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Seasonal dynamics of infiltration in soil horizon A in Zhůří enclave

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Abstract
The objective of long-term measurements of infiltration with ring infiltrometers in the meadow enclave Zhůří was to describe the dynamics of infiltration through the surface soil horizon A at a grassland site in the growing season, and to confirm the hypothesis about seasonal variation in bulk density in the course of vegetation. There was at least one cylinder in each treatment where only infiltration, but not sinking, occurred during measurements in 1999 and 2000, i.e. the existence of a preferential path was not demonstrated. The validity of these hypotheses was demonstrated at a significance level of a = 0.05: infiltration rate is dependent on soil temperature. Infiltration rate is not dependent on soil moisture after sufficient saturation of soil with water. The validity of the hypothesis that infiltration rate is dependent on the amount of soil organic matter and on the reduced bulk density of soil was not demonstrated at the significance level of $\alpha = 0.05$.

Key words: grassland management (mulching, no cut, one cut), infiltration, method of Nestěrov, macropores

INTRODUCTION

The references in the paper by JARAMILLO & al. (2000) document that field measurements of hydraulic properties of soil with ring infiltrometers are current and widespread methods. The number of references in this paper is adequate to the importance of determined information on hydraulic properties of soil. The review by JARAMILLO & al. (2000) contains a list of all used methods of infiltration measurement, description and characteristics of phenomena influencing infiltration, including the results of case studies.

Absolute values of measured hydrological properties of soil are influenced by many factors. Infiltration is affected mainly by the particle-size distribution of soil profile layers, is variable in time (CERDA 1999) and space (KUTÍLEK 1993, CHAN & al. 1993), the results are influenced by soil compaction and structure (BOUMA & al. 1979), by the sequence and thickness of these layers (ŠTEKAUEROVÁ 1997), and humus content (BABEJOVÁ & al. 2000). The mode of water penetration into the soil is also important, particularly of infiltration, i.e. the movement of water through soil pores due to gravitation and capillary forces, and sinking, i.e. the flow of water into the soil through fissures and galleries made by zooedaphon and dead roots. Water infiltration into the soil is one of the examples of unsteady flow in an unsaturated medium when hydraulic conductivity is not constant, and is the function of soil properties and water content in the soil (matrix potential) and soil temperature (GIAKOUMAKIS 1991), because the viscosity of soil solution depends on temperature as well as on the concentration of soil solution and composition of soluble ions.

The objective of long-term measurements of infiltration with ring infiltrometers in the meadow enclave Zhůří was to describe the dynamics of infiltration through the surface soil horizon A at a grassland site during the growing season and to confirm the hypothesis about seasonal variations in bulk density in the course of vegetation.

Locality description

Soil cover on the locality is formed by Dystric Cambisol on paragneiss, sandy loam, slightly gravelly, medium deep with no clean-cut structure, mild by moist, with loose consistence and slight biological activity, deep and densely rooted. The characteristics and detailed description of the enclave Zhůří – Huťská hora Mt. see in Mašková & al. (2001).

Material and Methods

Infiltration is influenced by the initial water content in the soil. Dry soil absorbs a high amount of water at a high rate of infiltration, but it has low hydraulic conductivity, so the wetting front proceeds more slowly. The curve of the rate of water infiltration into the soil in relation to time descends with the amount of infiltrated water. After a longer time, the rate is stabilized and the curve assumes linear shape. The values of hydraulic conductivity are highest for the full water saturation of soil, with water when all interconnected pores are filled with water and will be active during water transport (saturated flow). These are the reasons why the dynamics of infiltration in the growing season was investigated after it had become stabilized, i.e. infiltration of saturated medium was measured. Measurements of infiltration – coefficient of hydraulic saturation K, i.e. the rate of water absorption into the soil, have been carried out with 6 stationary infiltrometers on an experimental plot in the Zhůří – Huťská hora Mt. locality since 1999, on sites with three types of grassland management (one cut, no cut and one mulching in a year), with two replicates in each treatment, four times each year of observation on the dates corresponding to the beginning of the growing season (mid-May), period of fast biomass growth (end of June), period after cut and mulching (end of July) and end of the growing season (mid-September).

Before taking measurements from surface flooding, the time of infiltration of ten constant specific doses of 1 l in volume (the amount equivalent to 10 mm in the inside cylinder) was recorded. A two-cylinder method was used to reduce flow from the middle cylinder. The volume of specific dose was chosen as optimum under the given conditions with respect to accuracy (measuring of the dose, reading off the moment of the level break) and time (possibility of omitting evaporation, total time of experiment duration, interval between the doses, required number of persons). A constant dose was used to see, in the course of measurements, when the values of the time of infiltration are steady. In order that about ten doses be enough (irrespective of the initial state of medium saturation) the medium should be pre-wetted before measurements. A dose of 100 mm applied at least two hours before the experiment appears sufficiently high for pre-wetting. The tips located at the same height maintain the same level in both cylinders, i.e. they create comparable conditions of infiltration. This step had to be taken on the basis of results of the first measurement (in May 1999) when the water level in the annulus was not maintained at the same height and the time of infiltration was influenced by water level in the annulus. Therefore, the data from this measurement were not used for further processing.

In 1999, infiltration was evaluated by three different methods of calculation (methods of Nestěrov, Philip and Peltier) to enable better comparison and verification of suitability of the different methods. A comparison betwen the Nestěrov and Peltier methods proved a small difference in the values: – 0.008 mm.min^{-1}. The values calculated by Peltier method are on average by 2–10% lower than those obtained by Nestěrov method. In spite of these differences it can be stated that the methods give comparable results.

The method according to Nestěrov was used to process the measured values (SG GEOTECHNIKA 1999). The method can be used under the following conditions: *in situ* earth, vertical measurements, permeable earth, water from the inside cylinder infiltrates into soil vertically on the ground surface because water from the outside annulus prevents flow to all sides. If initial saturation is sufficiently long, the path of a water particle L is basically identical with the difference between the levels H; this means that hydraulic gradient I equals one ($I = \Delta H / \Delta L = 1$). It derives from Darcy s law for water filtration through an area: $K = q / I \times F$, and from the assumption of vertical filtration: $F_1 = F_2$ and $H = L + h$. Then

$$K = \frac{q}{I.F} = \frac{\Delta h.F}{I.F_2 \Delta t} = \frac{\Delta h}{\Delta t_1}$$, where:

K ...filtration coefficient (m.s^{-1}),
q ...filtration (m^3.s^{-1}),
I ...hydraulic gradient (-),
F_1 ...area of inside cylinder (m^2),
F_2 ...area of water filtration into soil at depth H (m^2),
Δh ...difference between the levels in the inside cylinder for time Δt (m) – 1 l is equivalent to 10 mm, i.e. 0.01 m,
Δt ...time of infiltration of specific dose (s).

For description of other soil characteristics that are correlated with infiltration see the paper by KVITEK & al. (2001).

RESULTS AND DISCUSSION

Measurements of the coefficient of hydraulic conductivity were taken to confirm or refute the following hypotheses:

i) Only infiltration occurs during measurements and no sinking exists in experimental cylinders (hypothesis of the nonexistence of preferential path).

ii) Rate of infiltration is dependent on soil temperature.

iii) Rate of infiltration after sufficient saturation of soil with water before measurement is independent of the initial soil moisture content.

iv) Rate of infiltration is dependent on soil organic matter content.

v) Rate of infiltration is dependent on reduced bulk density of soil.

Verification of the hypothesis of nonexistence of preferential path

The hypothesis of the nonexistence of preferential path was verified by discarding the remote values for all measured and calculated values taken together, and for each concrete measurement (regardless of the year). Table 1 shows the coefficients of hydraulic conductivity K from 1999 and 2000 calculated for particular cylinders by Nestěrov method (42 data) while the remaining values, after discarding all remote values (25), are plotted in Fig. 1.

The measured values of hydraulic conductivity in cylinder 5 in 1999 were demonstrated to be extremely remote (3.75–26.99 mm.min^{-1} – designated as the preferential path previously). It was also demonstrated by Tukey's test that the measured and calculated values of hydraulic conductivity in cylinder 1 in July 1999 (2.91 mm.min^{-1}) and in cylinder 4 in September 1999 (2.47 mm.min^{-1}) were remote values; these values were classified as resulting from the existence of preferential path in the cylinder. Only those cylinders were left for further analyses that did not show any remote values in any of the years and there was no suspicion of the existence of preferential path in them. As cylinder 5 was transplanted before the 2000 season, the year 2000 is sufficient to confirm the nonexistence of preferential path in a newly located cylinder.

The nonexistence of preferential path in cylinders 2, 3, 6 and newly planted cylinder 5 (in 2000) was demonstrated by discarding the remote values. The values of hydraulic conductivity (25 values) range from 0.27 to 1.00 mm.min^{-1} in these cylinders. Fig. 1 shows the seasonal dynamics of infiltration in 1999–2000 with fitting the trend curves to the values of infiltration coefficient K after all cylinders showing remote values were discarded, i.e. cylinders 1 and 4 in both years and cylinder 5 in 1999.

The values of hydraulic conductivity coefficient amounted to 26.99 mm.min^{-1} before the remote values were discarded. Minimum value was 0.25 mm.min^{-1}. Maximum values were attained in macropore flow (preferred path). The determined values of hydraulic conductivity coefficient are realistic. The macropore flow when water is infiltrated through various preferred paths is more frequent in grasslands than the "classical" way of infiltration, mainly in summer months. Macropores contribute to the infiltration capacity of soil particularly in the events of intensive rains when the capillary infiltration capacity of the surface soil layer is exceeded and water on its surface starts to form a continuous film. Although the functional macropores, i.e. those connected with the soil surface, account for about 1–5% of total porosity, they are capable of conducting up to 50% of water when the intensity of irrigation or rain is higher than the saturated hydraulic conductivity (LITSCHMANN 2000).

The seasonal dynamics of hydraulic conductivity coefficient does not show the same trend in the two years.

Verification of the hypothesis "Rate of infiltration is dependent on soil temperature"

The hypothesis was verified by graphical comparison of the trends of both variables in 1999 and 2000 (cf. Figs. 1 and 2) and by the statistical method of correlations, see Table 2.

The hypothesis "Rate of infiltration is dependent on soil temperature" was proved at a significance level of $\alpha = 0.05$.

Temperature influences water flow in two ways. The mean soil temperature influences the water flow rate, and temperature gradients in soil cause temperature-induced transport of water. The result of this hypothesis is in agreement with conclusions drawn by CONSTANZ (1990), CERDA (1999) and GIAKOUMASKIS (1991).

Table 1. – Coefficients of hydraulic conductivity K in the cylinders in 1999-2000.

Variant	**One cut**		**No cut**		**Mulching**	
Cylinder	**V1**	**V2**	**V3**	**V4**	**V5**	**V6**
Year/ month	**K (mm.min^{-1})**					
1999 / June	1.54	0.68	0.41	1.93	3.75	0.71
1999 / July	2.91	0.77	0.43	1.72	11.87	1.00
1999 / September	1.86	0.47	0.42	2.47	26.99	0.28
2000 / May	1.18	0.38	0.45	1.11	0.57	0.48
2000 / June	1.50	0.55	0.67	0.87	0.53	0.59
2000 / July	0.25	0.82	0.27	0.71	0.40	0.34
2000 / September	1.21	0.74	0.41	0.90	0.48	0.38

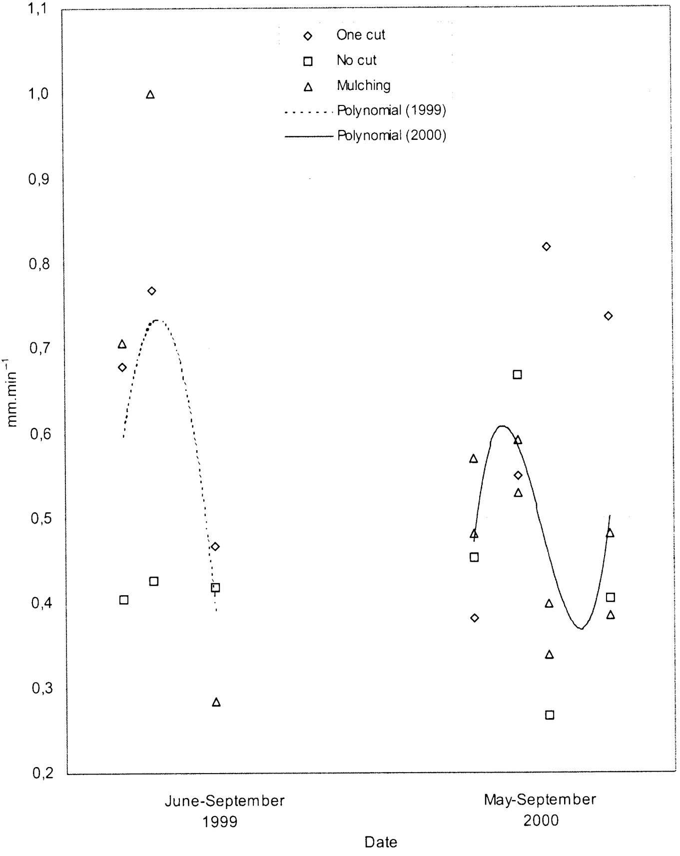

Fig. 1. – Seasonal dynamics of the coefficient of hydraulic conductivity in 1999–2000.

Table 2. – Correlations of the soil characteristics from samplings corresponding to measurements of infiltration (means of replicates and depths) with the values of infiltration coefficients (after discarding all cylinders with potential existence of preferential path) from 1999 and 2000.

Soil characteristic	Soil temperature (°C)	Soil moisture content	TOM (weight %)	OM ($g.cm^{-3}$)
Type of model	Exponential	Reciprocal	Linear	Reciprocal
Significance level	0.027	0.280	0.652	0.733
Correlation coefficient r	0.299	0.225	0.095	0.071
Standard deviation	0.287	0.685	0.183	0.701
Interval of reliability R^2	VIII.91	5.V	0.90	0.51
F–value	5.186	1.224	0.208	0.119
Number of correlated pairs	54	24	24	24
Number of values from which the mean was calculated	8	9 (1999) 30 (2000)	30	30
Proof of hypothesis	Yes	No	No	No

Verification of the hypothesis "Rate of infiltration after sufficient saturation of soil before measurement is independent of the initial soil moisture content"

The hypothesis was verified by graphical comparison of the trends of both variables in 1999 and 2000 (cf. Figs. 1 and 3) and by the statistical method of correlations, see Table 2.

The hypothesis "Rate of infiltration after sufficient saturation of soil before measurement is independent of the initial moisture content of soil" was proved at a significance level of $\alpha = 0.05$.

Verification of the hypothesis "Rate of infiltration is dependent on the soil organic matter content"

This hypothesis was verified by a graphical comparison of the trends of both variables in 1999 and 2000 (cf. Figs. 1 and 4) and by the statistical method of correlations, see Table 2.

The hypothesis "The rate of infiltration is dependent on the soil organic matter content" was not proved at a significance level $\alpha = 0.05$. The results are not consistent with the conclusions drawn by Šantrůček & al. (1993) and Velich in Klesnil & al. (1984), who stated that an extremely dense system of fine adventitious rootlets penetrates every clod of topsoil in which 80–95% of all rootlets are usually located; it leads to consolidation and compaction of A horizon and to an increase in soil resistance. This relationship probably applies to organic – poor soil with prevailing mineral fraction.

Verification of the hypothesis "Rate of infiltration is dependent on reduced bulk density"

The hypothesis was verified by a graphical comparison of the trends of both variables in 1999 and 2000 (cf. Figs. 1 and 5) and by the statistical method of correlations, see Table 2.

The hypothesis "The rate of infiltration is dependent on reduced bulk density" was not proved at a significance level of $\alpha = 0.05$. This hypothesis remains to be tested in the future because of seasonal variability in bulk density (Kvítek & al. 2001).

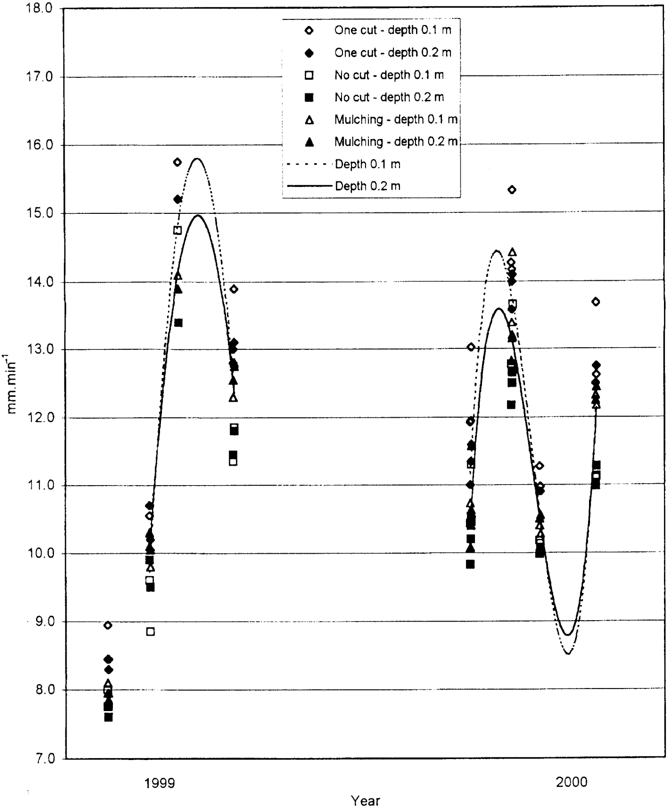

Fig. 2. – Soil temperatures on the dates of infiltration measurements in 1999–2000 and the trend curves fitted to the values.

Conclusions

The results of verification of the initial hypothesies:

i) In each treatment there was at least one cylinder in which only infiltration, but not sinking, occurred during measurements in 1999 and 2000, i.e. the existence of preferential path

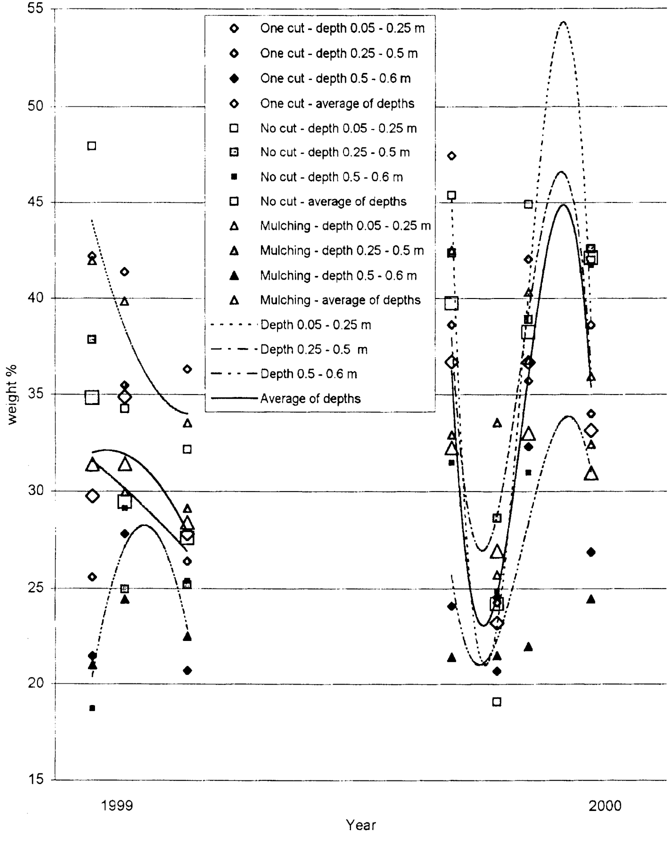

Fig. 3. – Soil moisture contents in percent. soil fresh weight on the dates of infiltration measurements in 1999–2000 and the trend curves fitted to the values.

was not demonstrated. All cylinders should be evaluated for the existence of preferential path in 2001 because this hypothesis is not predictive.

ii) The validity of these hypotheses was proved at a significance level of $\alpha = 0.05$. Rate of

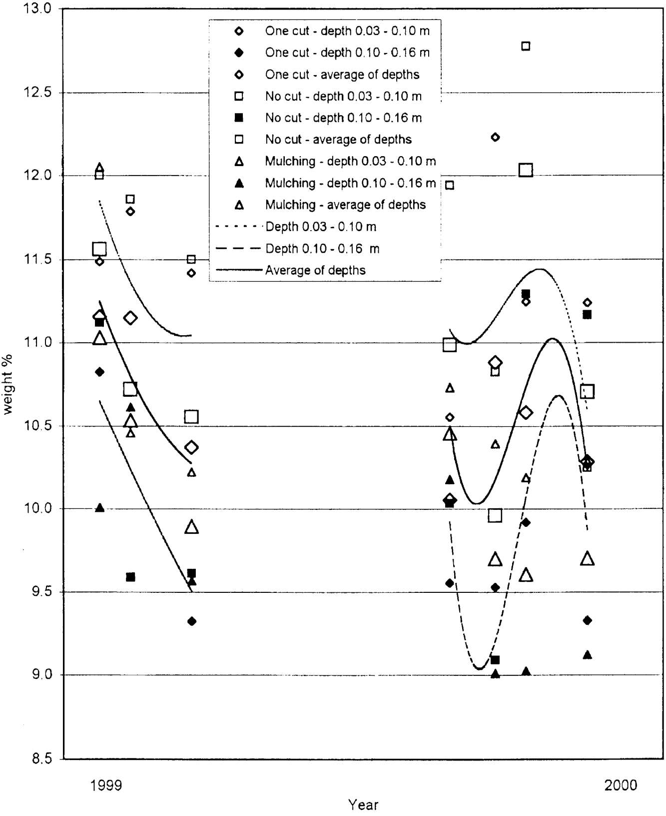

Fig. 4. – Contents of soil organic matter in percent. soil fresh weight on the dates of infiltration measurements in 1999–2000 and the trend curves fitted to the experimental values.

filtration is dependent on soil temperature. Rate of filtration after sufficient saturation of soil with water before measurement is independent of the initial moisture content of soil.

iii) The validity of these hypotheses was not proved at a significance level of $\alpha = 0.05$. Rate of filtration is dependent on the content of soil organic matter. Rate of filtration is dependent on reduced bulk density of soil.

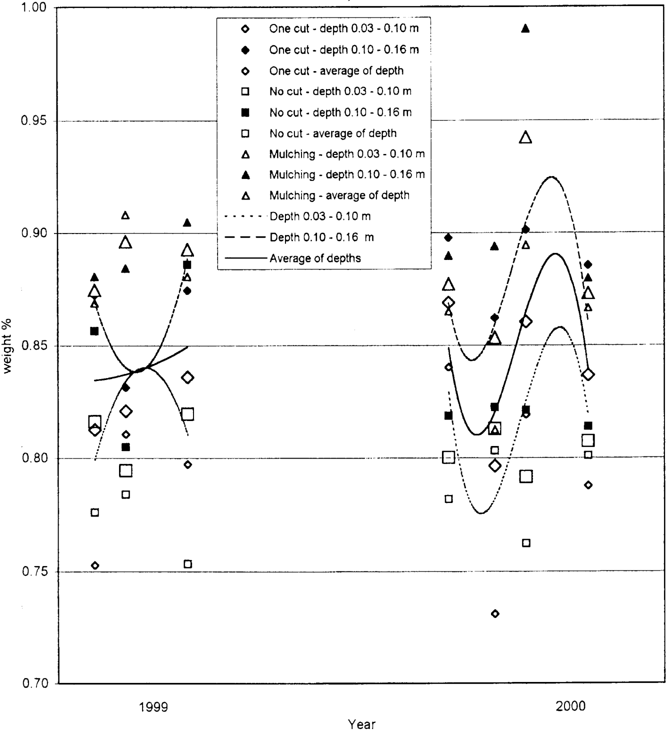

Fig. 5. – Reduced bulk density of soil on the dates of infiltration measurements in 1999–2000 and the trend curves fitted to the values.

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