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Temporal variability of surface soil hydraulic properties under various tillage systems

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ABSTRACT

Any disturbance of the surface soil layer, caused either by natural factors, such as rain, or by human interventions, such as cultivation result in changes of the characteristics of its pore space. Such changes seriously affect the hydraulic properties of that layer and consequently the water budget of the whole soil profile. The purpose of this study was to follow the temporal variations of the hydraulic properties of the surface soil layer, cultivated and kept bare (RT), uncultivated and kept bare (NT) and uncultivated but covered by local weed vegetation (NV), and to detect their influence, on the infiltration of rain water. For this purpose, the hydraulic conductivity at saturation (K_s) and soil water retention curves (SWRCs) were determined on undisturbed soil samples extracted from the surface layer under the three different treatments during the period of three years. Samples were collected after each rainfall event but also at intermediate times. Further the changes of the water volume retained in the soil profile up to 1 m depth were followed after each rainfall event in order to estimate the amount of water infiltrated and stored into the soil profile after each event. Remarkable variations of K_s over time were detected for the RT and NT treatments, with minimum values prevailing during rainy and maximum ones during dry periods. On the contrary, K_s for the NV treatment varied only slightly through the two periods, although minimum values were measured again during the rainy periods, which however were about two times greater than those for RT and NT treatments. Pore size distributions revealed by the soil water retention curves, obtained on samples taken from all plots, exhibited remarkable variation over time, particularly in the case of pores draining in the range of soil water pressure head (h) down to −60 cm. The time variation of measured K_s values could be related to the pore size distribution changes observed. Considerable differences of the rain water stored in the soil were recorded, with those of the NV treatment being almost twice as high than those for the RT and NT treatments.

1. Introduction

The study of soil hydraulic properties of the surface soil layer is of importance, since they regulate the entry of rain or irrigation water into the soil profile but also its runoff when rainfall intensity exceeds the infiltration capabilities of the soil. Any disturbance of this layer may affect its properties not only immediately after its application but also their variability behavior at later stages. Extensive research on the effect of various treatments applied on these properties has been conducted, but focused mainly on the immediate effect of disturbances and their spatial variability (Strudley et al., 2008; Lindstrom and Onstad, 1984; Mapa et al., 1986; Poulovassilis, 1990; McGarry et al., 2000; Kribaa et al., 2001; Moret and Arrue, 2007; Benjamin, 1993; Mahboubi et al., 1993; Azooz and Arshad, 1996, 2001; Ehlers and van der Ploeg, 1976; Kargas et al., 2012). However, relatively less research work has been conducted on the time variability of the soil hydraulic properties at later stages following the treatments applied. Angulo-Jaramillo et al. (2000) reported findings of soil hydraulic properties' time variability in two soils (sand and sandy loam) covered by corn plants using tension infiltrometers. In the sandy soil, where furrow irrigation had been applied, a remarkable decrease of K_s, and more generally of hydraulic conductivity function $K(h)$ was observed at the end of the irrigation period relative to the respective values at the beginning of irrigation. On the other hand, in the sandy loam soil the temporal change in $K(h)$ was less pronounced. Or et al. (2000) presented a model that described temporal changes of the soil hydraulic properties after tillage based on the evolution of the pore size distribution as this was obtained by numerically solving a Fokker Plank type

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differential equation (Risken, 1989) which was assumed to govern the pore size distribution as a function of time and pore radius. Xu and Mermoud (2001) investigating the effect of tillage practices on topsoil properties in a typical silt loam soil in a maize field found that K_s was exponentially related to the soil bulk density (ρ_b) and that it decreased with time over the growth period. It was shown that a 10% increase of ρ_b resulted in a 50% or higher reduction of K_s. Bulk density varied between 1.15 and 1.40 g cm^{-3}. Hu et al. (2012) also found that the time variability of K_s was related to the change of bulk density in natural landscapes with few human activities. Their results indicated that K_s was more susceptible to temporal change than ρ_b. Leij et al. (2002) considering further the basic idea of the work of Or et al. (2000) presented an analytical solution of the Fokker Plank equation through which one could predict the temporal pore size distribution evolution after tillage for certain cases and investigated the possibility of its application for the SWRC and $K(h)$ prediction. The study showed that SWRC prediction was rather satisfactory, while $K(h)$ prediction based on the conceptual model of Mualem (1976) was poor compared with the measured $K(h)$ values. This poor prediction was attributed to the model providing pore size distribution, which did not incorporate additional mechanisms for the reduction in structural pore space. Moret and Arrue (2007) investigated the dynamics of soil hydraulic properties during a long-term field experiment under three different cultivation practices (conventional tillage CT, reduced tillage ReT and no tillage NT) based on tension infiltrometer measurements. They found $K(h)$ near saturation under NT to be smaller than under CT although the pore space under the former treatment contained macropores (draining in the h range 0 to −3 cm, Luxmoore, (1981)) which were missing under the latter one. This was attributed to the increase of the relative volume of mesopores, draining in the h range from −3 to −300 cm (Luxmoore, 1981). They also reported that soil reconsolidation following post-tillage rains reduced hydraulic conductivity (K) with time at a rate that increased with the intensity of the rainfall event. Zhou et al. (2008) studied the behavior of surface hydraulic properties and their temporal changes in four soil series under different land uses. For three consecutive years (2004–2006) in May and October they were measuring $K(h)$ at h values 0, −1, −2, −3, −6, and −12 cm. The statistical analysis indicated that the measurement time (May or October) had the greatest impact on all measured $K(h)$, while the land use and soil series had different impacts on specific values of $K(h)$ e.g. at different h-values. Hu et al. (2009) found that soil hydraulic properties were changing with time irrespectively of the land use. Schwen et al. (2011a) presented findings of soil hydraulic properties' time variability for two consecutive years in a wheat field. In their experiments, they examined, by using tension infiltrometers, the influence of three cultivation practices (CT,ReT,NT) on the soil hydraulic properties and on how these hydraulic properties changed in time. They found that at given h (−1, −4, and −10 cm) the corresponding $K(h)$ values followed the order CT > ReT > NT with the maximum difference at $h = -10$ cm. From the $K(h)$ data the authors estimated the appropriate parameters of the van Genuchten (1980) equation, α and n. They found that n presented very little time variability and kept similar values in all three cultivation treatments. Contrary to this, parameter α presented a quite large time variability and also large deviations among treatments in the order CT < ReT < NT. They also observed a decrease in the relative volume of the hydraulically active pores during the winter period, while in spring and summer this volume increased gradually. They argued that rainfall intensity as well as wetting–drying cycles were responsible for the above changes. Schwen et al. (2011b) comparing simulated and observed data in terms of soil water content and water storage near the soil surface showed that inclusion of the temporal variability of the soil hydraulic properties improved the simulation performance.

In the studies mentioned above the hydraulic properties were determined from the infiltration data provided by tension infiltrometers while in the present study, they were determined on undisturbed soil samples.

The objective of this study was to investigate the temporal variations of the SWRCs and K_s of the surface soil layer, rototilled and kept bare (RT), undisturbed and kept bare (NT) and undisturbed but covered by local weed vegetation (NV), and to detect their influence, on the infiltration of rain water. It has to be mentioned that rototillage is extensively applied for weed control and for the preparation of seed-beds. Soils covered by local weed vegetation are met in farm lands left idle. Bare soils often appear after conflagrations of bush and wood lands. Thus, the main incentive of our work was to study comprehensively the effect of the three treatments applied on the soil surface, which are met widely under agricultural and natural conditions, on the hydraulic properties of that layer and consequently on the volume of the rain water stored in the soil profile.

2. Materials and methods

2.1. Treatments of the surface layer and sampling strategy

Experiments have been conducted in a level field of the Agricultural University of Athens, (Attica, Greece). Soil textural composition data up to a depth of 1 m is shown in Table 1. From this data the soil may be classified as loam of the Typic xerofluvent and according to SWRB classification (IUSS, 2007) as eutric fluvisol. This soil had been left uncultivated for some years before the initiation of the experiment. During that time it was covered by local weed vegetation.

Table 1
Soil textural composition of soil up to 100 cm for A–D experimental plots.

Plots	Depth	Sand (%)	Silt(%)	Clay(%)	
A	0–10	38.8	39.5	21.7	Loam
	10–20	37.3	39.0	23.7	Loam
	20–30	35.0	42.6	22.4	Loam
	30–40	32.0	41.6	26.4	Loam-CL
	40–60	32.0	40.6	27.4	Loam-CL
	60–100	34.4	35.9	29.7	Clay Loam
B	Depth	Sand	Silty	Clay	
	0–10	50.5	36	13.5	Loam
	10–20	40.6	35.6	23.8	Loam
	20–30	38.8	40.6	20.6	Loam
	30–40	32.8	44.3	22.9	Loam
	40–60	35.3	41.8	22.9	Loam
	60–100	38.9	36.1	25.0	Loam
C	Depth	Sand	Silty	Clay	
	0–10	34.3	40.3	25.4	Loam
	10–20	30.8	44.0	25.2	Loam
	20–30	34.8	40	25.2	Loam
	30–40	29.3	45.7	24.9	Loam
	40–60	31.4	45.7	22.9	Loam
	60–100	35.4	37.8	26.8	Loam
D	Depth	Sand	Silty	Clay	
	0–10	39.8	40.6	19.6	Loam
	10–20	40.1	37.3	22.6	Loam
	20–30	43.0	33.7	23.3	Loam
	30–40	37.0	39.4	23.6	Loam
	40–60	22.4	46.3	31.3	Clay Loam
	60–100	14.4	42.0	43.6	Si-clay loam

Plot A: rototilled 2010 (RT) and during the years 2011–2014 was untilled (NT); Plot B: rototilled (RT); Plot C: no tillage (NT); Plot D: natural vegetation (NV).