in agricultural soils compared to other soils. Giertz et al. (2005) evaluated the effects of land use change on soil physical properties and hydrological processes in the sub-humid tropical environment of West Africa. They observed significant decrease in the infiltrability of agricultural soils compared to those under forest and Savanna which was linked to weak soil structure and reduced activity of microorganisms due to lowered level of OM. Mielke and Wilhem (1998) found that initial and final saturated infiltration rates (measured by a double-ring infiltrometer) were greater in a pasture recently brought under cultivation than in a long-term cultivated

Table 5
Mean comparisons of soil hydraulic properties including macroscopic capillary length (λ_c) and unsaturated/saturated hydraulic conductivity values between different land uses.[a]

Land use	λ_c	K_{15}	K_{10}	K_5	K_2	K_s
	cm	mm h^{-1}				
Dryland farming	6.21b	5.97a	13.60ab	33.69a	61.15a	91.23a
Fallow	8.81a	7.81b	15.24a	31.01ab	48.39ab	65.59ab
Irrigated farming	6.79ab	5.11a	10.64b	24.79bc	44.33bc	67.72ab
Pasture	7.58a	4.88a	9.62 b	19.95c	31.81c	44.06b

[a] Figures followed by similar letters in each column are not significantly different at $p < 0.05$ (LSD).); λ_c is macroscopic capillary length, and K_{15}, K_{10}, K_5, K_2 and K_s are hydraulic conductivities at matric suctions of 15, 10, 5, 2 and 0 cm, respectively.

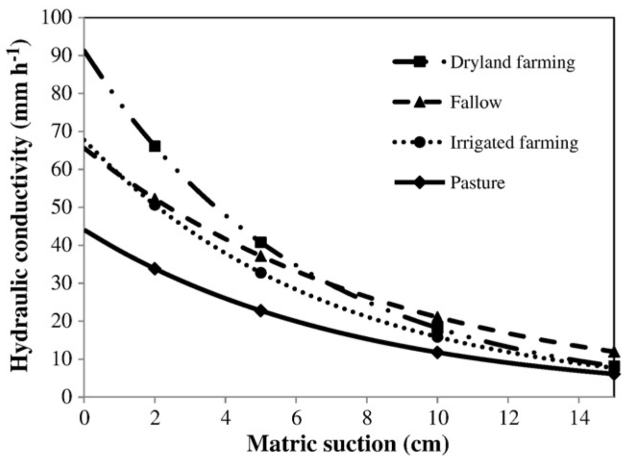

Fig. 3. Unsaturated hydraulic conductivity [$K(h)$] function of Gardner (1958) among the land uses; Slope of $K(h)$ function (i.e. α) in semi-logarithmic scale (i.e. log K vs. h) is equal to inverse of macroscopic capillary length (i.e. $\lambda_c = \alpha^{-1}$).

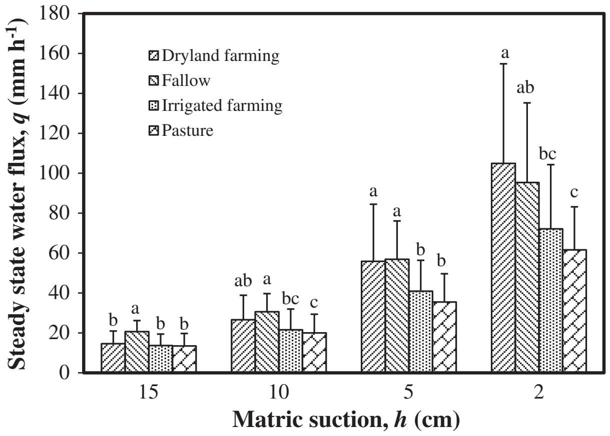

Fig. 4. Unsaturated steady-state water fluxes (q) at different matric suctions (h) among the land uses; In each group of bars (i.e. in a specific h value), similar letters stand for non-significant differences at $p < 0.05$ (LSD).

land. Lipiec et al. (2006) found that water infiltration was greatest in conventional tillage among different tillage systems.

The effects of land use on soil sorptivity (S) of Philip (1969) model at different h values are shown in Table 6. Similar to $K(h)$ and $q(h)$, the differences among the land uses of $S(h)$ became greater when approaching the saturated state. The $S(h)$ values in fallow and dryland farming were greater than those in irrigated farming and pasture (Table 6) which might be related to annual soil loosening and creation of macropores due to tillage.

Moosavi and Sepaskhah (2012) found that S increased with decreasing h value. However, we observed that under all land uses S decreased with h decrease from 15 to 10 cm and then increased with h decrease reaching its maximum value at $h = 2$ cm. We explain this interesting trend in this way: at first when the soil is dry (naturally) and matric forces are high, starting the infiltration test with $h = 15$ cm of water supply produced high S_{15} values. Changing h of water supply from 15 to 10 cm did not alter the soil sorptivity when compared to change from dry to 15 cm; therefore, in the h range 15–10 cm, the $S(h)$ decreased (Table 6). This decrease might be partially associated with clay (mostly smectitic) swelling processes so, reducing the size of soil pores, too. The increase in $S(h)$ with h decrease in the range 10–2 cm (Table 6) might be associated with contribution of macropores in the infiltration process. The highest variation of S within the studied h range was observed for dryland farming due to creation of heterogeneous pores by tillage. Whilst, the lowest variation of S within the h range was recorded for the pasture (Table 6) because of soil compaction during grazing which probably altered macropores to micropores (i.e. reduced size range of soil pores) towards a uniform pore size distribution.

4. Conclusions and recommendation

(1) Soil hydraulic properties are highly variable, and differently respond to land use changes depending on the management practices, tillage system and environmental conditions (e.g. climate). On average, near-saturated soil hydraulic properties were significantly affected by land use system (i.e. soil structure and management practices) but not by the soil textural class in the Koohrang region of central Zagros.

(2) Land use systems significantly affected the soil hydraulic parameters (hydraulic conductivity, steady-state flux and sorptivity) which became greater with decreasing matric suction, h (towards saturation). Soil hydraulic conductivity was lower in the pasture soils as compared to the other cultivated soils, which is related to the lower organic matter content and higher degree of compactness of pasture soils. Low soil organic matter content in the pasture is likely caused by hot and dry summers and uncontrolled livestock overgrazing. Soil compaction is also a reason caused by livestock overgrazing.

(3) Dryland farming has the best conditions in terms of soil physical properties, water infiltration and hydraulic properties. These findings might be because of preservation and/or creation of soil macropores due to shallow/reduced tillage by traditional tools using cows for draft. Conventional moldboard plowing and disking by tractors in the irrigated farming imposed higher mechanical energy to the soils. Relatively high degree of compactness in the fallow might be associated with absence of short-term soil loosening. The highest degree of compactness observed in pasture was related to soil compaction due to livestock overgrazing and undisturbed soil state.

(4) It was found that a small change in degree of compactness in the studied swelling soils would significantly affect water infiltration and soil hydraulic properties indicating structural susceptibility of the soils to management practices. Therefore, degree of compactness (quantified by relative and effective bulk densities) indirectly reflects the effect of land use and management. Degree of compactness is suggested as an input for derivation of pedotransfer functions of infiltration and soil hydraulic properties in the region.

Table 6
Mean comparisons of soil sorptivity (S) in Philip (1969) model at different matric suctions (h) between different by land uses.[a]

Land use	S_{15}	S_{10}	S_5	S_2
	mm h$^{-0.5}$			
Dryland farming	11.3b	10.8ab	20.7a	34.9a
Fallow	18.0a	14.5a	20.8a	30.6a
Irrigated farming	9.1b	8.7bc	14.5b	21.8b
Pasture	10.4b	7.7c	12.2b	19.6b

[a] Figures followed by similar letters in each column are not significantly different at $p < 0.05$ (LSD); S_{15}, S_{10}, S_5 and S_2 are soil sorptivities at matric suctions of 15, 10, 5 and 2 cm, respectively.

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