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THE USE OF SOIL HYDRAULIC PROPERTIES AS INDICATORS FOR ASSESSING THE IMPACT OF MANAGEMENT PRACTICES UNDER SEMI-ARID CLIMATES

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Abstract

Water retention capacity and hydraulic conductivity are major soil hydraulic properties that influence soil quality and the environment. The objective of this work was to assess major soil hydraulic characteristics in response to the effect of soil management and tillage practices. Eight soil treatments were considered: conventional tillage, reduced tillage, no-tillage, fallow no-tillage, abandoned soil, compacted soil, plough on compacted soil, and application of super absorbent polymers. The experiments were conducted at Koohin station, Iran. The equality of field saturated hydraulic conductivity (K_{fs}) and estimated K_{fs} was studied. Moreover, the contribution of the porosity to soil water flux was investigated and quantified. At the -1500 kPa potential, water content was influenced by the compacted treatment at soil depth of 0 to 25 cm. In this study, van Genuchten water retention curve parameters n, α, and θ_r values were not significantly different among treatments. The fit of the van Genuchten equation to the soil water retention data resulted in low sum of squared errors. No distinct trend was observed for estimated sorptivity in the studied area. The sorptivity values were not significantly different among soil management practices. Moreover, estimated K_{fs} values by DISC software were lower than measured K_{fs}. Soil treatments did not influence the soil water-conducting medium and macropores. Unsaturated hydraulic conductivity may partly be affected by soil texture and soil structure which were uniform under all treatments. Soil water retention and transmission may be manipulated with changes in pore size distribution under different tillage and management practices in long-term.

Key words: sorptivity, super absorbent polymers, transmissivity, water-conducting porosity

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1. Introduction

Soil water retention characteristic is a basic property that is required. Soil water retention at field capacity and permanent wilting point is important to estimate the crop water need, which may be influenced by soil management practices. Several researchers have reported that management practices have an important impact on the soil hydraulic characteristics (Bormann and Klassen, 2008; Sonneveld et al., 2003; Tey et al., 2017). Simulation models can be employed to describe soil water retention (Monokrousos et al., 2018; Sonneveld et al., 2003). Indirect estimation of soil hydraulic properties has been proposed as an alternative approach. To estimate the effect of management practices on soil water capacity, the van Genuchten equation (Van Genuchten, 1980) may be employed. Sonneveld et al. (2003) used the Mualem-van Genuchten model for fitting soil water retention data for the soil water retention curves in the case of different land uses. Consequently, physically based models, such as the van Genuchten equation, may be considered as suitable tools to simulate the soil water characteristics in different management practices.

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Studies on soil hydraulic characteristics as influenced by management practices are not comprehensive in compared to investigations on soil chemical properties.

In the recent decades, disadvantage effects of soil inversion have demonstrated especially in semi-arid regions. Conservation tillage system with approximately 30% of the soil surface crop residue is proposed to conserve soil from raindrop effect and soil sealing. No-tillage and non-inversion tillage systems are developed to combat soil erosion and reduce evaporation to protect the soil water storage, especially in the regions with an arid and semi-arid climate (Álvarez and Steinbach, 2009). The influence of no-tillage system on soil physical characteristics has not been consistent across different soils and experimental designs (Strudley et al., 2008). Udawatta and Anderson (2008) have concluded that computed tomography- measured parameters may be employed to quantify the effect of management practices relative to improved water transport and environmental benefit. Some researchers have found a decrease in the soil total porosity under no-tillage system compared with conventional tillage (Costantini et al., 2006; Ferreras et al., 2000). In the other hand, the soil compaction influences soil porosity, resulting in a considerable change in the porous media. Strudley et al. (2008) have reviewed the effects of tillage systems on soil hydraulic characteristics and found that no-tillage system would improve macropore connectivity than conventional tillage. Bhattacharyya et al. (2006) have evaluated the effect of zero-tillage (ZT), conventional tillage (CT), and minimum tillage (MT) on soil hydraulic conductivity and pore size distribution of a sandy clay loam soil. They found that the values of soil water retention constant were higher under ZT than those observed under CT. Mean values of effective pores volume for retaining available water were according to: CT < ZT < MT and the mean values of pores volume draining freely with gravity were according to: CT > MT > ZT.

Several researchers have assessed the infiltration behavior under no-tillage system, with contradictory results. Some authors reported that soils under conventional tillage practice have lower infiltration rate than under no-tillage system (Steinbach and Álvarez, 2006) and the others observed a lower infiltration rate under no-tillage (Ferreras et al., 2000). The assessment of soil macro porosity is a challenging subject to govern soil water transport process (Bodner et al., 2010).

The tension disc infiltrometer is an applied device to measure and monitor the water transport through soil macropores near saturation (Watson and Luxmoore, 1986), and to monitor the effect of soil tillage systems on the surface hydraulic characteristics (Moret and Arrúe, 2007). In this study, the tension disc infiltrometer was used to quantify the contribution of water-fluxing macro- and medium pores during infiltration process to evaluate the effect of management practices on the surface hydraulic characteristics.

The objectives of this investigation were as follows: 1) to quantify, evaluate, and document the effect of soil management practices on soil water capacity, 2) comparing the van Genuchten equation parameters, obtained in different soil managements, 3) to compare the observed soil hydraulic conductivity with that obtained by DISC software, 4) to compare the sorptivity and transmissivity factors among different soil management practices, and 5) to assess and quantify the effect of soil management on soil porosity contribution to soil water flux.

2. Materials and methods

2.1. Study site

This study was conducted in a dryland farming field at the Soil Conservation Research Center of Koohin, Qazvin province, Iran. The site (36° 18′ to 36°25′ N and 49° 28′ to 49° 38′ E) had an elevation of 1354 m above sea level, with homogeneous soils (Fig. 1). The slope was approximately 8%. The studied soils were clay loam (Fine, mixed, super active, mesic, vertic calcixerepts). The soil pH ranged from 7.9 to 8.4 for eight treatments and depths of 0 to 25 cm and 25 to 50 cm. The EC of the soils ranged from 0.42 to 0.62 dS m^{-1}. The TNV of the treatment soils ranged from 12.2 to 16.5 %, lowest and highest at 0 to 25 cm depth and 25 to 50 cm depth of soil, respectively. The average temperature and mean annual rainfall of region are 12.1°C and 330 mm respectively.

Four tillage systems were arranged in plots with four replicates of 20 m × 4 m per plot, ranging from conventional tillage (CT) and reduced tillage (RT), to the no-tillage (NT) and fallow no-tillage (FNT). After harvesting, approximately 90% of the soil surface covered by crop residues in case of NT and approximately 30% of the surface covered by residues in case of RT. Since 2010, the no-tillage treatment has been applied. In 2014, the NT plots were split into four FNT and four NT plots. A total of 32 plots were studied (8 treatments × 4 replications). The CT plots have been tilled (to a depth of 30 to 45 cm) with moldboard ploughing + heavy-offset disk harrows for several decades. Since April 2012, a reduced tillage system (chisel packer or combined tillage to a depth of 15 to 20 cm) was applied.

In the present study, the advantage of soil tillage as a best management practice for compacted soils was also evaluated. By establishing plots with traffic (Compacted) and without traffic (control plot), it was determined whether the tillage has advantage in terms of improved soil water retention. In 2014, a conventional tillage was applied to the compacted plots with moldboard plowing (to a depth of 30 to 45 cm) in order to reduce soil compaction. Therefore, other four treatments were: control (i.e., abandoned plot), compacted soil, plough on compacted soil (Tilled), and application of super absorbent polymer (SAP) on abandoned plots. The Abandoned plots were set as the control (without SAP), and four plots were assigned the SAP treatment.

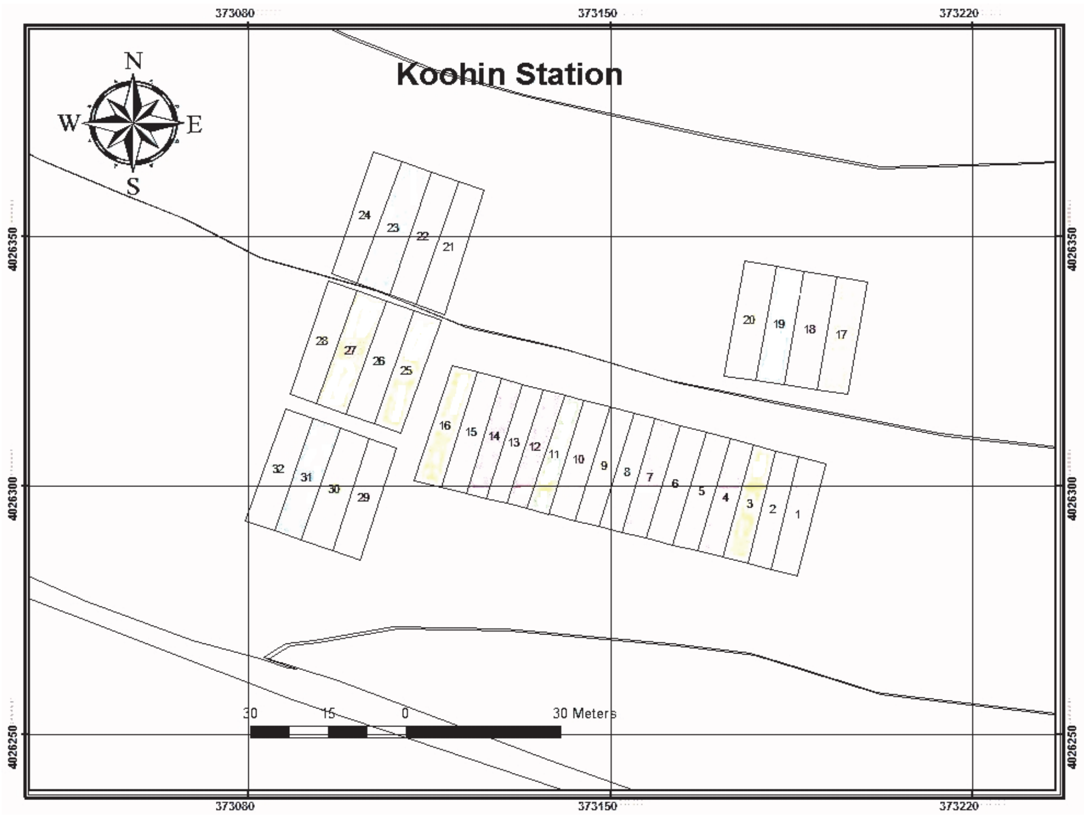


Fig. 1. A map of study site and soil management treatments 1 to 8: compacted and Tilled plots; 9 to 16: Abandoned and SAP plots; 17 to 20: FNT plots; 21 to 24: NT plots; 25 to 28: RT plots; 29 to 32: CT plots

SAP was applied at 625 kg ha^{-1}. The abandoned plots had been deteriorated due to long-term CT before abandonment and were kept weed free after abandonment.

2.2. Experiments

Soil sampling was done at each plot for assessing changes in field capacity (FC), wilting point (PWP), and pore size distribution. Sixty four disturbed and undisturbed samples were used to determine soil properties. The soil θ_h were determined by undisturbed steel cores that by 5 cm diameter with four replicates taken from depths of 0 to 25 cm and 25 to 50 cm. The hydrometer method was used to determine soil partcle size distribution (Gee and Bauder, 1986). Soil hydraulic conductivity measurements were done on each plot using tension disc infiltrometer device over different water pressure heads, including - 1.5, - 1, - 0.5, and 0 kPa.

The contribution of the medium and macropores to flow water, φ (%), was estimated as flow rate occurring between water pressure heads of -5 and -15 cm and, between 0 and -5 cm, respectively. The water retention (θ_h) was measured in laboratory at different potentials (0 kPa, -33 kPa, -50 kPa, -100 kPa, -500 kPa, -1000 kPa, and -1500 kPa) by a pressure chamber device (Klute, 1986). The van Genuchten model was fitted to the soil water retention data to derive α, n, and θ_r parameters using the RETC (retention curve) computer software (Van Genuchten et al., 1991). The van Genuchten equation is presented as follows (Eq. 1):

$$\theta(h) = \theta_r + \frac{\theta_s \quad \theta_r}{(1+|\alpha h|^n)^m} \qquad \theta_{(h)} = \theta_s \qquad h \geq 0 \qquad (1)$$

where $\theta_{(h)}$ (cm^3 cm^{-3}), θ_r (cm^3 cm^{-3}), and θ_s (cm^3 cm^{-3}) are the soil water content, residual water content, and the saturated water content, respectively; m is 1 - (1/n); n and α (cm^{-1}) are parameters describing the water retention curve, which were obtained for each soil management treatment. In addition, parameter n is associated with water retention curve steepness.

The DISC software introduced by Simunek and van Genuchten (1997) was employed to examine the field saturated hydraulic conductivity (Kf_s). This software analyzes disc infiltrometer data numerically based on the approach presented by Simunek and van Genuchten (1997). This method is based on the knowledge of the initial and final volumetric water content and cumulative infiltration rate and then, optimizes hydraulic parameters. The DISC software is simple in entering the input data and displaying the results. The contributions of water-conducting porosities were calculated as follows (Eq. 2):

$$\varphi_i(\%) = \frac{K(\phi_i) - K(\phi_{i-1})}{K(\phi_0)} \times 100, \quad i = 1,...,n \qquad (2)$$

where $K(Ø_i)$ is the hydraulic conductivity at the various matric potential (i.e., K_{-15}, and K_5).

2.3. Philip model

The Philip two-term model is defined as follows (Eq. 3) (Philip, 1957):

$$i(t) = \frac{1}{2} St^{-0.5} + A \quad (3)$$

where A is transmissivity parameter (cm min^{-1}); S is sorptivity factor, a function of soil matric potential (cm min$^{-0.5}$). The sorptivity and transmissivity factors were estimated and then evaluated using Philip two-term model.

2.4. Statistical analysis

A significant test on the soil management practices was performed using the analysis of variance (ANOVA) by the general linear model (GLM) of SAS. The van Genuchten model performance was assessed using R^2 and sum of squared errors (SSQ).

3. Results and discussions

Table 1 shows basic soil characteristics for depths of 0 to 25 cm and 25 to 50 cm corresponding to eight soil management treatments.

3.1. Soil pore size distribution

Significant differences in the macroporosity were not observed among management treatments (Fig. 2). It is obvious from Fig. 2 that medium porosity was higher at 0 to 25 cm soil depth of FNT and lower at 25 to 50 cm depth of RT and CT and micro porosity was higher at 0 to 25 cm soil depth of compacted soil. The highest medium porosity observed in FNT, even if not significant, may be due to the development of medium pores under low soil disturbance condition.

Decreased medium pores in CT can be probably due to a lower bulk density than the other managements resulted from tillage practices in CT treatment. In addition, it can be concluded that the micro-porosity is well developed in compacted and SAP treatments considering Fig. 2. A higher medium porosity under FNT may also be explained by a lower plant root and an increased medium size pore volumes. Medium pores seem more frequent under FNT compared to CT, and macro-pores which increase hydraulic conductivity are probably in a higher proportion in soils under tillage (Kay and Vanden Bygaart, 2002).

The insignificant difference of macro- and medium porosity under compacted treatment compared to other treatments may reflect a reduced macro-pore and an increased volume proportion of micro-pores due to compaction impact. The slightly higher medium porosity suggest that no-tillage may cause a better soil water availability for crops compared with moldboard ploughing under arid condition and drought period in long-term at the studied area. Li et al. (2014) reported that SAP may cause an increase in soil water content and soil hygroscopic moisture but no influence on the water availability and soil medium porosity compared to the control plots, in consistent with the finding in the present study.

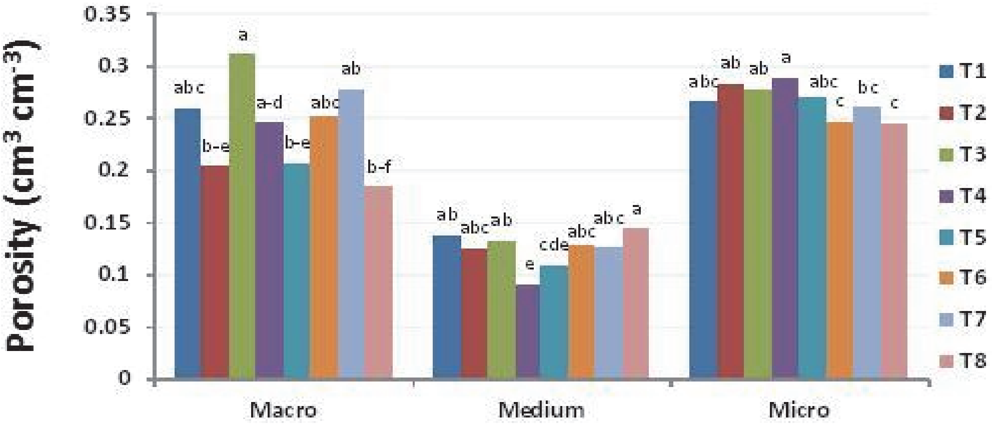
3.2. Water-conducting porosity

The water-conducting porosity was not significantly different among soil treatments. No significant difference in conducting medium porosity was detected among treatments (Fig. 3). The lack of macropores formation under NT has already been detected by Sasal et al. (2006) in accordance with our research. The proportion of macro-pores for water flux was more than medium pores and similar for all treatments (Fig. 2).

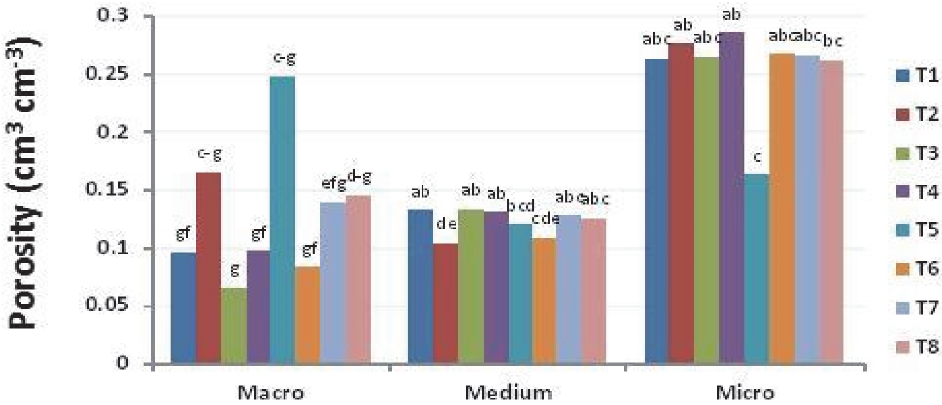
Table 1. General soil characteristics for the eight management treatments

Treatment	*Soil depth (cm)*	*Sand (%)*	*Silt (%)*	*Clay (%)*	***BD (g cm^{-3})*	**OC (%)*
Abandoned	0-25	30.0	35.5	34.5	1.448	0.58
	25-50	31.0	35.0	34.0	1.480	0.58
RT	0-25	27.8	36.2	36.0	1.467	0.59
	25-50	27.6	35.2	37.2	1.445	0.55
SAP	0-25	30.0	34.2	35.8	1.518	0.53
	25-50	30.0	34.0	36.0	1.474	0.49
Compacted	0-25	30.8	34.4	34.8	1.519	0.52
	25-50	30.8	33.2	36.0	1.494	0.51
Tilled	0-25	32.0	31.0	37.0	1.421	0.51
	25-50	31.8	32.8	35.4	1.346	0.50
CT	0-25	25.4	35.8	38.8	1.392	0.58
	25-50	25.5	35.5	39.0	1.351	0.54
NT	0-25	29.0	37.0	34.0	1.471	0.61
	25-50	28.6	35.2	36.2	1.481	0.54
FNT	0-25	30.8	34.8	34.4	1.446	0.67
	25-50	30.2	35.6	34.2	1.424	0.60

** Soil Organic carbon; ** Bulk Density*



(a)



(b)

Fig. 2. Soil pore size distribution at soil depth of (a) 0 to 25 cm and (b) 25 to 50 cm
T1: Abandoned, T2: RT, T3: SAP, T4: compacted, T5: Tilled, T6: CT, T7: NT, T8: FNT

This conclusion is in agreement with Cameira et al. (2003), who found that soil water was mainly flowed by macropores. This result does not support the assumption that management significantly influences water flux caused by the improvement of water-conducting macropores. It would be expected that under no-tillage, hardening over time may be compensated by macropores created from roots channels and biopores, thus porosity has not influenced compared to CT. For compacted soils it would be expected that compaction effect has reduced over time due to wet and dry cycles. The result of this research agrees with the result of Wilson and Luxmoore (1988), who found that macropores can move a higher portion of the water flux in the soil. Overall, the soil water flow was considerably conducted by soil macropores (Cameira et al., 2003). Future researches on the influence of soil management on water transport should emphasize on macroporosity.

3.3. Soil water capacity

Soil volumetric water content at different potentials under eight management practices is presented in Fig. 4. The difference among the FC of the soils under the all management practices were generally negligible, although FC amount was the lowest in compacted treatment close to Tilled and CT practices at the soil depth of 0 to 25 cm.

The lowest FC was observed in Tilled treatment, although the difference was not significant. The maximum PWP was estimated/measured in 0 to 25 cm depth of the SAP and compacted treatments. Compacted treatment had higher volumetric water content of PWP at both depths. Moreover, CT tended to lower PWP values at both depths. The highest saturated water content was detected in 0 to 25 cm depth of the SAP treatment, but differences in SWC among the management practices were not statistically significant at both depths (Fig. 4). Moreover, CT tended to have lower SWC values at the depth of 25 to 50 cm, but differences among all managements were not statistically significant.

The measured and estimated water retention curves did not reveal significant difference within the selected water potentials for soil managements in this study, except for compacted treatment. Measured θ_s value was found to be insignificantly higher for SAP treatment when compared with the other soil treatments at depth of 0 to 25 cm. Moreover, the compaction effect on soil water capacity was significant at a water potential of -1500 kPa obtained from laboratory experiments. The results revealed that the compaction of abandoned soils led to a significant decrease in the PWP at a depth of 0 to 25 cm.

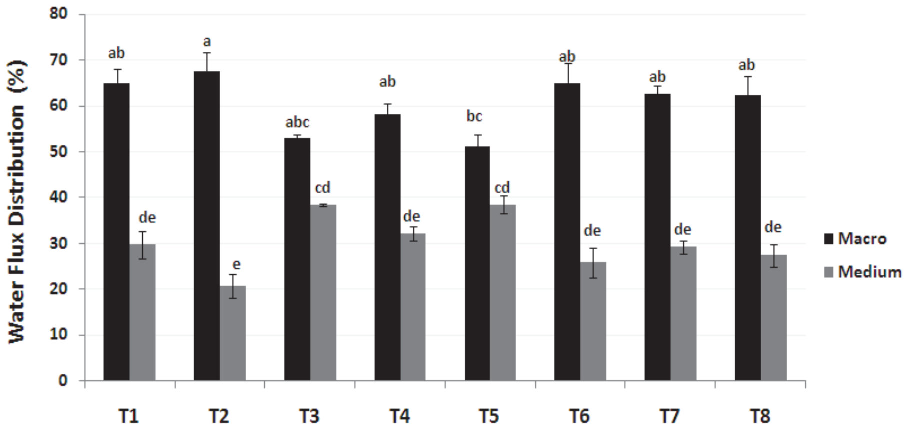


Fig. 3. Contribution to conduct water in macro- and medium pores
T1: Abandoned, T2: RT, T3: SAP, T4: compacted, T5: Tilled, T6: CT, T7: NT, T8: FNT

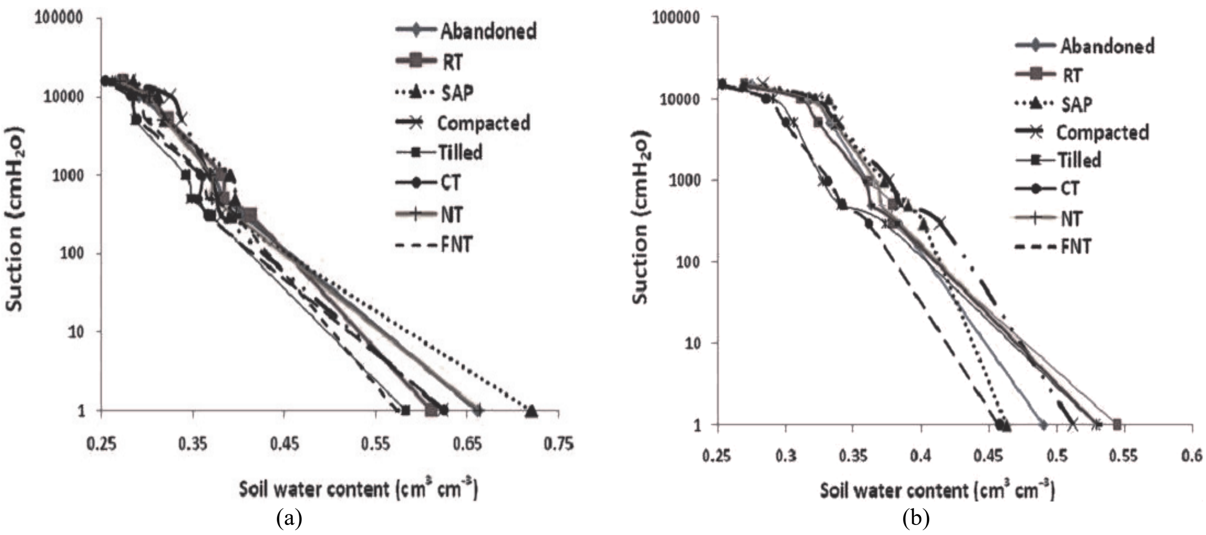


Fig. 4. Change in soil volumetric water content with the pressure head for eight treatments at depths of (a) 0 to 25 cm and (b) 25 to 50 cm

The highest PWP was observed in 0 to 25 cm depth of the SAP and compacted treatments and lowest one was observed in FNT at the same depth. The PWP was highest in SAP and Compacted at both depth of the soil and lowest in CT. The -33 *kPa* water content was not influenced by the management type. Figure 3a, b indicates that the mean field capacity and saturated water content was not considerably different in eight treatments at both depths. In this study, there were not statistically observed significant difference in volumetric water content at considered suctions between the tillage systems presented in Fig. 4.

A small reduction in FC was also observed on compacted plots probably due to a decreased macro- and medium-pores. Slightly higher water retention under NT demonstrates the influence of the water storage caused by negligible soil disturbance as stated by Fuentes et al. (2003).

Similar slight influence of different tillage practices on soil water has been reported by Van den Putte (2012) who observed that the soil water content indicated small differences among different tillage practices, in consistent with that of the current study. SAP had more saturated water content (volumetric content) but this higher water amount was not significant compared to the other management practices. This may be explained by the fact that the BD in SAP was not significantly different as compared to the other practices. Li et al. (2014) have found that SAP caused an increase in the soil water content and hygroscopic moisture but have had no influence on the soil water availability compared with the control, similar to the obtained result in this study. At pressure head -1500 *kPa*, the micropores number was influenced by the compaction practice. At -1500 kPa pressure head, the water is stored in soil micropores, which is affected by compacted treatment. Thus, maximum PWP obtained in 0 to 25 cm depth of the SAP and compacted treatments can probably explained by the higher portion of soil micropores.

Overall, it can be concluded that the unchanged soil pore size distribution and total porosity under different studied management practices can lead to no significant difference in water storage at suctions of -33 kPa and 0 kPa. Improper soil management practices can disturb the soil macroporosity in the long-term influencing the θ_s (Ndiaye et al., 2007), but no significant difference in soil macroporosity was observed in this study. Higher microporosity of compacted soils compared with the other practices and a higher medium porosity in FNT soils compared with the other tillage systems were found. As a result, a higher microporosity detected in the compacted soils has probably led to the higher soil water PWP affecting water storage properties. No alteration in the medium porosity can lead to insignificant difference at the potential of -33 kPa water content among treatments. The findings of this study demonstrated the negligible influence of short-term management on soil water retention in most of the practices. However, the more intensive use of the soil can lead to the less stored water in the soil at a given pressure head (Bormann and Klaassen, 2008). Soil water retention and transmission may be manipulated with changes in pore size distribution under different tillage and management practices (Bhattacharyya et al., 2006), especially in long-term.

3.4. Modeling performance

Estimated parameter values and standard errors obtained from the simultaneous fit of the soil water retention data to Eq. (1) are presented in Table 2. The standard error values indicate the deviation of estimated values from the observed ones. In the case of the Koohin soils, the van Genuchten model gave satisfactory estimates of θ_h and simulation result strongly corresponded with the laboratory measured soil water retention (Table 2).

The overall simulation result of the van Genuchten model indicated low *SE* and *SSQ* and high R^2 values (0.93 - 0.99) for clay loam soils from the studied area with eight treatments. Comparing the estimated *n* and α values did not show significant differences among studied practices (at $p < 0.05$) for both depths. In addition, the θ_s values were not significantly different and were similar to those measured ones. Similar finding was obtained by Schwartz et al. (2000) who reported that the use of the van Genuchten equation yields acceptable results. As reported by Ndiaye et al. (2007), the *n* parameter can be affected by soil texture, which is associated with soil particle size distribution. Therefore, this parameter may be changed with an alteration in sand, silt, and clay particles (Porebska et al., 2006) and cannot be influenced by soil management practices. Since *α* and *n* are van Genuchten's empirical parameters affecting the shape of the water retention curves (Sonneveld et al., 2003), it was concluded the retention curves of treatments are not statistically different. This conclusion may be attributed to the no significant influence of soil management practices on soil porosity distribution except for microporosity in compacted soil. This result was revealed by comparing the shape of the obtained curves showed in Fig. 3.

3.5. Observed and estimated K_{fs}

Table 3 presents the measured values of hydraulic conductivity and Fig. 5 depicts the obtained relationship between the estimated values of K_s by DISC and observed ones. The K_0 values were not statistically different ($p < 0.05$) among soil managements practices. No-tillage and conventional tillage did not differ statistically for K_0. Unsaturated hydraulic conductivity may partly be affected by soil texture and soil structure (Bormann and Klaassen, 2008) which were uniform under all management and tillage treatments. The sensitivity of the unsaturated hydraulic conductivity is less significant than the saturated hydraulic conductivity (Bormann and Klaassen, 2008).

The results showed that the field measured K_0 was positively related to the obtained K_{fs} by DISC (R = 0.603) (Fig. 5). The results revealed that field measured values of the K_0 were higher than the estimated ones by DISC at all treatments.

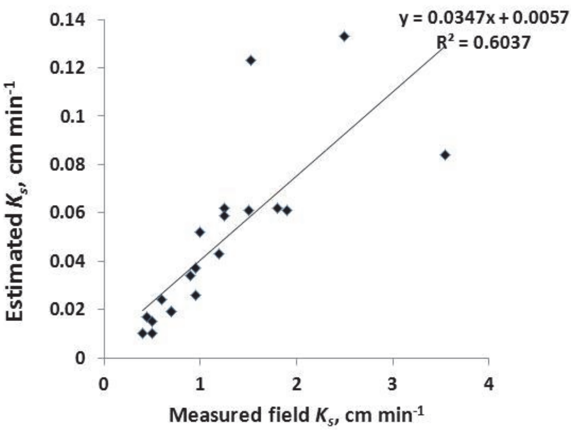


Fig. 5. Relationship between obtained and estimated field saturated hydraulic conductivity (K_s)

The DISC model was able to estimate the K_s (except for CT), but the estimated values of this parameter were different compared to observed ones. A complicated and unpredictable condition in the field (e.g. produced preferential flow) may be a probable reason for the difference between observed and estimated K_s (Haghighi et al., 2010) by DISC. An acceptable estimated K_0 may be resulted from measuring soil pore sizes in addition to the typical model inputs (soil texture, bulk density, and organic matter). Thus, selecting a suitable model or developing an appropriate model is an important and challenging task for application in the study region. In the present study, the no significant different of K_0, for the different managements, is attributed to unchanged soil particle size distribution (Table 1), because of considerable dependency of hydraulic conductivity on soil particle size distribution or texture (Mohammadi and Refahi, 2006; Rawls, 1992). In addition, field spatial variation can influence the measured values and consequently the correlation between estimated and measured K_{fs} values.

Table 2. Simulation result from van Genuchten model

Abandoned	*Parameter*	*Value*	*SE*	*Lower*	*Upper*	*θr*	*SSQ*	*R^2*
0-25 cm	***θs***	0.6616	0.0097	0.6347	0.6886			0.996
	α	0.5090	0.0422	0.3918	0.6262	0.0003	0.00038	
	n	2.0060	0.1094	1.7028	2.3106			
25-50 cm	***θs***	0.4900	0.0154	0.4471	0.5329			0.965
	α	0.3210	0.0533	0.1730	0.4690	0.0000	0.00096	
	n	1.9570	0.2992	1.1263	2.7878			
RT	***Parameter***	***Value***	***SE***	***Lower***	***Upper***	***θr***	***SSQ***	***R^2***
0-25 cm	***θs***	0.6109	0.0114	0.5791	0.6427			0.993
	α	0.4220	0.0364	0.3209	0.5231	0.0002	0.00053	
	n	2.0896	0.1483	1.6780	2.5014			
25-50 cm	***θs***	0.5440	0.0165	0.4981	0.5899			0.976
	α	0.4111	0.0763	0.1992	0.6231	0.0005	0.00110	
	n	1.8874	0.2416	1.2164	2.5584			
Compacted	***Parameter***	***Value***	***SE***	***Lower***	***Upper***	***θr***	***SSQ***	***R^2***
0-25 cm	***θs***	0.6237	0.0164	0.5781	0.6693			0.985
	α	0.7118	0.2292	0.0753	1.3483	0.0000	0.00108	
	n	1.5984	0.1695	1.1278	2.0690			
25-50 cm	***θs***	0.5118	0.0127	0.4766	0.5471			0.980
	α	0.2921	0.0242	0.2249	0.3593	0.0006	0.00065	
	n	2.2830	0.2598	1.5616	3.0045			
SAP	***Parameter***	***Value***	***SE***	***Lower***	***Upper***	***θr***	***SSQ***	***R^2***
0-25 cm	***θs***	0.7205	0.0170	0.6732	0.7678			0.991
	α	0.7036	0.1568	0.2683	1.1390	0.0000	0.0011	
	n	1.7655	0.1619	1.3159	2.2152			
25-50 cm	***θs***	0.4611	0.0188	0.4089	0.5134			0.936
	α	0.2368	0.0190	0.1840	0.2897	0.0004	0.00144	
	n	2.8746	0.6460	1.0811	4.6682			
Tilled	***Parameter***	***Value***	***SE***	***Lower***	***Upper***	***θr***	***SSQ***	***R^2***
0-25 cm	***θs***	0.5834	0.0080	0.5611	0.6057			0.996
	α	0.5318	0.0519	0.3878	0.6759	0.0001	0.00026	
	n	1.8539	0.0992	1.5785	2.1293			
25-50 cm	***θs***	0.5299	0.0140	0.4911	0.5688			0.983
	α	0.4462	0.0755	0.2364	0.6561	0.0002	0.00078	
	n	1.8717	0.2016	1.3120	2.4314			
CT	***Parameter***	***Value***	***SE***	***Lower***	***Upper***	***θr***	***SSQ***	***R^2***
0-25 cm	***θs***	0.6253	0.0135	0.5878	0.6629			0.992
	α	0.5684	0.0863	0.3288	0.8080	0.0004	0.00073	
	n	1.8880	0.1553	1.4568	2.3192			
25-50 cm	***θs***	0.4574	0.0103	0.4287	0.4861			0.983
	α	0.3062	0.0270	0.2313	0.3812	0.0002	0.00043	
	n	2.1603	0.2243	1.5376	2.7830			
NT	***Parameter***	***Value***	***SE***	***Lower***	***Upper***	***θr***	***SSQ***	***R^2***
0-25 cm	***θs***	0.6637	0.0122	0.6298	0.6977			0.994
	α	0.5975	0.0854	0.3602	0.8348	0.0002	0.00060	
	n	1.8353	0.1300	1.4744	2.1963			
25-50 cm	***θs***	0.5306	0.0158	0.4865	0.5747			0.974
	α	0.3920	0.0751	0.1834	0.6007	0.0002	0.0010	
	n	1.8528	0.2444	1.1741	2.5316			
FNT	***Parameter***	***Value***	***SE***	***Lower***	***Upper***	***θr***	***SSQ***	***R^2***
0-25 cm	***θs***	0.5719	0.0128	0.5362	0.6076			0.989
	α	0.3969	0.0358	0.2974	0.4964	0.0005	0.00066	
	n	2.1791	0.1836	1.6693	2.6890			
25-50 cm	***θs***	0.5304	0.0143	0.4907	0.5702			0.980
	α	0.4013	0.0672	0.2147	0.5879	0.0000	0.00082	
	n	1.8746	0.2175	1.2708	2.4785			

n: Empirical parameter; α: Empirical parameter (cm^{-1}); SE: Standard error; θ_s: Soil saturated water content ($cm^3\ cm^{-3}$), θ_r: Residual water content ($cm^3\ cm^{-3}$), SSQ: Sum of squared errors

Table 3. Values of soil hydraulic conductivity for different soil management treatments

K (cm min^{-1})	*Abandoned*	*RT*	*SAP*	*Compacted*	*Tilled*	*CT*	*NT*	*FNT*
K(0)	1.30a	0.84a	0.89a	0.98a	1.27a	1.71a	1.59a	0.67a
K(5)	0.47a	0.27 a	0.48a	0.44a	0.71a	0.63a	0.62a	0.24a
K(10)	0.15ab	0.14ab	0.20ab	0.19ab	0.29a	0.24ab	0.24ab	0.11b
K(15)	0.07a	0.09a	0.08a	0.10a	0.14a	0.11a	0.13a	0.07a

The K values sharing the same letters (a-d) are not statistically different at $p < 0.05$

3.6. Sorptivity and transmissivity factors

The sorptivity parameter, from the Philip's model, changed from 0.345 to 0.665 cm min^{-1} among the different treatments (Table 4). The sorptivity and transmissivity parameters did not show significant differences among treatments based on statistical analysis (at $p < 0.05$). In general, no significant difference in terms of sorptivity and transmissivity may be attributed to the no statistically difference in K_s and soil texture among treatments.

Table 4. Estimated sorptivity and transmissivity parameters for different soil managements

Treatment	*Log transmissivity (cm h^{-1})*	*Sorptivity (cm min^{-1})*
Abandoned	1.876 a	0.359 a
RT	1.670 a	0.440 a
SAP	1.696 a	0.452 a
Compacted	1.726 a	0.628 a
Tilled	1.843 a	0.650 a
CT	1.990 a	0.508 a
NT	1.953 a	0.665 a
FNT	1.570 a	0.345 a

The change in the sorptivity parameter revealed no distict pattern among treatments in the study region. This is in consistent with the obtained result of Machiwal et al. (2006) and Haghighi et al. (2010). In the other hand, soil pore size distribution can be an effective factor in observed changes in sorptivity (Machiwal et al., 2006). In general, probable reasons for no significant difference in the sorptivity and transmissivity parameters among management practices can be resulted from no significant change in effective porosity, soil texture, matric characteristics, and assumed preferential flow (Haghighi et al., 2010). Therefore, investigating the relationship between the sorptivity, transmissivity parameters and pore size distribution is a challenging task that needs to be further investigated.

4. Conclusions

Results of the present study revealed that soil compaction affects soil water storage only at a -1500 *kPa* potential in the top 25 cm of soil based on laboratory test. The results demonstrated that a higher microporosity can be expected upon compaction of abandoned soils. In addition, the saturated water content and field capacity were not statistically affected by the management. Moreover, since soil management did not influence water-fluxing macro- and medium porosity significantly, it was concluded that soil water retention at low suctions was not affected by the management practices.

The tillage practice did not affect the value of water-fluxing macro- and medium porosity and saturated hydraulic conductivity significantly. The fit of the van Genuchten equation to the measured data resulted in a low *SSQ* and high R^2. The effect of soil management and tillage practices on sorptivity and transmissivity parameters was not also significant. Unsaturated hydraulic conductivity may partly be affected by soil texture and structure which were uniform under all management and tillage practices.

Soil water retention and transmission may be manipulated with changes in pore size distribution under different tillage and management practices in long-term. Therefore, additional research is crucial to investigate the relationship between the sorptivity, transmissivity parameters, and pore size distribution in long-term.

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