Differences in topsoil properties of a sandy loam soil under different tillage treatments

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Abstract

Soil tillage is one of the key soil management practices in agricultural land use. Hydraulic conductivity of the surface layer modifies water infiltration into the soil profile and possible runoff formation. The treatment of the surface layer affects the soil pore system (distribution and connectivity of macroscopic cracks, voids, holes, etc.). The aim of this study was to evaluate an effect of different tillage treatments on soil hydrophysical properties in the top layer of a sandy loam soil. The tillage treatments were as follows: conventional plough, shallow plough, minimum tillage, direct drill and no-treatment. The effect of wheel traffic was also evaluated by measuring the infiltration rates in the wheel marks. An automated tension infiltrometer (Špongrová *et al.,* 2009) was employed to measure the infiltration rates. The following soil characteristics were calculated: hydraulic conductivity function K (h), hydraulic conductivity at saturation K_s, numbers of macro- and mesopores per m^2 of soil. The ANOVA results show that the plot with no-treatment and minimum tillage had higher $K(h)$ values near saturation than the tilled soils which did not differ significantly from each other. The wheel traffic led to soil compaction and a significant reduction in the hydraulic conductivity close to saturation.

Key Words

Soil properties, hydraulic conductivity, tillage, wheel traffic

Introduction

Tension infiltrometry is a useful *in situ* technique commonly used to estimate the hydraulic conductivity of the soil matrix near saturation without the influence of preferential flow usually affecting measurements of hydraulic conductivity in saturated conditions. This allows one to characterise the infiltration capacity of hydraulically active and fast water-conducting macro- and mesopores *in situ* (Bodhinayake *et al.,* 2004), which is essential for understanding the influence of soil and water management practices on water infiltration and solute and contaminant transport as well as temporal changes and spatial variability of surface hydraulic properties.

Methods

Field experiments

Infiltration tests were carried out in the field on Cranfield University farm between 27th July and 12th August 2006 on a sandy loam soil (Cottenham series). The texture of the soil was 63% sand, 23% silt and 15.0% clay. Five different tillage treatments were tested: conventional tillage (CT, depth 25 cm), shallow plough (SP, depth 12.5 cm), minimum tillage (MT, depth 12.5 cm), direct drill (DD, 7.5 cm) and no-treatment (NT, untreated soil, no plants sieved). The soil ploughing and cultivation were carried out on 24 April 2006, and drilling on 4 May 2006. In three of the treatments (CT, MT, and NT) infiltration tests were also carried out in the wheel-marks created by wheel-traffic after the tillage. The weather conditions during the period between the soil cultivation and the experimental period were relatively warm and dry. Monthly averaged maximum temperatures ranged between 12.8°C (April) and 26.6°C (July); total amounts of precipitation (rain) ranged between 16 mm (June) and 99.2 mm (August); May was also relatively rainy with 87.8 mm of precipitation. Three fully automated tension infiltrometers connected to a single Mariotte bottle (Špongrová *et al.,* 2009) were used to determine the infiltration rates for soil near saturation for each treatment. The soil surface was smoothed and levelled before the infiltrometers were placed onto the plots. The sandy loam soil was relatively easy to smooth and level using a knife, and good hydraulic contact was achieved without the need for any contact material creating an additional layer. The replicates were placed approximately 1 m apart. Infiltration measurements were performed for 8 water pressure heads in the following order: -13, -11, -9, -7, 5, -3, -2 and -1 cm. The tensions were set to change automatically every 60 minutes. The datalogger sampling interval for the water level measurements in the reservoirs was set to 3 minutes. When the measurement was finished, three undisturbed soil samples (100 cm^3, sampling depth 0-6 cm) were taken from below each infiltration surface. The soil during the sampling was almost saturated, however, no visible change in the soil structure or soil compaction due to the weight of the infiltrometer was observed. The samples were weighed and left to saturate on wet filter paper immersed in water. Initial and final volumetric moisture content as well as moisture content at saturation and dry bulk density were determined by oven-drying the undisturbed soil samples at 105°C for 48 hours.

Data analysis

Šimůnek and van Genuchten (1996, 1997), and Šimůnek *et al.* (1998) proposed an inverse numerical method to estimate the parameters of the hydraulic conductivity function from transient infiltration data from disc infiltrometers. The soil hydraulic functions are commonly described by the expressions defined by Mualem (1976) and van Genuchten (1980). HYDRUS-2D model (Šimůnek *et al.*, 1999) was used for the numerical solution of the Richards' equation and to estimate the hydraulic parameters (θ_r, θ_s, α, n and K_s) by minimising the sum of squared deviations between observed and simulated cumulative infiltration. The values of θ_s were determined in the laboratory by saturation and oven-drying of three undisturbed soil samples, while θ_r, α, n and K_s were used as fitting parameters in the inverse modelling procedure. To evaluate the amount of meso- and macropores present in the soil for each tillage treatment, number of conductive pores per unit area N_h characteristic was used. The expression reported by Reynolds *et al.* (1995) was used to estimate the N_h value needed to observe the particular value of $K(h)$. The same criteria as in Moret and Arrúe (2007) were used to define macro- and mesopores. Pores that drain at pressure heads close to saturation with a lower pressure head limit of -4 cm were defined as macropores; and pores draining at lowerer pressure heads with an upper limit of -4 cm (in this study pressure heads between -4 and -13 cm) were defined as mesopores.

Statistical analysis

Analysis of variance (significance level 0.05) was performed to determine whether the different tillage treatments and wheel traffic had a significant effect on $K(h)$ or not. In order to obtain normally distributed data, Log_{10} (logarithm to the base of 10) transformed $K(h)$ data were used for the analysis.

Results and discussion

The infiltration experiments were carried out approximately three months after the soil cultivation, the sandy loam soil had already consolidated and no large differences in dry bulk densities between tilled and untilled plots were observed. The mean of the initial and final moisture content as well as that of the soil moisture content at saturation and the dry bulk density are summarised in Table 1 for each of the treatments. The HYDRUS-2D results, the fitting parameters θ_r, K_s, α and n, together with the coefficient of determination R^2, averaged over the three replicates, are presented in the left part of Table 2.

The values of $K(h)$ for CT, ranged between 0.0010 cm min^{-1} at tension -12 cm and 0.5125 cm min^{-1} at saturation. The ranges of $K(h)$ for other tillage treatments were as follows: 0.0010 to 0.6473 cm min^{-1} for SP, 0.0025 to 0.5345 cm min^{-1} for MT, 0.0011 to 0.5162 cm min^{-1} for DD, and 0.0012 to 0.5404 cm min^{-1} for NT. Figure 1 shows the mean Log $K(h)$ values calculated for each tension using the hydraulic functions obtained by numerical inversion for the different tillage treatments. The results show the soil with MT had a significantly higher hydraulic conductivity than all the other treatments (CT, SP, DD, NT) at almost all tensions except at saturation. In addition, the differences were, in general, larger at higher tensions.

Table 1. Mean initial ($\theta_{initial}$), final (θ_{final}), and water content at saturation (θ_s), and dry bulk densities (ρ_d) for each tillage treatment.

Tillage treatment	$\theta_{initial}$ ($cm^3\ cm^{-3}$)	θ_{final} ($cm^3\ cm^{-3}$)	θ_s ($cm^3\ cm^{-3}$)	ρ_d ($g\ cm^{-3}$)
CP	0.100	0.293	0.348	1.39
SP	0.081	0.283	0.323	1.39
MT	0.098	0.260	0.332	1.41
NT	0.089	0.281	0.350	1.43
DD	0.099	0.331	0.380	1.45
MT wheel mark	0.126	0.276	0.363	1.48
CP wheel mark	0.110	0.303	0.356	1.50
NT wheel mark	0.089	0.281	0.350	1.50

Table 2. HYDRUS-2D model parameters for each tillage treatment; scaling parameter of the van Genuchten's equation α, curve shape parameter of van Genuchten's equation n, hydraulic conductivity K_s at saturation, residual soil water content θ_r, and coefficient of determination for measured and modelled infiltration rates R^2 (left part). The right part of the table contains information about numbers of macropores and mesopores per unit area calculated for each tillage treatment.

Tillage treatment	α (cm^{-1})	n (-)	K_s ($cm\ min^{-1}$)	θ_r ($cm^3\ cm^{-3}$)	R^2	Numbers of macropores per m^2	Numbers of mesopores per m^2
CP	0.169	1.464	0.419	0.050	0.998	122	542
SP	0.175	1.549	0.460	0.062	0.998	153	711
MT	0.147	1.392	0.467	0.050	0.999	177	824
NT	0.189	1.519	0.499	0.050	0.998	161	842
DD	0.192	1.462	0.501	0.050	0.998	150	586
MT wheel mark	0.121	1.473	0.259	0.050	0.999	91	488
CP wheel mark	0.110	1.681	0.234	0.050	0.999	70	649
NT wheel mark	0.186	1.440	0.240	0.050	0.998	66	377

Conversely, the tilled soils did not differ significantly from each other and formed a homogeneous group together with plots with DD and NT. Furthermore, the highest *K(h)* values were measured on the plot with MT, and the corresponding Log *K(h)* values were significantly larger than those of the NT treatment for tensions higher than 2.5 cm.

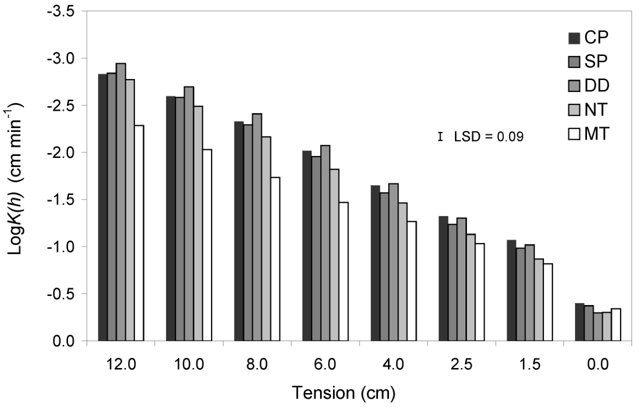

Figure 1. Log *K(h)* values calculated for each applied tension (-13, -11, -9, -7, -5, -3, -2, and -1 cm) using the hydraulic functions obtained by numerical inversion in HYDRUS-2D for the different tillage treatments.

Number of conductive pores per unit area N_h was increasing with increasing *K(h)* values. The N_h values varied for all tillage treatments and throughout the whole range of tension between 664 and 1004 pores m^{-2} (right part of Table 2). There was about four times more mesopores than macropores for CT, SP, and MT; for DD and NT, the number of mesopores was even larger. The data suggest that the CT operation carried out in this study changed the soil structure generated naturally under NT systems, leading to a reduction in mesopore class sizes and the creation of new macropore volumes which resulted in lower hydraulic conductivity at higher tensions. These results are in agreement with those of Cortadeur *et al.* (2002), who compared tilled and untilled soils and reported the reducing effect of ploughing on the near-saturated hydraulic conductivity, with *K(h)* values in the ploughed soil being one third of those measured on the untilled soil. However, as reported by Pelegrin (1990) and Ferreras *et al.* (2000), when K_s was measured *in situ*, the values for tilled soils were significantly higher than those measured on untilled soils. However, studies of the influence of tillage on infiltration rates are not always conclusive; Cameira *et al.* (2003) and Ankeny *et al.* (1990) reported little difference in *K(h)* when comparing untilled and tilled soils. When characterising the effect of wheel traffic, the following ranges of *K(h)* were measured on wheel-marks: 0.0004 to 0.2651 cm min^{-1} for CT, 0.0019 to 0.3692 cm min^{-1} for MT, and 0.0004 to 0.2636 cm min^{-1} for NT. Except for the CT, the reduction in Log*K(h)* on plots with MT and NT was significant at all tensions ($P < 0.001$). The largest reduction in *K(h)* was observed at lower tensions (2.5 cm, 1.5 cm, and 0 cm) and was most significant for K_s with a reduction varying between 50% and 60%. For the CP, there was a 43% reduction in macropores per unit area, while the number of mesopores increased by 20%. For the plots with

MT and NT, the macropores were reduced by 49% and 59%, and the mesopores by 41% and 55%, respectively. This shows that wheel-traffic leads to the loss of hydraulically active macropores. The soil compaction created by the wheel traffic is also shown by the values of the soil dry bulk density (Table 1), which are significantly higher in the wheel-marks for all three tillage treatments (t-test, significance level 0.05). Ankeny *et al.* (1990) showed that wheel-traffic is one of the main source of soil compaction in agricultural fields. The effect of wheel traffic on *K(h)* was also reported by Courtadeur *et al.* (2002) who measured a 60% reduction in hydraulic conductivity at saturation in the wheel-mark of a tilled soil.

Conclusion

Soil tillage operations carried out on the tested sandy loam soil led to a reduction of mesopores and had no beneficial effect on the near-saturated hydraulic conductivity of the soil. In addition, wheel traffic resulted in large reductions in near-saturated hydraulic conductivity through compaction and the loss of macropores.

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