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THE IMPACT OF DIFFERENT TILLAGE TREATMENTS ON HYDRAULIC CONDUCTIVITY OF LOAMY SOIL

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Abstract

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Water infiltration into the soil profile, surface runoff and soil erosion in arable lands depend on the conditions of the top layer. The tillage treatment of the top layer plays a key role in changes of the hydro-physical properties, mainly saturated hydraulic conductivity K_s of the surface layer. The aim of this study was to asses the impact of different tillage treatments on hydraulic conductivity in the locality Bohaté Málkovice. Field experimental works in this area were performed in 2009 and were repeted in 2011 on Haplic Chernozem, medium heavy loamy soil. The experimental area was divided into two parts; top layer of these plots was cultivated by applying conventional and reduced tillage treatment. Both these plots were sown with spring barley (*Hordeum vulgare*). For the field measurement of water infiltration into the soil was used double-ring infiltrometer (2009, 2011) and Minidisk infiltrometer (2011). Near the point were the infiltration was measured, the soil samples were always collected for laboratory determination of basic physical properties of soil (bulk density, porosity, initial and saturated water content, aeration of the soil) and saturated hydraulic conductivity $K_{s.}$ For laboratory determination of K_s was used permeameter with constant gradient.
For evaluation of saturated hydraulic conductivity K_s using the double-ring infiltration method was used Philip's three-parameter equation and for evaluation of unsaturated hydraulic conductivity *K(h)* using Minidisk infiltrometer was used Zang's method. After two years of using repeatedly applied different tillage treatments was significantly influenced saturated hydraulic conductivity K_s. The K_s value increased approximately six times for reduced tillage and more than three times for conventional tillage. Laboratory determined average values of K_s were compared with the average estimates of K_s from infiltration tests. The results were burdened by a number of errors (compaction, preferential flow). These mean values were higher for conventional and reduced tillage. Unsaturated hydraulic conductivity *K(−2cm)* for reduced tillage was higher, for conventional tillage decreased approximately three times.

tillage treatment, hydraulic conductivity $K_{s,}$ unsaturated hydraulic conductivity *K(h)*, double-ring infiltration method, Minidisk infiltrometer

Soil has a dominant position in the hydrological cycle of the landscape. Not only the volume of water retained in the soil, but also volume of flowing through the soil is significant. Unbalanced cycle of water in the landscape, especially accelerated water outflow, results alternation of floods and droughts, which is connected with soil degradation. Most of soils in Czech Republic belong to the category of soils with very low and low water retention capability.

Water regime of soil significantly affects the production ability of soil and is part of soil-forming processes. It determines the movement of soil water, its temporal and spatial distribution. Direction of water flow in the soil profile depends on the moisture potential; properties of water movement in the soil determine the hydraulic conductivity in unsaturated and saturated soil environment. The saturated hydraulic conductivity K_s is an indicator of the soil's ability to lead and transmit the water needed for plants to the root zone, as well as drain excess water out of the root zone (Topp *et al.*, 1997). A K_s value in the range 5×10^{-3} cm.s^{-1} to 5×10^{-4} cm.s^{-1} may be considered "ideal" for promoting rapid infiltration and redistribution of needed crop-available water, reduced surface runoff and soil erosion and rapid drainage of excess soil water (Reynolds *et al.*, 2003).

Saturated hydraulic conductivity K_s can be determined in the field or in laboratory. The basic field methods include infiltration experiments with different types of infiltrometers (double-ring infiltrometer, Guelph's permeameter) or rain simulator. In the laboratory are used permeameters with constant or variable slope, into which are inserted saturated soil samples (cylinder of Kopecký with uniform volume 100 cm^3). Permeameter with variable slope is suitable for the less permeable soil and permeameter with constant slope for more permeable soils. Unsaturated hydraulic conductivity is a characteristic describing the hydraulic conductivity based on soil moisture $K(\theta)$ or on moisture potential $K(h)$. The most common device for determining unsaturated hydraulic conductivity $K(h)$ in the field is disk infiltrometer (*Smettem et al.*, 1992, Ankeny *et al.*, 1991; Haverkamp *et al.*, 1994). To evaluate the data from these infiltrometers were developed methods (Smettem *et al.*, 1989; Ankeny *et al.*, 1991; Reynolds *et al.*, 1991), which are based on Wooding's approximation of steady-state of infiltration. Minidisk infiltrometer (Decagon Inc., Pulman) has small dimensions of device and low water consumption. It can be used for fast tentative determination of $K(h)$.

The aim of this study was to asses the impact of different tillage treatments on hydraulic conductivity of loamy soil in the locality Bohaté Málkovice in the years 2009 and 2011.

MATERIALS AND METHODS

The experimental area is close to the locality Bohaté Málkovice, the District Vyškov, near the road Bohdalice – Bohaté Málkovice (sugar beet production area, altitude is around 279 m above the sea level, annual precipitation during the growing season: 2009–359 mm, 2011–308.5 mm and with annual average temperature around 8.4 °C). The genetic soil representative is Haplic Chernozem and the pedogenic substrate is loess. Basic soil type: medium heavy loamy soil.

The experimental plots are approximately 300 m apart; they are processed for long-term by different tillage treatments (conventional tillage – ploughing to a depth of 22 cm and the reduced tilagge - during autumn the cultivation of spring crops is done by vertical hoeing of soil to a depth of 20 cm). Both these plots were sown with spring barley (*Hordeum vulgare*).

For the measurement of water infiltration into the soil was used double-ring infiltrometr and Minidisk infiltrometer Decogon Device, Inc. Infiltration tests using the double-ring infiltration method were started in 2009 and were repeated in 2011. Infiltration tests using Minidisk infiltrometer were performed in 2011. In case of double-ring infiltration method infiltration cylinders are flooded with water, in both cylinders is maintained same minimum water level (1–3 cm) in order to minimize the overpressure on the soil. In the inner cylinder is observed time needed for decreasing of water level to the stable level above ground surface, outer cylinder serves to maintain verticality of streamline under the inner cylinder during infiltration. Own measurements were performed by repeated filling of water dosage with known volume (1l) above the reference level which is stabilized by specific spike (1.5–2 cm). Measurements were finished with reached steady infiltration velocity. Method of measurement and evaluation of measured data given from Minidisk infiltrometer is described in the Minidisk infiltration user's manual or at http://www.decagon.com/education/minidisk-infiltrometer-manual/. Infiltration for pressure head $h_0 = -2$ cm lasted 20 min; the water level in reservoir was deducted in regular minute intervals.

Near the point were the infiltration was measured, the soil samples were always collected from arable layer (10, 30 cm) for laboratory determination of basic physical properties of soil (bulk density, porosity, initial and saturated water content, aeration of the soil) and saturated hydraulic conductivity $K_{s.}$

For evaluation of field infiltration measurement using double-ring infiltration method was used **Philip equation**, 1957, which is given at the form of an infinite time series

$$I = C_1 t^{1/2} + C_2 t + C_3 t^{3/2} + C_4 t^2 + \ldots + C_m t^{m/2} + \ldots, \qquad (1)$$

where

$C_1, C_2, C_3, C_4, \ldots C_m$.....parameters,

t ..... time (min).

First three members of equation (1) were used for estimation of saturated hydraulic conductivity K_s

$$I = C_1 t^{1/2} + C_2 t + C_3 t^{3/2}, \qquad (2)$$

where

C_1 ....estimate of sorption (cm.min$^{-1/2}$),

C_2, C_3 ..parameters, C_2 (cm.min^{-1}), C_3 (cm.min$^{-3/2}$).

The estimate of saturated hydraulic conductivity K_s is calculated from

$$K_s = (C_1 C_3)^{1/2} + C_2. \qquad (3)$$

Zhang's method, 1997 is based on the first two members of Philip's equation, it provides an estimate of the sorptivity and unsaturated hydraulic conductivity for pressure head $h \leq 0$ from

$$I = C_1 t^{1/2} + C_2 t, \qquad (4)$$

where

C_1, C_2 ..parameters, C_1 is related to the unsaturated hydraulic conductivity (m.s^{-1}) and C_2 is the soil sorptivity (m.s$^{-1/2}$).

The unsaturated hydraulic conductivity for pressure head h ≤ 0 is then computed from

$$K(h_0) = C_1(h_0)/A, \quad (5)$$

where

C_1 ....slope of the curve of cumulative infiltration vs. square root of time, A is a value relating to the van Genuchten parameters for a given soil type and to the suction rate and radius of the infiltrometer disk.

The diagram of the minidisk infiltrometer together with its detailed description can be found in the Minidisk Infiltrometer User's Manual (Decagon, 2005).

For laboratory determination of saturated hydraulic conductivity K_s was used permeameter with constant gradient in which were placed the saturated soil samples with volume of 100 cm³. The calculation is done using **Darcy's relation**, 1856

$$K_s = \frac{V \times L}{S \times \Delta H \times t}, \quad (6)$$

where

V.......volume of water passed through the soil sample (m³),

L.......height of soil sample in the direction of water flow (m),

ΔH...difference of levels before and behind sample (m),

S ....flow area of sample (m²),

t ....time (s).

In this study was used equation (3) and (6) for calculation of saturated hydraulic conductivity K_s. For calculation of unsaturated hydraulic conductivity *K(h)* was used equation (5), needed parameters were taken from the Table 2 in the Minidisk Infiltrometer User's Manual (loamy soil: A(–2 cm) = 6.4, α = 0.036, n = 1.56).

RESULTS AND DISCUSSION

On experimental plots were carried out repeatedly infiltration experiments using the double-ring infiltrometer and Minidisk infiltrometer. Near the points where the infiltration was measured, the soil samples were always collected for laboratory determination of the soil physical properties and saturated hydraulic conductivity K_s. The field experiments were carried out in four phases (May 2009, July 2009, beginning and the end of June 2011). In 2009 were performed 8 infiltration experiments using double-ring infiltration method (on each area: 4). In 2011 were performed 16 infiltration experiments using double-ring infiltration method and Minidisk infiltrometer (on each area: 8). In 2009 and 2011 were taken 20 samples from top soil layer (10 cm) on each plot for laboratory determination of saturated hydraulic conductivity K_s and 24 soil samples from arable horizon (10, 30 cm) on each plot for determination of basic physical properties of soil.

Basic physical properties of soil of tested plots were analyzed using standard methodology in the pedological laboratory of the Institute of Landscape Water Management of the Faculty of Civil Engineering at Brno University of Technology, Table I. The values show differences of basic physical characteristics of the soil, not only between variants, but also in the years 2009 and 2011.

The initial water content θ_i has an infuence on the infiltration rate *v(t)* of an early and medium stage of infiltration (Kutílek *et al.*, 1994). As can be see from Table I, average value of θ_i was higher in 2009 than in 2011 for both experimental plots. Laboratory determination values of θ_i for convetional and reduced tillage in 2009: $\theta_{i,con.}$ = 13.75 – 27.31 % vol., $\theta_{i,red.}$ = 14.12 – 25.65 % vol. and 2011: $\theta_{i,con.}$ = 11.69 –12.55 % vol., $\theta_{i,red.}$ = 13.56 –12.44 % vol. The infiltration rate *v(t)* supposes to decrease as θ_i increases. This can be seen in Figure 1.

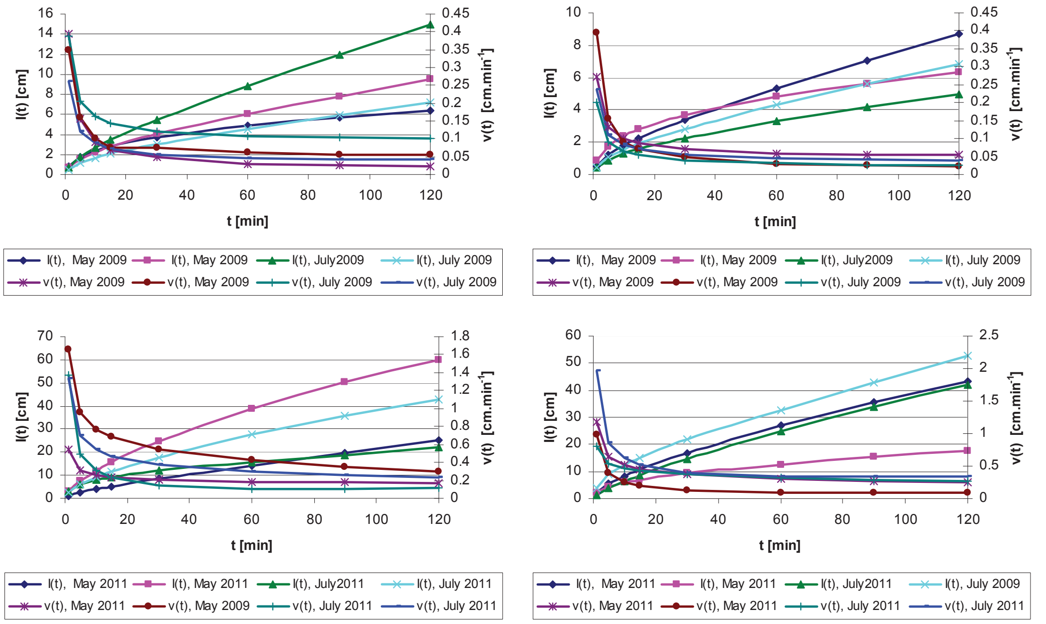
Results of unsaturated hydraulic conductivity *K(–2 cm)* and saturated hydraulic conductivity K_s obtained in locality Bohaté Málkovice are shown in Table II. Values *K(–2 cm)* and K_s are given for individual infiltration tests and as arithmetic mean of 4 measurments, laboratory set K_s values are given as the arithmetic mean of 5 measurements.

Reached results show high variability of soil hydraulic characteristics, which is related to heterogeneity of soil environment (Kutílek *et al.*,

I: *Basic physical properties of soil of tested plots in the locality Bohaté Málkovice*

Year of collecting	tillage treatment	Depth of sampling (cm)	θ_i (% vol.)	θ_s (% vol)	ρ_d (g.cm⁻³)	P (% obj.)	V_z (% obj.)
2009	conventional	10	20.53	32.16	1.50	35.08	19.05
		30	20.59	27.98	1.70	32.71	12.12
	reduced	10	19.83	33.11	1.37	44.46	24.63
		30	22.31	29.42	1.63	36.00	14.66
2011	conventional	10	12.12	31.14	1.45	41.19	20.55
		30	14.61	26.64	1.60	36.52	18.22
	reduced	10	13.96	34.32	1.48	39.91	20.21
		30	11.72	33.13	1.55	39.18	20.57

Explenation: θ_i – initial water content, θ_s – saturated water content, ρ_d – bulk density, P – porosity, V_z – aeration of soil



1a, b, c, d: *Cumulative infiltration I(t) and intensity of infiltration v(t) for plot with convential (a, c) and reduce tillage (b, d) in 2009 and 2011*

II: *The impact of tillage treatment on the hydraulic conductivity in the locality Bohaté Málkovice*

Year	tillage treatment	*K(−2 cm)* - eq. (5) (cm.min⁻¹)	*K(−2 cm)* - eq.(5) (cm.min⁻¹)	K_s - eq. (3) (cm.min⁻¹)	K_s - eq. (3) (cm.min⁻¹)	K_s - eq. (6) (cm.min⁻¹)
2009	conventional	not measured	not measured	0.016	0.044	0.052
				0.020		
				0.100		
				0.040		
	reduced	not measured	not measured	0.050	0,035	0.048
				0.020		
				0.060		
				0.010		
2011	conventional	0.0080	0.003	0.170	0.155	0.217
		0.0030		0.210		
		0.0002		0.100		
		0.0007		0.140		
	reduced	0.0170	0.0098	0.160	0.203	0.233
		0.0070		0.080		
		0.0047		0.240		
		0.0103		0.330		

1994). In 2009 both experimental plots had relatively low and balanced average value of K_s, lower K_s value was reached on the plot with reduced tillage. In 2011 was apparent significant increase of K_s value for both experimental plots. The K_s value increased approximately six times for reduced tillage and more than three times for conventional tillage. Plot with conventional tillage reached ¾ of K_s value compared to plot with reduced tillage. A decrease of K_s value in the plot with conventional tillage related to the change of physical properties of soil at greater depths (an increase of bulk density, lower porosity and higher initial water content).

Laboratory determination average values of K_s were compared with average estimates of K_s from infiltration tests. Results of laboratory measurements have been burdened with a number of errors (smaller sample volume than the representative elementary volume (REV), compaction in cropping, disruption of the sample collection, preferential flow along the wall rollers and roots). The measured values of K_s ranged between two orders of magnitude, it did not only show signs of compaction, but also preferential flow. The means values of K_s in top layer (10 cm) were higher and practically identical for conventional and reduced tillage, can be considered "ideal" for promoting rapid infiltration and redistribution of water needed for plants, reducing surface runoff and erosion of soil and rapid drainage of permeating soil water (2009: $K_{s,con.} = 8.7 \times 10^{-4}$, $K_{s,red.} = 8 \times 10^{-4}$ cm.s^{-1}, 2011: $K_{s,con..} = 3.8 \times 10^{-3}$, $K_{s,red.} = 3.9 \times 10^{-3}$ cm.s^{-1}).

In 2011 was reached higher mean value of unsaturated hydraulic conductivity *K(−2 cm)* for reduced tillage, for conventional tillage decreased approximately three times.

CONCLUSIONS

Long-term applied technologies of tillage treatments affect the physical properties and water infiltration into the top layer. Water infiltration into the soil reflects the overall condition of the soil where the changing of water and air regime takes place. These findings are important with regard to other tillage treatment. The results showed that the reduced tillage of medium heavy loam soil in sugar production area is more advantageous from an economic and ecological point of view.

SUMMARY

The aim of this study was to asses the impact of different tillage treatments on hydraulic conductivity in the locality Bohaté Málkovice, the District Vyškov. The field experiments were performed in 2009 and were repeted in 2011 on Haplic Chernozem, medium heavy loamy soil. The experimental area was divided into two parts; top layer of these plots was cultivated by applying conventional and reduced tillage treatment. Both these plots were sown with spring barley (*Hordeum vulgare*).

On experimental plots were carried out infiltration experiments using the double-ring infiltrometer (2009, 2011) and Minidisk infiltrometer (2011). For evaluation of saturated hydraulic conductivity K_s using the double-ring infiltration method was used Philip's three-parameter equation and for evaluation of unsaturated hydraulic conductivity *K(h)* using Minidisk infiltrometer was used Zang's method. Near the points where the infiltration was measured, the soil samples were always collected for laboratory determination of basic physical properties of soil and saturated hydraulic conductivity $K_{s.}$ For laboratory determination of K_s was used permeameter with constant gradient. Basic physical properties of the soil of tested plots are in Table I. Results of unsaturated hydraulic conductivity *K(−2 cm)* and saturated hydraulic conductivity K_s obtained in locality Bohaté Málkovice are in Table II. In 2009 both experimental plots had relatively low and balanced average value of saturated hydraulic conductivity K_s, lower K_s value was reached on the plot with reduced tillage. In 2011 was apparent significant increase of K_s value for both experimental plots. The K_s value increased approximately six times for reduced tillage and more than three times for conventional tillage. Plot with conventional tillage reached ¾ of K_s value compared to plot with reduced tillage.

Laboratory determination average values of K_s were compared with average estimates of K_s from infiltration tests. Results of laboratory measurements have been burdened with a number of errors (smaller sample volume than REV, compaction in cropping, disruption of the sample collection, preferential flow along the wall rollers and roots). The measured values of K_s ranged between two orders of magnitude, it did not only show signs of compaction, but also preferential flow. The means values of K_s in top layer (10 cm) were higher and practically identical for conventional and reduced tillage, can be considered "ideal" for promoting rapid infiltration and redistribution of water needed for plants, reducing surface runoff and erosion of soil and rapid drainage of permeating soil water. In 2011 was reached higher mean value of unsaturated hydraulic conductivity *K(−2 cm)* for reduced tillage, for conventional tillage decreased approximately three times.

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