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Evaluation of Soil Hydraulic Parameters in Soils and Land Use Change

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1. Introduction

The knowledge of soil water properties and land-use effects on these properties are important for efficient soil and water management. Furthermore, the use of the pedotransfer functions (PTFs) to estimate soil water content (θ_h) is important to assess. The loosening effect of dryland farming on soil water retention is known. In this chapter we review soil water content, pedotransfer functions and some infiltration models applicability for two land-use types. The land-use effect on soil water retention may be significant at water potentials of -33 *kPa* and 0 *kPa* in the soil. At the -1500 *kPa* pressure head, water content may not be affected by cultivation of rangeland at different soil depths. In addition, pedotransfer functions can be used as a physically based model for soil water retention characterization in the various areas. Moreover, it is essential to evaluate the infiltration models applicability for different soils and various land-uses.

1.1 Definition

1.1.1 Soil hydraulic properties

Soil hydraulic properties govern transport processes and water balance in soils. Water retention capacity, infiltration rate, and saturated hydraulic conductivity are important soil hydraulic properties. Soil water retention and saturated hydraulic conductivity (K_s) are necessary input data for the simulations of water flow in soil and water engineering. Characterizing hydrological behavior of catchments requires knowledge of hydraulic parameters.

1.1.2 Soil water retention

Soil water retention at field capacity (*FC*) and permanent wilting point (*PWP*) are used to estimate the water depth applied by irrigation (Hansen et al., 1980), and to calculate water availability, as a crucial factor to assess the land area suitability for crop producing (Sys et al., 1991).

2. Soil water retention capacity and land use

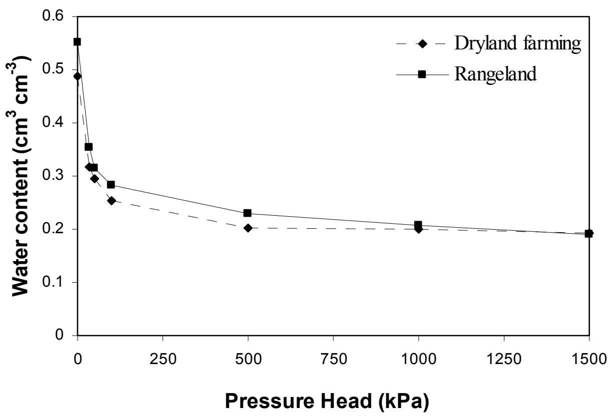
One important soil hydraulic property is water retention capacity, which affects soil productivity and management. Soil water content (θ_h) governs the transport characteristics of water and solutes in soils. The knowledge of water retention capacity and land use effects on this property is important for efficient soil and water management. Upon conversion of natural lands to cultivated fields, water retention capacity is strongly influenced (Schwartz *et al*., 2000; Bormann and Klaassen, 2008; Zhou *et al*., 2008). Soil water retention at field capacity (*FC*) and permanent wilting point (*PWP*) are important to estimate the irrigation water depth which may be affected by land use change. Soil water retention characteristic, is affected by soil organic matter (SOM) content and porosity, which are significantly influenced by land use type (Zhou *et al*., 2008).

We conducted a study to evaluate, document, and quantify the effect of cultivation of rangeland on soil water retention in field capacity (*FC*), permanent wilting point (*PWP*), and to test the use of the van Genuchten equation to estimate θ_h in cultivated and natural lands in the same soils of the Taleghan watershed in Iran.

Significant differences in the OM and bulk density (BD) were observed between dryland farming and rangeland at both depths of 0 cm - 15 cm and 15 cm - 30 cm. Soil sample water contents at different pressure heads under both land use types are presented in Figures 1. The overall measured and fitted soil water retention curves did not show significant difference within the selected water potentials for both land use types in this study. However, measured θ_s (0 *kPa*) values were found to be significantly lower for dryland farming when compared with rangeland at depths of 0 cm - 15 cm and 15 cm - 30 cm, respectively. Moreover, the land use effect on soil water retention was significant at a water potential of -33 *kPa* (*FC*) based on laboratory measurements only at the top (15 cm depth). The results indicated that the conversion of rangeland to dryland farming led to a significant decrease (16.56% on average) in the *FC* at a depth of 0 cm - 15 cm. The mean -1500 *kPa* (*PWP*) water content was not affected by the land-use type. Figure 1 indicates that the mean total field capacity (*FC*) was significantly greater in rangeland when compared with dryland farming at a depth of 0 cm - 15 cm. In this study, there were not statistically significant differences in water content at other potentials (-50 *kPa*, -100 *kPa*, -500 *kPa*, and -1000 *kPa* pressures) between the two types of land use presented in Figure 1. At those pressure heads and at a -1500 *kPa* water content, the amount of micropores were not affected by cultivation of rangelands (Fig. 1). Overall, the results showed that the soil pore system and reduced total porosity under dryland farming can decrease water storage capacity at water potentials of -33 *kPa* and 0 *kPa*. Ndiaye et al., (2007) has shown that improper soil management decreases the soil macroporosity in the long-term affecting the θ_s. The data obtained in our study demonstrated the loosening effect of dryland farming on soil water retention. Previous studies on the effect of land use have demonstrated clear changes in soil physical properties, such as soil porosity, SOM, and BD, in relation to hydraulic properties (Bormann and Klassen 2008; Haghighi et al., 2010b).

3. Pedotransfer functions (PTFs)

Determination of soil water properties required as input data for simulation models is time consuming and relatively costly (Wösten *et al*., 1995). Thus, indirect estimation of these characteristics has been proposed as one alternative to direct estimation of the soil hydraulic parameters based on the measured water retention data. Pedotransfer functions (PTFs) are emerged as the relationship between soil hydraulic and other more available measured properties (Bouma, 1989) which can be used to estimate hydraulic parameters. PTFs are useful tools for modeling applications.



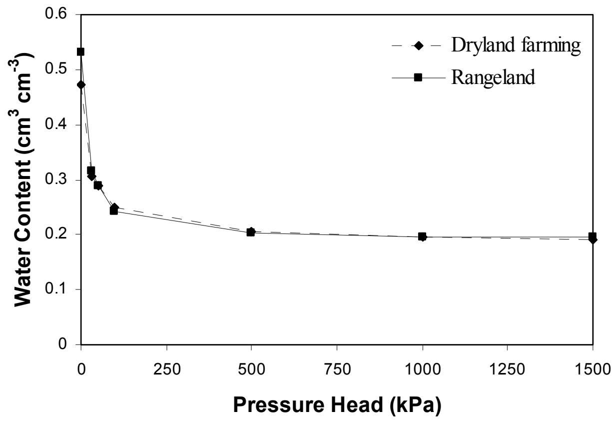


Fig. 1. Soil water content as a function of the pressure head for two landuse types at depths of (a) 0 cm -15 cm and (b) 15 cm - 30 cm.

4. Pedotransfer functions (PTFs) and different land uses

To estimate the land use effects on soil water retention, van Genuchten model (Van Genuchten, 1980) may be applied. Some researches have correlated van Genuchten parameters with soil organic matter, bulk density (BD), and soil particle size distribution and many researchers have estimated the water retention curve using soil texture, bulk density, and porosity.

Many statistical equations (pedotransfer functions) characterizing the water retention curve have been presented (Kutilek and Nielsen., 1994). PTFs are useful tools for modeling applications. Such analytical functions are derived involving various soil data. Such data are measured in the field and laboratory analysis. Soil hydraulic parameters derived through PTFs can be used to express soil hydraulic properties and water retention (Brooks and Corey, 1964). Consequently, physically based models such as van Genuchten representing a pedotransfer function may be considered as a valuable tool to simulate the soil water properties in different land uses.

The $\theta_{(h)}$ data may be fitted to van Genuchten equation to derive retention curves and parameters (a, n, and θ_r), using the RETC (RETention curve) optimization computer code (Van Genuchten *et al.*, 1991). The van Genuchten model (van Genuchten, 1980) is defined as:

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

Where $\theta_{(h)}$ ($cm^3\ cm^{-3}$) is the volumetric water content (for h<0), θ_r ($cm^3\ cm^{-3}$) is the residual water content, and θ_s ($cm^3\ cm^{-3}$) is the saturated water content. Here, m is 1-(1/n) with n>1. a (cm^{-1}) and n are empirical parameters determining the shape of the curve which were obtained for each core. Parameter n is related to steepness of the water retention curve.

$$K(S_e) = K_s S_e[1-(1-S_e^{(1/m)})^m] \tag{2}$$

Where K_s (mm/h) is saturated hydraulic conductivity and S_e is the effective saturation expressed as:

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} \tag{3}$$

The effect of landuse type on soil water retention and PTF applications have not been documented for different land-uses to the best of our knowledge. In developing countries, there is a lack of large databases that are needed to develop PTFs. Thus, in many developing countries, the use of available PTFs can cause errors for estimating soil hydraulic properties. This encourages further investigations of the model applications and development of suitable point and parametric PTFs for estimating soil hydraulic properties in the studied area. The selection of more suitable PTFs for application where there are not developed PTFs caused by a lack of large databases is difficult. Consequently, it is essential to evaluate the model applicability and to develop point and parametric PTFs for estimating soil hydraulic properties for the soils in various sites. Thus, the estimates may be improved by comprehensive local studies.

Location (site)	Depth: 10–20 cm					Depth: 25–50 cm				
	K_{sat} (cm/day)	θ_{sat} (–)	α (1/cm)	l (–)	n (–)	K_{sat} (cm/day)	θ_{sat} (–)	α (1/cm)	l (–)	n (–)
A	16.0	0.43	0.007	0.944	1.37	23.1	0.43	0.014	−0.350	1.41
B	16.0	0.42	0.007	0.331	1.36	15.8	0.40	0.009	−0.448	1.33
C	17.4	0.40	0.008	0.093	1.35	14.7	0.38	0.010	−0.482	1.33

Table 1. Mualem-van Genuchten parameters calculated for old grassland (site A), recently reseeded grassland (site B) and previous maize cultivated land (site C) (Sonneveld et al, 2003)

5. Evaluation of common infiltration models for different land-uses

The evaluation of infiltration characteristics as a hydrologic process in soils is necessary in agricultural studies. The knowledge of final steady infiltration rate is important for irrigation water efficiency, designing desirable irrigation systems, and loss of water. Thus, infiltration rate is important factor in sustainable agriculture, effective watershed management, surface runoff, and retaining water and soil resources. Since measuring the final infiltration rate is time consuming, several physical and empirical models have proposed to determine it. The empirical models such as Kostiakov (1932) and Horton (1940), and physical model such as Philip (1957) are the most common models to estimate infiltration rate of the soils.

5.1 Kostiakov-Lewis model

The model of Kostiakov modified for long times as follows:

$$f = at^{-b} + f_c \tag{4}$$

Where a and b are the equation's parameters ($a>0$ and $0<b<1$). i_c is the steady infiltration rate (LT^{-1}).

5.2 Horton's model

The Horton's infiltration model (Horton, 1940) is expressed as follows:

$$f = \left(f_0 - f_c\right)e^{-kt} + f_c \tag{5}$$

Where i_c is the presumed final infiltration rate (LT^{-1}), i_0 is the initial infiltration rate (LT^{-1}) and t is time (T). k is the infiltration decay factor.

5.3 Philip two-parameter model

The Philip two-term model is expressed as (Philip, 1957):

$$f = \frac{1}{2}St^{-0.5} + A \tag{6}$$

Where f is the infiltration rate (LT^{-1}) as a function of time.
A= Transmissivity factor (LT^{-1}) as a function of soil properties and water contents, S = Sorptivity that is function of soil matric suction ($LT^{-0.5}$).
t= time (T)
Singh (1992) expressed that the various models can estimate different values of the final infiltration rate in a soil which seems to be uncorrect, because of the final infiltration rate is a soil-dependent factor. Compared to the previous investigations on soil infiltration properties and models, studies on soil infiltration modelling depending on land use are scarce. Nevertheless, it can be assumed that landuse type have a significant impact on soil infiltration and infiltration models performance. Machiwal et al (2006) observed the infiltration process was well described by the Philip’s model in a wasteland of Kharagpur, India. However, different soil management that influences the final infiltration rate is a major reason for different applicability of these models. Long-term effects of land use changes on soil infiltration and infiltration models (e.g., Horton, Kostiakov, and Philip models) can be observed (Navar and Synnott, 2000; Shukla et al, 2003).
Thus, the variability of soil infiltration characteristics and goodness of fit of the infiltration models for different land-uses should be considered during infiltration modelling studies helping on correct predictions of final infiltration for different land uses. Ability of these models for estimating the infiltration rate in different land-uses and soil management has been examined by some researchers. Gifford (1976) observed among the Horton, Kostiakov and Philip's models, the Horton's model was the best model to fit the infiltration data in mostly semi-arid rangelands from the Australia, but only under specific conditions. Shukla et al (2003) evaluated some of the infiltration models at different soil management and land-use systems in Ohio and observed among infiltration models, the Swartzendruber model was the best ones and fitted the observed infiltration data with lower sum of squares and higher model efficiency. Davidoff and Selim (1986) examined the goodness of fit for eight infiltration models on a Norwood soil with four winter cover crop treatments and results of their study showed that the Philip, Kostiakov and Horton's models had best predictions than the other models. Haghighi et al (2010b) evaluated the effects of rangeland and dryland farming land uses on performance of some infiltration models to estimate the final infiltration rate of soils. The study was conducted on some soils of Taleghan watershed, Iran. According to reports (Taleghan watershed study report, 1993), investigated soils are calcareous and classified as Typic Xerorthents. Mean annual rainfall alters from 464 to 796 mm and lands slope is by 15 %. The soil texture varied from clay-loam to silty clay loam.

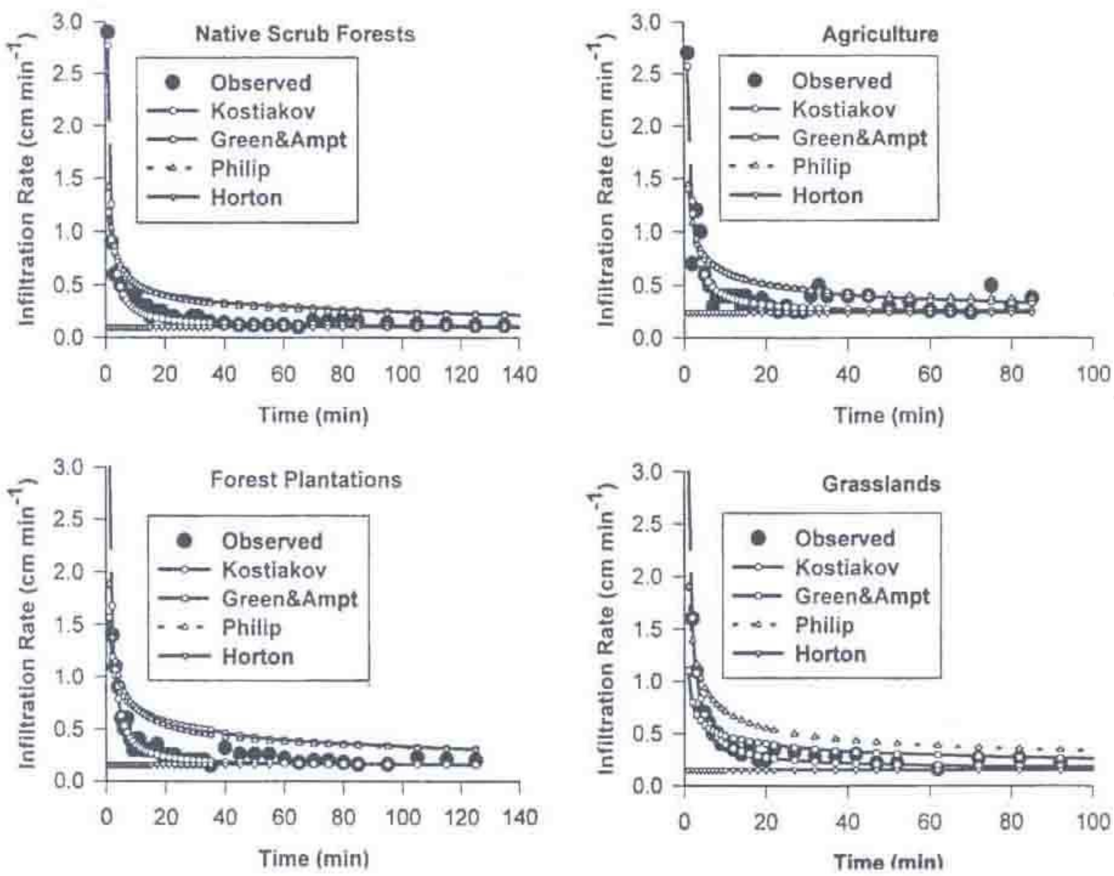


Fig. 2. Effects of land use changes on soil infiltration and infiltration models (Navar and Synnott, 2000)

In our study, the goodness of the fit of selected models and ability of them for estimating the final infiltration rate of rangeland and dryland farming soils was evaluated using the root mean squared errors (RMSE). The values of R^2 were determined high (0.99) and equal for all sites and land-uses, but the values of RMSE and the final steady infiltration showed that the estimated infiltration rates by the infiltration model of Horton, approached more closely to the measured ones at the selected area [Table 1]. The Horton's model was the best model selected for both of land-uses. It can be expressed that various models can suppose different final infiltration (f_c) values for a soil, which seems to be not practical, because f_c is a soil-dependent parameter, in general. Common changes in land-use negatively affect soil physical properties and decrease soil infiltration rate and could change modelling performance. Effect of land-use should be well documented aiming on good predictions in the studied areas and elsewhere.

The infiltration models can be used for estimating the infiltration rate in soils, well. But only, one or some of these models are better and appropriate for a specific site. Thus, the infiltration models should be analyzed for their ability to estimate the infiltration rate of each location. The investigation of Haghighi et al (2010a) showed that the Horton's model is the best ones selected for rangeland and dryland farming and land-use type is not an important factor to affect infiltration models efficiency. Due to a few number of investigation in this field of research, there is a need for further investigation on land-use effect on infiltration modelling and for the impact of land-use on soil infiltration characteristics, as well.

Land use	Kostiakov-Lewis model			Philip two-term model		Horton's model			Observed final infiltration rate (cm min^{-1})
	c	b	a	S	A	β	f_0	f_c	
Rangeland 1	0.2052	0.543	1.136	1.217	0.223	0.130	0.894	0.299	0.2803
Rangeland 2	0	0.770	1.058	1.322	0.235	0.021	0.596	0.190	0.2441
Rangeland 3	0.0870	0.606	0.839	0.970	0.127	0.090	0.556	0.183	0.1613
Rangeland 4	5.13×10^{-14}	0.855	0.5076	0.543	0.208	0.045	0.387	0.225	0.2285
Dryland farming 1	0.0585	0.636	1.475	1.741	0.162	0.085	0.909	0.258	0.2347
Dryland farming 2	0	0.522	2.863	2.984	0.018	0.120	1.601	0.200	0.1863
Dryland farming 3	1.37×10^{-12}	0.781	0.4857	0.592	0.119	0.029	0.290	0.120	0.1098
Dryland farming 4	0.0452	0.681	0.2555	0.315	0.073	0.071	0.198	0.089	0.0869

Table 2. Parameters of the selected infiltration models in both of land use types (Haghighi et al, 2010a)

6. Conclusions

Soil management and land use change may affect soil water retention at a -33 *kPa* (*FC*) potential in the soil based on laboratory measurements and model simulations. Lower water content at the -33 *kPa* potential would be expected upon conversion of natural lands to cultivated lands. In addition, the saturated soil water content (θ_s) may be affected by cultivation of rangeland. Moreover, because cultivation of natural lands affects soil macroporosity, we suggest measuring soil water retention at higher suction heads to document the land use effect on soil water retention properties in relation to soil macropores. Appropriate technology for dryland farming and suitable measures are necessary to improve soil water retention where cropping is required.
The findings show that the van Genuchten model is useful in describing soil water retention. Thus, use of this model may be considered as a valuable tool to gain more knowledge of hydraulic properties for various soil types. The effect of land use type on soil water retention and PTF applications have not been documented for dryland farming to the best of our knowledge. In many developing countries, such as Iran, the use of available PTFs can cause errors for estimating soil hydraulic properties. This review encourages further investigations of the model applications and development of suitable point and parametric PTFs for estimating soil hydraulic properties. The selection of more suitable PTFs for application where there are not developed PTFs caused by a lack of large databases is difficult. Consequently, it is essential to evaluate the model applicability and to develop point and parametric PTFs for estimating soil hydraulic properties for different land uses.

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We are increasingly faced with environmental problems and required to make important decisions. In many cases an understanding of one or more geologic processes is essential to finding the appropriate solution. Earth and Environmental Sciences are by their very nature a dynamic field in which new issues continue to arise and old ones often evolve. The principal aim of this book is to present the reader with a broad overview of Earth and Environmental Sciences. Hopefully, this recent research will provide the reader with a useful foundation for discussing and evaluating specific environmental issues, as well as for developing ideas for problem solving. The book has been divided into nine sections; Geology, Geochemistry, Seismology, Hydrology, Hydrogeology, Mineralogy, Soil, Remote Sensing and Environmental Sciences.