The influence of tillage treatments on water infiltration into soil profile

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ABSTRACT

Water infiltration into the soil profile and runoff losses in arable lands are related to the condition of the top layer. The tillage treatment (included no-till) of the top layer plays a key role in changes of the hydro-physical properties, mainly saturated hydraulic conductivity (K) of the treated layer. This paper is focused on the influence of repeated tillage treatments in the same locality on K in a relatively homogeneous soil profile. The field experimental work was conducted in 1997 and repeated in 2000 after three years of repeated treatments in an experimental field of the Research Institute of Plant Production, Prague on Hapludalfs (US Classification)/Orthic luvisol (FAO). The whole experimental site was divided into four tillage treatment areas (TTA) that were maintained using different tillage treatments. A pressure ring infiltrometer (Matula and Kozáková 1997), mounted on the top of a single iron infiltration ring was used to run infiltration tests. The infiltration during the steady state flow (for a long time) was measured, evaluated and K values were calculated. Matula (2002) summarised the theoretical background for the pressure ring infiltrometer and described the final equations for evaluation of the infiltration test results. The conventional ploughing did not give any significant changes in K values after three years. Reduced till treatment and no-till treatment show a significant decrease in the infiltration rate $v(t)$ after three years. The K value decreased approximately three times for reduced till and six times for no-till treatment. The decrease on this type of soil can cause several negative results from the aspect of surface soil hydrology and agriculture (surface runoff increase, water storage decrease, yield decrease, increase in soil compaction of surface layer, soil erosion increase).

Keywords: saturated hydraulic conductivity K; tillage treatments; pressure infiltrometer; infiltration test; transect

Tillage can have both favourable and unfavourable effects on different physical properties of treated topsoil. When tillage treatments are carried out especially on the wet soil, stable soil aggregates are crushed or smeared, macro porosity is decreased and puddled soil is created. This action exposes organic matter that was protected inside the aggregates, accelerating its loss by decomposition (Brady and Weil 1999). Some studies have shown that aggregation and the associated desirable soil physical properties (bulk density, porosity, degree of aeration, capillary water capacity and others) and hydro-physical properties related to infiltration rate decline after long periods of tilled row-crop cultivation. Le Bissonnais and Arrouays (1997) published that the infiltration rate under rain corresponds well with aggregate stability measurements and the soil structure stability declined as organic carbon declined.

The classical type of tillage, applied since the Middle Ages, is a mouldboard plough followed often by a secondary tillage operation for example harrowing. Repeated traffic activities related to mouldboard ploughing and using heavy machinery cause soil compaction. In recent years, conservation tillage practices have largely been developed. Those systems greatly reduce tillage treatment, and in some cases no tillage treatment at all is rather successfully applied. The reviews of conservation tillage treatments were published by Blevins and Frye (1992) and Carter (1994). The Conservation Technology Information Center, West Lafayette, IN, USA divided the conservation tillage systems into five types (Brady and Weil 1999) (Table 1).

Klute (1982) presented a review of tillage effects on the hydraulic properties of soil. Infiltration of water through the soil profile and surface runoff on agricultural soils are strongly dependent on the type of tillage treatment of topsoil layer. One of the dominant soil hydraulic properties related to tillage treatment is saturated hydraulic conductivity (K) of the topsoil.

This article is focused on the influence of repeated tillage treatments in the same locality on K in a relatively homogeneous soil profile.

Elrick and Reynolds (1992) considered as important soil hydrophysical properties: saturated hydraulic conductivity, matrix and tension flux potentials, and sorptivity. These properties can be measured on core samples in a laboratory, however field measurements using infiltrometers and permeameters are far more reliable and have been used extensively around the world in the last decade.

This work was partly supported by Project No. MSM 412100004.

Table 1. General classification of different conservation tillage systems

No-till	Soil undisturbed prior to planting, which occurs in narrow seedbed, 2.5 to 7.5 cm wide. Weed control primarily by herbicides.
Ridge till (till, plant)	Soil undisturbed prior to planting, which is done on ridges 10–15 cm higher than row middles. Residues moved aside or incorporated on about one-third of soil surface. Herbicides and cultivation to control weeds.
Strip till	Soil undisturbed prior to planting. Narrow and shallow tillage in row using rotary tiller, in row chisel, and so on. Up to one-third of soil surface is tilled at planting time. Herbicides and cultivation to control weeds.
Mulch till	Soil surface disturbed by tillage prior to planting, but at least 30% of residues left on or near soil surface. Tools such as chisels, field cultivators, disks and sweeps are used (e.g. stubble mulch). Herbicides and cultivation to control weeds.
Reduced till	Any other tillage and planting system that keeps at least 30% of residues on the surface.

Angulo-Jaramillo et al. (2000) published a review and recent developments of using infiltrometers *in situ*. The existing techniques to infer hydraulic properties from measurements of either transient flow rates or steady ones that emanate from a disc infiltrometer are discussed here. Similarly the flow of water from a ring infiltrometer is described mathematically and analysed. The description of water and solute flow from a tension disc infiltrometer using one-dimensional two region mobile-immobile water model and solute exchange equation is reviewed in detail.

Angulo-Jaramillo et al. (2000) divided the infiltrometers into:

– tension disc infiltrometers
– pressure ring infiltrometers

In the presented study a laboratory-made pressure ring infiltrometer (Matula and Kozáková 1997) was applied *in situ*.

MATERIAL AND METHODS

The pressure ring infiltrometer (Matula and Kozáková 1997) consists of a Mariotte bottle, mounted on the top of a single iron infiltration ring of 0.15 m inner diameter, driven to a short distance (0.08–0.01 m) into the soil top layer. A wide range of steady water pressure can be applied to the soil surface inside the infiltration ring using a moveable air tube within the Mariotte bottle. A schematic diagram of the pressure ring infiltrometer (Matula and Kozáková 1997) is shown in Figure 1.

The field experimental work was conducted in 1997 and repeated in 2000 in an experimental field of the Research Institute of Plant Production (RIPP), Prague-Ruzyně on Hapludalfs (US Classification)/Orthic luvisol (FAO). The whole experimental site was divided into four tillage treatment areas (TTA4, TTA1, TTA2, TTA3) in 1997–1999 and four TTA in 1999–2000 (TTA01, TTA02, TTA03, TTA04) that where maintained using different tillage treatments (Figure 2).

The TTA were segregated mechanically (paths) and marked from each other with an application of chemical spray (Gramoxon). Land slope was about 4% within each area. The tillage practices carried out on these separated TTA are presented in Table 2.

The particle size distribution curves of the topsoil in TTA and subsoil of the experimental field are presented in Figures 3–7. Particle densities of the topsoil and subsoil, measured in 2000 are also in Table 2.

Transects were marked across the whole site perpendicularly to the land slope, rows and/or machinery movement (Figure 2).

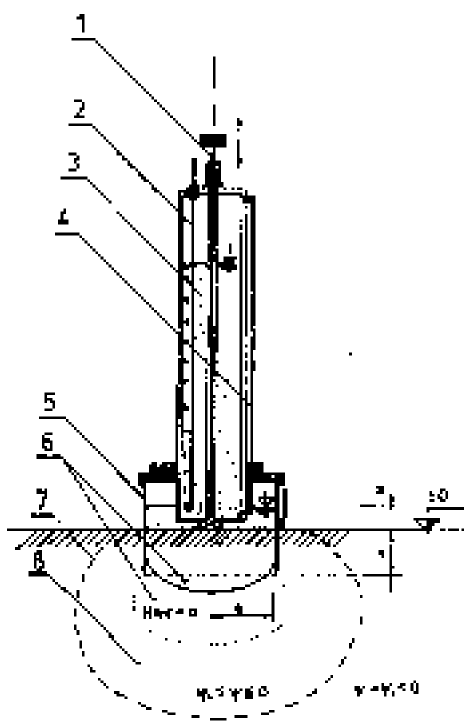

Figure 1. Pressure ring infiltrometer (Matula and Kozáková 1997): 1. piston valve to open/close the water outlet, 2. moveable air tube of Mariotte bottle to set the water level (H) inside the infiltrometer ring, 3. Mariotte bottle, 4. fool's cup, 5. infiltrometer ring, 6. bulb full of field saturated soil, 7. wetting front, 8. wetting zone

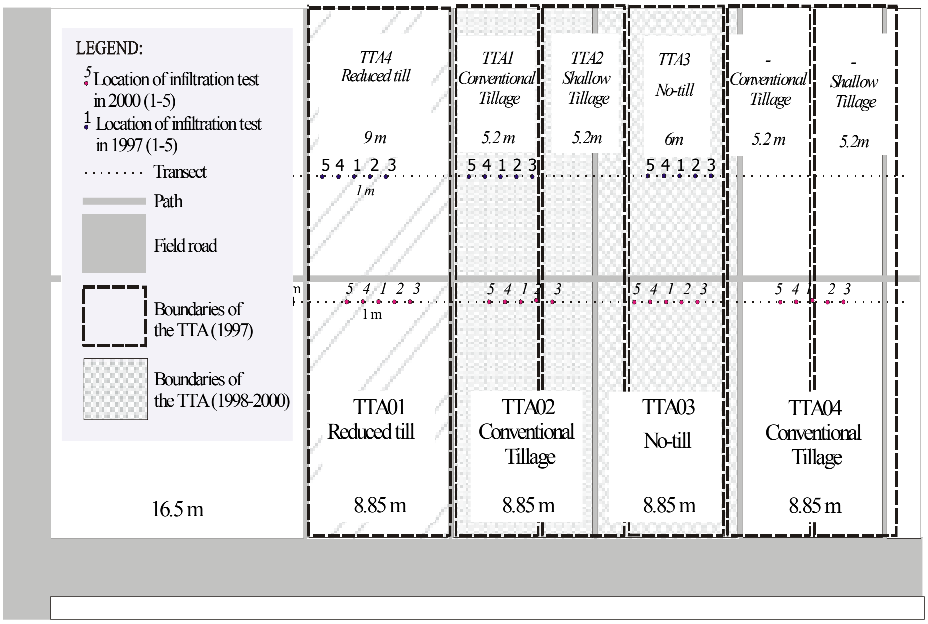

Figure 2. The location of tillage treatment areas in 1997 and from 1998 to 2000 and the location of transects

A series of five infiltration tests was carried on each TTA and in both experimental years (Figure 2). The first run of infiltration tests was conducted in 1997 (Matula and Křivohlavý 1998a, b), the second one in 2000. An equidistant space 1 m between the test locations was used. The pressure ring infiltrometer (Matula and Kozáková 1997) with iron ring 0.15 m inner diameter was inserted 0.08 m into the soil. The results of the infiltration experiments are presented as cumulative infiltration (I) versus time (t) in selected time steps. The infiltration rate $v(t)$ was calculated from this data. The results are presented in Figures 8–10.

The flow into unsaturated soil from the pressure ring infiltrometer occurs at two stages. Initially, the flow goes through an initial transient phase and then approaches steady state. During the transient period both the field saturated bulb and the surrounding wetting zone increase in size by migrating downwards and outwards from the infiltration surface. After reaching the steady state, the field-saturated bulb remains essentially constant in size and shape but the wetting zone continues to increase in size by the outward migration of the wetting front. The final size of the steady state field saturated bulb is determined by the positive pressure head H applied by the infiltrometer, the dimensions of the infiltration surface and soil properties, in particular by texture, structure, initial water content and/or initial (background) water potential (ψ_i) (Elrick and Reynolds 1992).

The infiltration during the steady state flow (for a long period of infiltration) can be calculated by the equation formulated by Philip (1985), Reynolds and Elrick (1990, 1991) and Elrick and Reynolds (1992). Matula (2002) described the theoretical background for the pressure ring infiltrometer, the final equation for saturated hydraulic conductivity (K) determined from the pressure ring infiltrometer test was formulated as:

$$K = Q.G/(a.H + a^2.G.\mathrm{p} + a/\alpha^*) \qquad (1)$$

where: K = saturated hydraulic conductivity (m/s)
Q = the steady flow rate of water into the soil out of the pressure ring infiltrometer (m^3/s)
G = a geometry function which accounts for the geometry of the infiltration surface
a = the radius of the infiltration ring (m)
H = a positive pressure head (m)
α^* = alpha parameter (m^{-1})

Table 2. Tillage treatments, crop and particle densities for three selected tillage treatment areas and different depths

TTA	Soil treatment	Crop	Depth of soil (m)	Particle density ρ_d (kg/m^3)
1, 02, 04	conventional	wheat	0.0–0.1	2 630
4, 01	reduced till	wheat	0.1–0.2	2 600
3, 03	no-till	wheat	0.0–0.1	2 580
			0.1–0.2	2 590
All	no treatment – subsoil	–	0.2–0.3	2 610–2 640

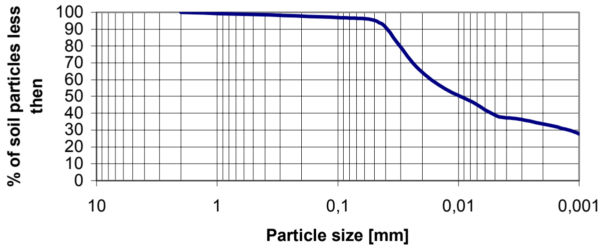

Figure 3. Particle size distribution curve – topsoil, conventional tillage (TTA02, TTA04, TTA1), depth 0–0.1 m

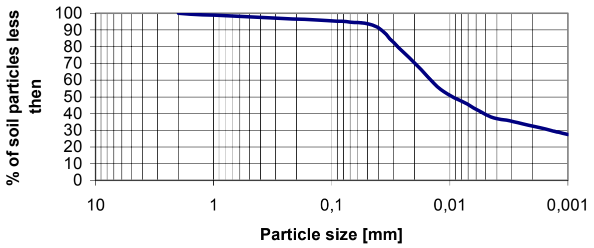

Figure 4. Particle size distribution curve – topsoil, reduced till (TTA01, TTA4), depth 0.1–0.2 m

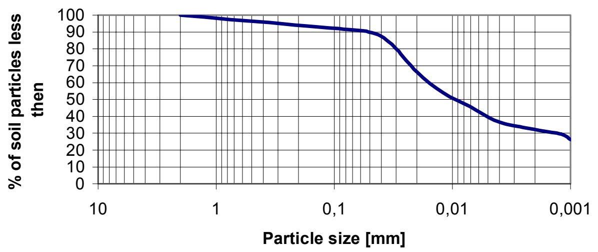

Figure 5. Particle size distribution curve – topsoil, no-till (TTA03, TTA3), depth 0–0.1 m

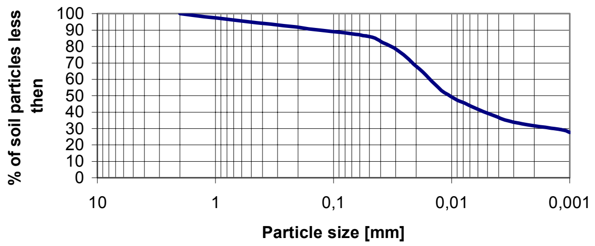

Figure 6. Particle size distribution curve – topsoil, no-till (TTA03, TTA3), depth 0.1–0.2 m

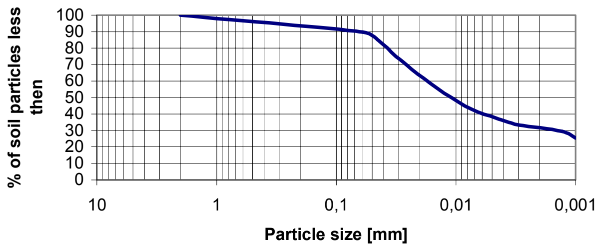

Figure 7. Particle size distribution curve – subsoil, a typical one (for all TTA), depth 0.2–0.3 m

The geometry function (G) is defined by Reynolds and Elrick (1990) for the pressure ring infiltrometer as:

$$G = 0.316\,(d/a) + 0.184 \qquad (2)$$

where: d = depth of infiltration ring insertion (m)
a = the radius of the infiltration ring (m)

The geometry function G is a dimensionless shape parameter determined by numerical solution from Richard's equation. Reynolds and Elrick (1990) found that G is essentially independent of H, K and ϕ_m for a constant radius a and depth of insertion d of the infiltrometer ring, ϕ_m is matrix flux potential (m^2/s).

Equation (1) employs parameter α^* that has to be chosen. White and Sully (1987) suggested setting the value to 10 m^{-1} for most soils. Elrick and Reynolds (1992) in their Table 1-1 used soil texture/structure categories for site estimation of α^*. It ranged from $\alpha^* = 1\ m^{-1}$ for compacted, structure-less, clayey materials to $\alpha^* = 36\ m^{-1}$ for coarse, gravelly sands or soils with large macro-pores. For most soils they recommended the value of $\alpha^* = 12\ m^{-1}$ (Elrick and Reynolds 1992). Matula and Kozáková (1997) found the values of α^* for their average measured K values around $\alpha^* = 12.55$ and 13 m^{-1}, which are very close to the value recommended by Elrick and Reynolds (1992). Thus the value $\alpha^* = 12\ m^{-1}$ was chosen for the present calculations.

RESULTS AND DISCUSSION

The infiltration tests were carried out on each TTA. Fifteen infiltration tests were taken (five on each area) in total in 1997 and 20 tests (again five on each area) in 2000.

The initial water content was measured before the beginning of the tests using the TDR TRIME FM3; the results of measurements for the three types of tillage treatment are in Table 6.

The measured $I(t)$ was then evaluated, the $v(t)$ was calculated for each test. The results of cumulative infiltration $I(t)$ and infiltration rate $v(t)$ for selected three tillage treatments are plotted in Figures 8–10.

The calculated values of saturated hydraulic conductivity (K) for the same tillage treatments and some basic statistics are in Tables 3–5.

Equations (1) and (2) and α^* based on Elrick et al. (1989) were applied to the steady state flow rate of water into the soil, when I is linearly related to t and the K values were calculated.

The comparison of K values for each location of the infiltration tests and years 1997 and 2000 for reduced till, no-till, and conventional tillage are presented in Figure 11.

The technological reasons (applied technology of treatment) resulted unfortunately in the changes of the size of TTA in 1999 in the fields with a span equal to 8.85 m. However the type of treatment was not changed significantly.

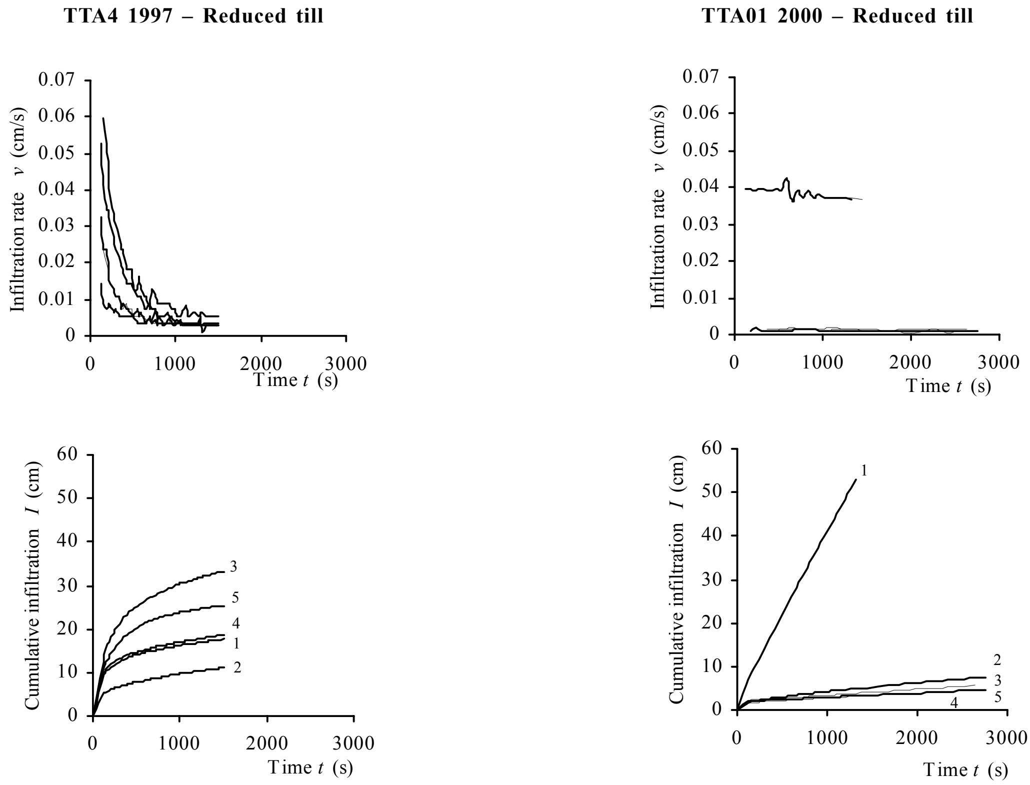

Figure 8. Infiltration rate $v(t)$ and cumulative infiltration $I(t)$ for TTA4 and TTA01 in 1997 and 2000 [numbers added to cumulative infiltration curves represent the transect test numbers; the infiltration rate curves are not marked due to available space, however the highest $I(t)$ relates the highest $v(t)$ and vice versa]

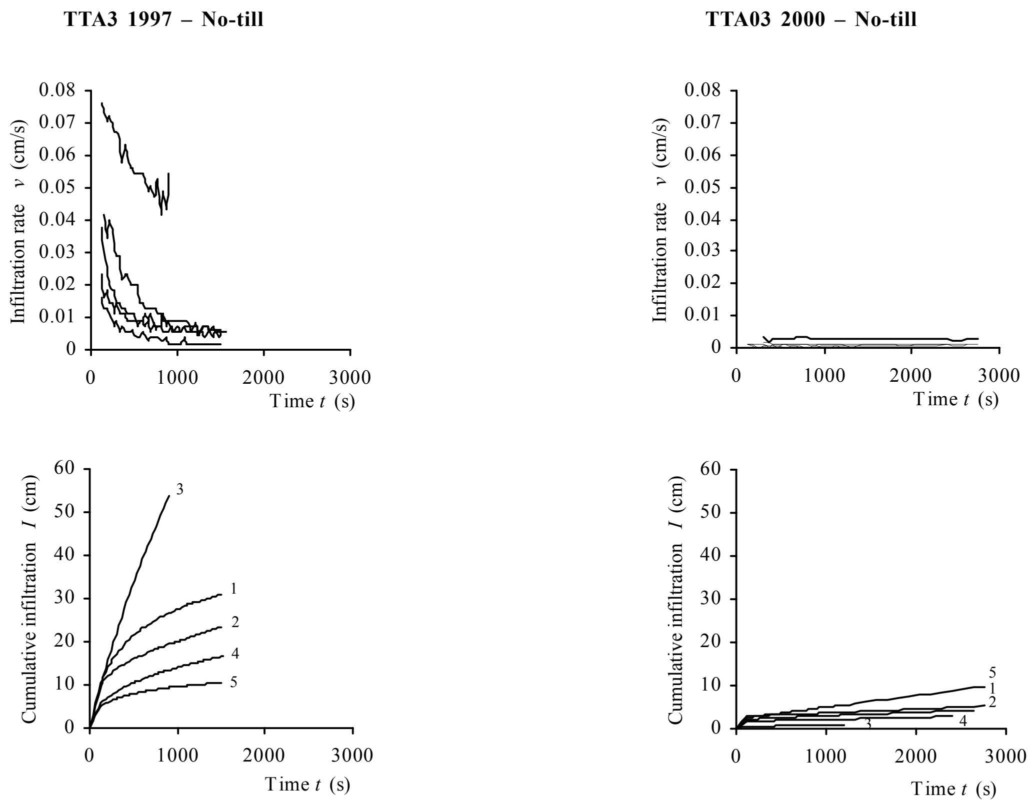

Figure 9. Infiltration rate $v(t)$ and cumulative infiltration $I(t)$ for TTA3 and TTA03 in 1997 and 2000 [numbers added to cumulative infiltration curves represent the transect test numbers; the infiltration rate curves are not marked due to available space, however the highest $I(t)$ relates the highest $v(t)$ and vice versa]

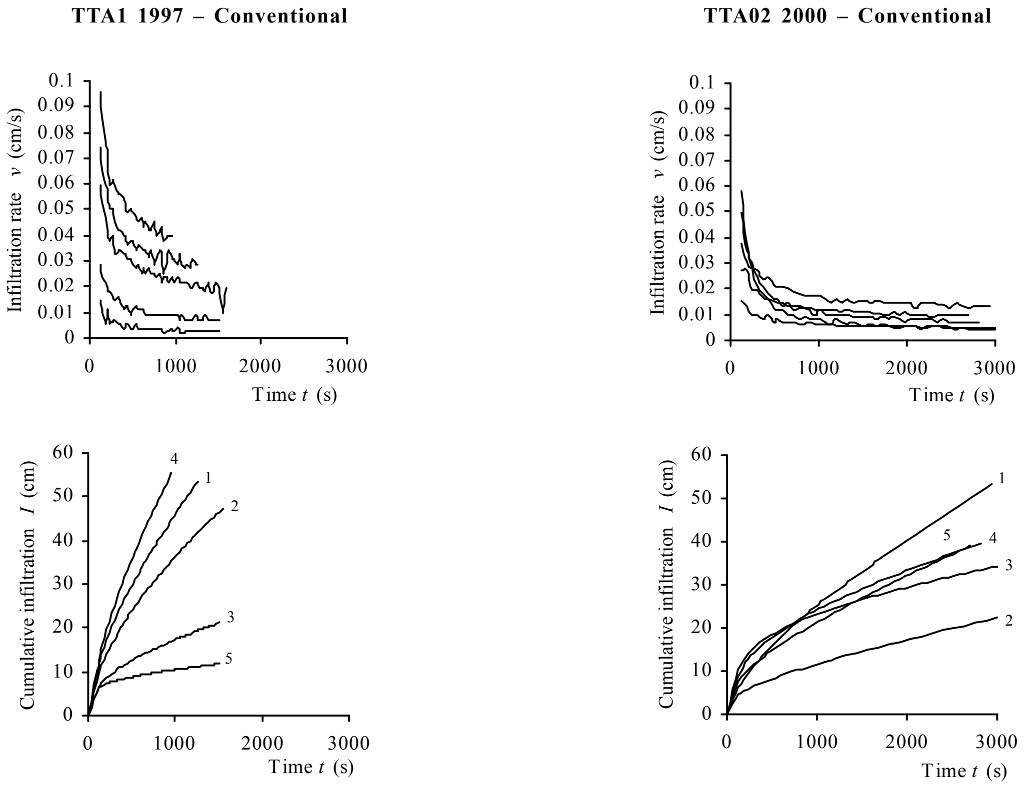

Figure 10. Infiltration rate $v(t)$ and cumulative infiltration $I(t)$ for TTA1 and TTA02 in 1997 and 2000 [numbers added to cumulative infiltration curves represent the transect test numbers; the infiltration rate curves are not marked due to available space, however the highest $I(t)$ relates the highest $v(t)$ and vice versa]

CONCLUSIONS

After three years of very similar tillage treatment applied on the TTA, the repeated infiltration tests were carried out. The fixed equidistant space 1 m between infiltration rings was kept strictly, thus the same locations were always selected for the tests. Unfortunately, the three-year data set collected until now is not large enough for a detailed geo-statistical evaluation. The experimental tests will continue during the coming years. However some conclusions based on the experiments carried out until now can be made. The initial water con-

Table 3. *K* values and basic statistics related to *K* for TTA4 and TTA01 in 1997 and 2000; reduced till (restricted tillage)

	Infiltration ring No.				
	1	2	3	4	5
			TTA4 1997		
K (cm/s)	0.00175	0.00180	0.00352	0.00242	0.00178
Mean of *K* values		0.00225		cm/s	
Median of *K* values		0.00180		cm/s	
			TTA01 2000		
K (cm/s)	0.02487*	0.00079	0.00091	0.00060	0.00059
Mean of *K* values		0.00555*	(0.00072)	cm/s	
Median of *K* values		0.00079		cm/s	

* An underground passage produced by a field mouse was found connected after digging the infiltration ring out of the soil layer when the test was over. This event made the *K* value representing ring No. 1 significantly higher. The calculations excluding ring No. 1 are in brackets.

Table 4. K values and basic statistics related to K for TTA3 and TTA03 in 1997 and 2000; no till

	Infiltration ring No.				
	1	2	3	4	5
			TTA3 1997		
K (cm/s)	0.00372	0.00411	0.03530*	0.00380	0.00123
Mean of K values		0.00963*	(0.00410)	cm/s	
Median of K values		0.00380		cm/s	
			TTA03 2000		
K (cm/s)	0.00062	0.00061	0.00008	0.00030	0.00177
Mean of K values		0.00068		cm/s	
Median of K values		0.00030		cm/s	

* A field mouse nest was found close to the ring after digging the infiltration ring out of the soil layer when the test was over. This event makes the K value representing ring No. 3 significantly higher again. The calculations excluding ring No. 3 are in brackets.

Table 5. K values and basic statistics related to K for TTA1 and TTA02 in 1997 and 2000; conventional tillage

	Infiltration ring No.				
	1	2	3	4	5
			TTA1 1997		
K (cm/s)	0.02092	0.01458	0.00475	0.03298	0.00175
Mean of K values		0.01500		cm/s	
Median of K values		0.01458		cm/s	
			TTA02 2000		
K (cm/s)	0.01124	0.00154	0.00902	0.00124	0.00264
Mean of K values		0.00514		cm/s	
Median of K values		0.00264		cm/s	

Conventional tillage creates large heterogeneity of the top layer

tent was measured before the beginning of the tests using the TDR TRIME FM3 in all cases. As can be seen from Table 6, the initial water content (θ_i) was higher in 2000 than in 1997 in all locations of the infiltration tests. The initial value of water content (θ_i) has an influence on the infiltration rate of an early and medium stage of ponded infiltration (Kutilek and Nielsen 1994). The infiltration rate (v) supposes to decrease as θ_i increases. This can be seen in all presented cases as demonstrated in Figures 8–10.

The fluctuation of the measured data of the infiltration and also K values (Figure 11) in the case of conventional tillage was created by the quality of ploughing and of course the location of measurement is important within

Table 6. Initial water content (θ_i) of the topsoil for selected TTA in 1997 and 2000, measured by the TDR

TTA No.	Location of the infiltration tests (Figure 2.2) and measured initial water content (θ_i) (% by volume)					Year	Tillage treatment
	1	2	3	4	5		
4	19.0	21.8	21.7	21.7	21.0	1997	reduced
01	28.6	27.3	22.6	22.9	24.5	2000	reduced
3	24.2	25.6	25.5	25.8	25.6	1997	no-till
03	34.4	31.60	32.7	27.5	30.7	2000	no-till
1	15.3	14.9	16.1	13.2	21.7	1997	conventional
02	25.7	29.6	17.6	31.0	25.5	2000	conventional

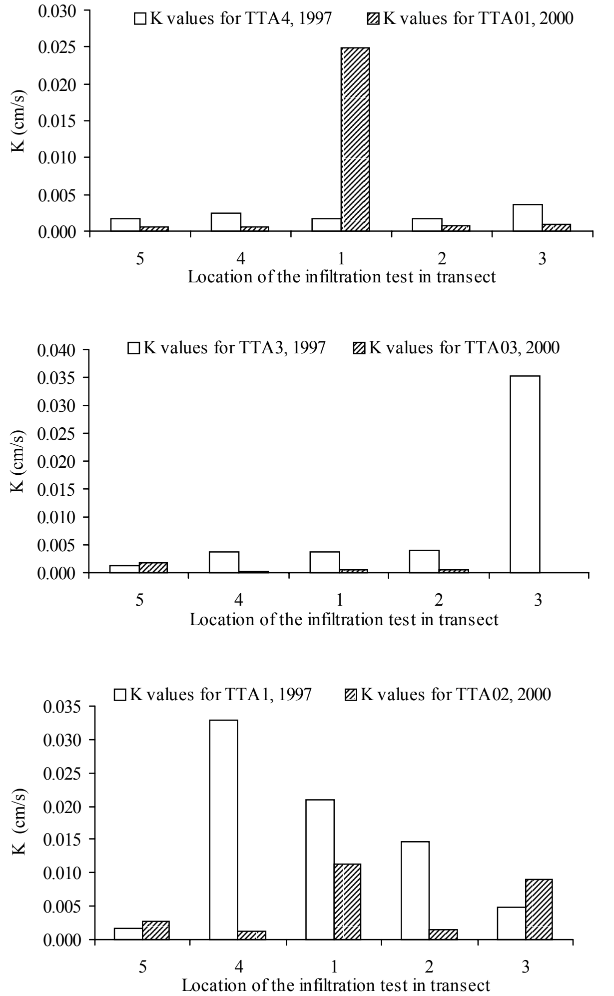

Figure 11. Calculated values of *K* (cm/s) for reduced till, no-till and conventional tillage for the transect tests in 1997 and 2000

a particular TTA. It was found that the heterogeneity of the top layer after conventional tillage was enormous and it is possible to detect by the tests the resultant troughs of ploughing. However the conventional ploughing did not give any significant changes in *K* values after three years. This work is focused on the influence of repeated reduced till and no-till on infiltration and *K* values.

Reduced till treatment and no-till treatment show a significant decrease of $v(t)$ values after three years compared to the situation in 1997 (Figures 8–10). The *K* decreased approximately three times for reduced till and six times for no-till treatment (Tables 3, 4 and Figure 11).

The decrease on this type of soil can cause several negative results from the aspect of surface soil hydrology and agriculture:

– surface runoff increase
– decrease in water storage in the soil profile
– decrease in the quality and yield of plant production during dry years
– possible increase in soil compaction of surface layer
– possibly increased soil erosion in hilly areas

Acknowledgement

I thank Dr. Pavel Růžek from the RIPP for the use of his experimental fields and his co-operation and Pavel Křivohlavý, MSc., for the close co-operation in the matter of fieldwork and some data processing.

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Received on February 20, 2003

ABSTRAKT

Vliv zpracování půdy na infiltraci vody do půdního profilu

Infiltrace vody do půdy a ztráty vody povrchovým odtokem na orných půdách závisejí na podmínkách v orniční vrstvě. Zpracování půdy orbou (včetně bezorebných systémů) hraje významnou úlohu ve změnách hydrofyzikálních vlastností půdy, především nasycené hydraulické vodivosti (*K*) orniční vrstvy. Tato práce je zaměřena na vliv opakovaně aplikovaného systému zpracování půdy na stejné lokalitě na hodnoty *K* u relativně homogenního půdního profilu. Terénní experimentální práce na experimentální základně VÚRV v Praze byly provedeny v roce 1997 a opakovány v roce 2000 na Luvisolu, hnědozemi modální na spraši (klasifikace ČR)/Hapludalfs (US Classification)/Orthic luvisol (FAO). Experimentální plocha byla rozdělena na čtyři části (TTA), u nichž byl v letech 1997 až 2000 aplikován obdobný systém zpracování orniční vrstvy. Infiltrační testy byly prováděny tlakovým válcovým infiltrometrem (Matula a Kozáková 1997) s ocelovým infiltračním válcem. Infiltrace z infiltračního testu byla měřena a v části stacionárního proudění (pro delší čas infiltrace) také vyhodnocena a použita pro stanovení *K*. Matula (2002) uvádí teorii pro tlakový válcový infiltrometr a popisuje odvození rovnic pro vyhodnocení výsledků infiltračních testů. Opakovaná klasická orba po třech letech změnila výsledné hodnoty *K* jen nepatrně. Omezené zpracování půdy a bezorebná technologie ovlivnily po třech letech hodnoty rychlosti infiltrace $v(t)$ výrazně. Hodnoty *K* pro omezené zpracování půdy poklesly přibližně třikrát a u bezorebné technologie šestkrát. Tento pokles hodnot vodivosti může mít řadu negativních důsledků pro půdní hydrologii a zemědělství (zvýšený povrchový odtok, snížená retence vody v profilu, ovlivnění výnosu plodin, zvýšení ulehlosti povrchové vrstvy, nebezpečí eroze).

Klíčová slova: nasycená hydraulická vodivost *K*; zpracování půdy; tlakový infiltrometr; infiltrační test; transekt

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