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COMPARISON OF INFILTRATION CAPACITY OF PERMANENT GRASSLAND AND ARABLE LAND DURING THE 2011 GROWING SEASON

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Abstract

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The aim of this paper was to compare the rate of infiltration and cumulative infiltration in permanent grassland (PG) and in arable land over the course of the 2011 growing season. The measurement of water infiltration into soil was conducted via ponded infiltration method based on the use of two concentric cylinders in field conditions. Kostiakov equations were applied to evaluate the ponded infiltration. Based on field measurements, the dependence of infiltration rate (v) on time (t) was determined and also the dependence of cumulative infiltration (i) on time (t). In order to determine physical properties of soil and carry out a grain size analysis, intact soil samples of plough layer from the depths of 10, 20 and 30 cm were collected using Kopecký cylinders along with individual infiltration attempt in each measurement carried out on experimental plots. In order to assess the infiltration capacity of soil on experimental plots, four measurements were conducted, each with three repetitions. Infiltration attempts were held on May 12, June 28, August 24 and October 6, 2011. On average, a faster water infiltration into soil and a higher cumulative infiltration during the 2011 growing period were detected in arable land. The soil's initial water content has proven to be the crucial factor affecting the rate of water infiltration into soil in case of PG; in case of arable land, it was bulk density indicating the soil's compaction. The PG showed a more balanced course of infiltration rate and cumulative infiltration values during the growing season. Arable land is characterized by a greater dispersion of measured values between individual measurement dates.

infiltration rate, cumulative infiltration, ponded infiltration method, Kostiakov equations, hydro-physical properties of soil, permanent grassland, arable land

Hydrological cycle is one of the basic preconditions of life's existence on Earth. Within this cycle, the water present in the atmosphere gets into contact with the soil in the form of precipitation. Water may become a beneficial or a harmful agent based on how and in what quantities it can be absorbed by soil. The soil's infiltration capacity, i.e. the ability of soil to absorb water from rainfall, is influenced by many factors relating mainly to the actual properties of the soil, climatic conditions and also to human activity and human interventions in the landscape. An unbalanced water cycle in nature, especially a rapid outflow of water from the soil surface, results in alternating floods and droughts, which is related to soil degradation as well. Increasing the soil's ability to retain and accumulate water in the landscape is the fundamental solution to the issue of retention capacity of soil and landscape and its ecological functions.

MATERIALS AND METHODS

Characteristics of experimental territory

The studied area „U Jasana“ is located in Českomoravská vrchovina, 7 km south of Žďár nad Sázavou on the southern border of Protected Landscape Area (PLA) Žďárské vrchy (CHKO Žďárské vrchy), between the villages of Vatín and Sazomín in the Sazomín cadastral area (Fig. 1). The

1: *Orthophotomap with sites of interest highlighted – „U Jasana“*
[source: http://www.geoportal.gov.cz, map of BPEJ – VÚMOP Prague]

experimental plots, located in close proximity, of slightly sloping gradient with an omni-directional exposition, are being used by the Ostrov nad Oslavou collective farm.

According to the Atlas of Weather of the Czech Republic (Tolasz *et al.*, 2007), the average annual air temperature in the territory of interest ranges between 6–7 °C, the average annual rainfall reaches 600–650 mm in the long-term. Based on Quitt classification (1971), the territory of interest falls within the MT4 climate region (mildly warm area). According to the classification of climatic zones taken from the Atlas of Weather of the Czechoslovakia, the area of interest ranks among slightly warm regions, slightly moist sub-region, slightly warm district, slightly moist, upland (Vesecký *et al.*, 1958). The studied area is located in the Oslava river basin falling within the Žďárské vrchy geomorphological sub-unit (Culek *et al.*, 1996). The experimental area is situated at an altitude of 560 m. The code of valued soil-ecological unit (BPEJ) is 07.29.11 for the plots of interest. According to the Ministry of Agriculture Decree No. 327/1998 Coll. stipulating the characteristics of valued soil ecological units and the procedure for keeping and updating these, as amended by Decree No. 546/2002 Coll., this code expresses the following characteristics:

- *climate region:* MT4, mildly warm, moist,
- *main soil unit:* modal, eubasic to mesobasic Cambisols, medium-heavy to medium-heavy lighter, without skeleton to medium skeletal with prevailing good moisture conditions,
- *gradient:* moderate slope (3–7 °),
- *exposition:* omnidirectional,
- *skeleton:* non-skeletal with an admixture, slightly skeletal,
- *depth:* deep, medium-deep.

Experiments were carried out in permanent grassland (PG) and arable land with stand Triticale grenado. Following the harvest of the previous crop (Biscay wheat), which took place at the end of August 2010, stubble under-ploughing was carried out followed by ploughing in mid-September. Immediately after the pre-sowing soil preparation using a compactor on October 1, the sowing of triticale was carried out followed by the soil surface compaction and spraying herbicides. In spring 2011, a regeneration fertilization was carried out using ammonium nitrate with limestone (March 15), followed by production fertilization using ammonium nitrate with urea (April 28). A fungicide spray was applied on May 11. Harvesting took place on August 21, followed by stubble under-ploughing, manure spreading and ploughing on September 25. The PG was fertilized using ammonium sulphate (April 6) and liquid manure, in two doses (April 13, June 18). Mowing of the growth took place on May 18, June 14 and August 31, followed by harvesting hay on the following day.

Methods

The measurement of water infiltration into soil was conducted by means of the ponded infiltration method according to Vališ and Šálek (1970) using two concentric cylinders. In order to ensure statistical significance and minimize deflection in measurements, three sets of concentric cylinders were used for each measurement attempt (the diameter of the outer cylinder was 55 cm and that of inner cylinder was 30 cm). The principle of the method is based on the repeated refill of known volume of water (1 litre, 0.5 litre or 0.2 litre) into the inner cylinder above the measuring point

(2 cm above the soil surface) while recording the time needed for the absorption of the volume of water supplied. Experiments were terminated after stabilization of rate of water absorption into the soil; after a maximum of two hours of measurement.

Kostiakov equations were used to evaluate the ponded infiltration method. Based on field measurements, the dependence of infiltration rate *v* on time *t* was determined and also the dependence of cumulative infiltration *i* on time *t*. The expression of these dependences by means of empirical equations of Kostiakov was described in detail by Kutílek, Kuráž and Císlerová (1993), Vališ and Šálek (1970), Velebný and Novák (1989) *et al*. The results of infiltration attempts are presented in graphs with a logarithmic scale including interlaying values with a power function and calculating a regression equation.

Along with infiltration experiments, undisturbed soil samples were taken at the locality during each measurement by means of Kopecký physical cylinders from the soil depth of 10, 20 and 30 cm in compliance with the methodology (Zbíral *et al.*, 2004) always in three repetitions in each soil depth. Analysis of physical properties of intact soil samples was carried out in the laboratory of Department of Agro-chemistry, Soil Science, Microbiology and Plant Nutrition, Faculty of Agronomy, Mendel University in Brno. Based on this analysis, selected physical properties of soil were evaluated in compliance with the methodology (Zbíral *et al.*, 2004) including reduced volume weight, porosity, capillary, semi-capillary and non-capillary pores, actual soil moisture and aeration, and a grain size analysis was carried out. The proportion of humus was determined using the disturbed soil samples collected (Zbíral *et al.*, 2004).

RESULTS AND DISCUSSION

Four measurement attempts took place (each with three repetitions) in order to assess the infiltration capacity of soil on experimental plots (grassland and arable land) in the cadastral area of Sazomín during the growing season of 2011. Infiltration experiments including the collection of undisturbed soil samples were held on May 12, June 28, August 24 and October 6, 2011.

Basic characteristics of soils

According to Novák particle-size classification (Jandák *et al.*, 2009) and based on the collection of undisturbed soil samples, the soil on the location with stand triticale was evaluated as sandy-loamy in all depths. The proportion of clay particles (< 0.01 mm) in the depth of 10 cm was 25%, in the depth of 20 cm, it reached 24% and in the depth of 30 cm it achieved 23%. The soil with PG was evaluated as sandy-loamy in the depth of 10 and 20 cm and in the depth of 30 cm it was evaluated as loamy-sandy. In the depth of 10 cm, the proportion of clay particles reached 22%, in the depth of 20 cm, the proportion of clay particles was 21% and in the depth of 30 cm, it was 19%.

The humus content in soil was monitored as well – it was declining as the depth values were increasing. In PG, the humus content reached 3.26% in the depth of 10 cm, in the depth of 20 cm it achieved 0.76% and in 30 cm, it was 0.19%. In arable land, it reached 3.23% in the depth of 10 cm, 2.42% in the depth of 20 cm and 1.45% in 30 cm.

Physical properties of soil based on the result of the analysis of undisturbed soil samples collected at each experimental site in individual measurements are given in Tabs. I. to IV.

The highest average values of reduced volume weight were recorded on May 12 (arable land) and August 24 (PG). The volume weights, for which the critical value for sandy-loamy soils (1.55 $g.cm^{-3}$) and loamy-sandy soils (1,60 $g.cm^{-3}$) was exceeded, in case of PG in the depth of 30 cm, representing a harmful compaction of soil (Lhotský, 2000), have been highlighted. Except for PG on May 12, arable land on June 28 and on October 6, a gradual increase of volume weight in the direction from the surface layer of soil profile towards its lower layers was observed.

Porosity decreases in relation to increasing volume weight of soil. A decline in porosity under critical values according to Lhotský (2000) for sandy-loamy soils (<42% vol.) and loamy-sandy soils (<40% vol.) has been highlighted in Tabs. I. to IV. The lowest porosity has been detected in agreement

I: *Physical properties of soil (PG and arable land – May 12, 2011)*

Term of soil sampling	May 12, 2011					
Type of land	PG			arable land		
Depth of soil sampling [cm]	10	20	30	10	20	30
Bulk density [$g.cm^{-3}$]	1.41	1.48	1.38	1.46	**1.60**	**1.66**
Porosity [% vol.]	47.33	44.45	48.93	45.27	**40.61**	**38.58**
Capillary pores [% vol.]	34.09	32.79	26.14	31.65	33.65	20.67
Semi-capillary pores [% vol.]	8.55	7.20	11.67	6.46	4.60	9.51
Non-capillary pores [% vol.]	4.69	4.46	11.12	7.16	2.36	8.40
Initial water content [% vol.]	23.43	23.56	20.23	22.95	27.34	14.90
Aeration [% vol.]	23.89	20.88	28.70	22.32	13.27	23.68

II: *Physical properties of soil (PG and arable land – June 28, 2011)*

Term of soil sampling	June 28, 2011					
Type of land	PG			arable land		
Depth of soil sampling [cm]	10	20	30	10	20	30
Bulk density [g.cm^{-3}]	1.29	1.53	1.56	1.51	1.46	1.54
Porosity [% vol.]	50.95	42.10	41.83	42.56	44.56	42.27
Capillary pores [% vol.]	28.18	28.11	27.14	28.96	30.23	25.69
Semi-capillary pores [% vol.]	13.01	8.70	8.49	9.35	8.60	8.16
Non-capillary pores [% vol.]	9.76	5.28	6.20	4.24	5.73	8.43
Initial water content [% vol.]	21.40	19.90	18.22	20.18	14.62	10.72
Aeration [% vol.]	29.55	22.20	23.61	22.38	29.94	31.56

III: *Physical properties of soil (PG and arable land – August 24, 2011)*

Term of soil sampling	August 24, 2011					
Type of land	PG			arable land		
Depth of soil sampling [cm]	10	20	30	10	20	30
Bulk density [g.cm^{-3}]	1.37	**1.57**	**1.69**	1.43	1.45	**1.68**
Porosity [% vol.]	47.98	**41.60**	**37.16**	46.36	45.19	**38.16**
Capillary pores [% vol.]	29.56	20.28	16.52	25.70	31.33	21.88
Semi-capillary pores [% vol.]	13.73	13.36	12.53	12.75	8.11	9.03
Non-capillary pores [% vol.]	4.69	7.96	8.12	7.92	5.74	7.25
Initial water content [% vol.]	23.90	17.32	15.28	28.87	34.47	23.89
Aeration [% vol.]	24.08	24.28	21.88	17.49	10.72	14.27

IV: *Physical properties of soil (PG and arable land – October 6, 2011)*

Term of soil sampling	October 6, 2011					
Type of land	PG			arable land		
Depth of soil sampling [cm]	10	20	30	10	20	30
Bulk density [g.cm^{-3}]	1.42	1.47	1.49	1.21	1.28	1.26
Porosity [% vol.]	45.20	43.72	43.06	53.46	51.02	52.17
Capillary pores [% vol.]	30.06	29.17	29.06	25.34	29.07	28.07
Semi-capillary pores [% vol.]	9.54	8.81	7.14	16.51	11.47	13.98
Non-capillary pores [% vol.]	5.60	5.74	6.86	11.61	10.48	10.13
Initial water content [% vol.]	25.11	23.96	26.48	21.34	26.29	26.27
Aeration [% vol.]	20.09	19.75	16.58	32.12	24.74	25.90

with the highest volume weight in PG on August 24 in the depths of 20 and 30 cm. In arable land, the highest volume weight was detected on May 12 in the depths of 20 and 30 cm and on August 24 in the depth of 30 cm. The highest average porosity in PG in all inspected depths of soil profile has been recorded on May 12 (46.90 % vol.) and in arable land on October 6 following stubble under-ploughing and ploughing (52.22 % vol.).

Pores are divided according to size to capillary, semi-capillary and non-capillary. Soil condition is most favourable when the total porosity is divided from 1/3 to pores inter-pedal – non-capillary and semi-capillary and from 2/3 to intra-pedal – capillary pores (Jandák *et al.*, 2009). The optimum representation of capillary pores in all depths of the soil profile in PG has been achieved on October 6, June 28 in the depths of 20 and 30 cm and on August 24 in the depth of 10 cm. The proportion of semi-capillary and non-capillary pores in PG is characterized in almost all measurements by a greater or a minor domination of semi-capillary pores over non-capillary pores. In arable land, from the perspective of representation of individual pore types, favourable conditions were detected only on May 12 in the depth of 10 cm, on June 28 in 10 and 20 cm and on August 24 in the depth of 20 cm. During the last measurement, a significant increase has been detected in the proportion of inter-pedal pores while maintaining the volume of capillary pores at the level corresponding with previous measurements. In most cases, semi-capillary pores dominate over non-capillary pores same as in case of PG.

When evaluating the structure condition of humus layer based on the values of reduced volume weight and porosity for medium-heavy to heavy soils (Kutílek, 1966), it is possible to state that from the aforementioned perspective, the condition of soils at both locations of interest is unsatisfactory (volume weight 1.4–1.6 $g.cm^{-3}$, porosity 39–46 % vol.) and in lower layers of soil horizon lacking structure in some periods of the growing season (volume weight 1.6–1.8 $g.cm^{-3}$, porosity 31–39 % vol.) or close to this condition. A favourable structure condition of the humus layer in all depths monitored has been achieved in case of arable land only after stubble under-ploughing and ploughing on October 6 and on June 28 and August 24 in PG in the outer layer of soil profile.

The highest initial water content of soil has been recorded in PG on October 6 and on August 24 in arable land, which is, on the contrary, the date of recording the lowest moisture in PG for the entire period monitored. The aforementioned distribution of initial water content in PG and in arable land on August 24 is a reaction to the development stage of stand (PG in full growth a weak prior to the third mowing and in arable land stubble following the harvest of triticale). The lowest moisture rate in arable land, especially in the depths of 20 and 30 cm, has been recorded on June 28. The low levels of actual soil moisture (the lowest on average for the entire growing season on both plots of interest) were caused mainly by draining off water due to active root system of fully grown stand of triticale.

Aeration of soil, depending on actual soil moisture, ranges between 18 to 24% vol. for arable land horizons in good condition. The minimum air content in soil should not decrease below 9% vol. (Jandák *et al.*, 2009). No decline of soil aeration below the critical value has been recorded on experimental plots during the growing season. On August 24, the aeration of soil in the depth of 20 cm was close to this value reaching 10.72 % vol. The lowest values of soil aeration throughout the entire arable land horizon during the growing season were recorded on this date. The greatest decline in air content in soil in PG was detected on October 6 in the depth of 30 cm (16.58 % vol.). The PG showed a minor fluctuation in soil aeration throughout the growing season. Greater differences between the values measured were recorded in arable land. A significant increase in aeration of soil exceeding the upper limit of optimal range was recorded in some cases. The arable land showed the greatest aeration on October 6 in the depth of 10 cm (32.12 % vol.) and PG on June 28 also in the depth of 10 cm (29.55 % vol.).

Results of infiltration measurements

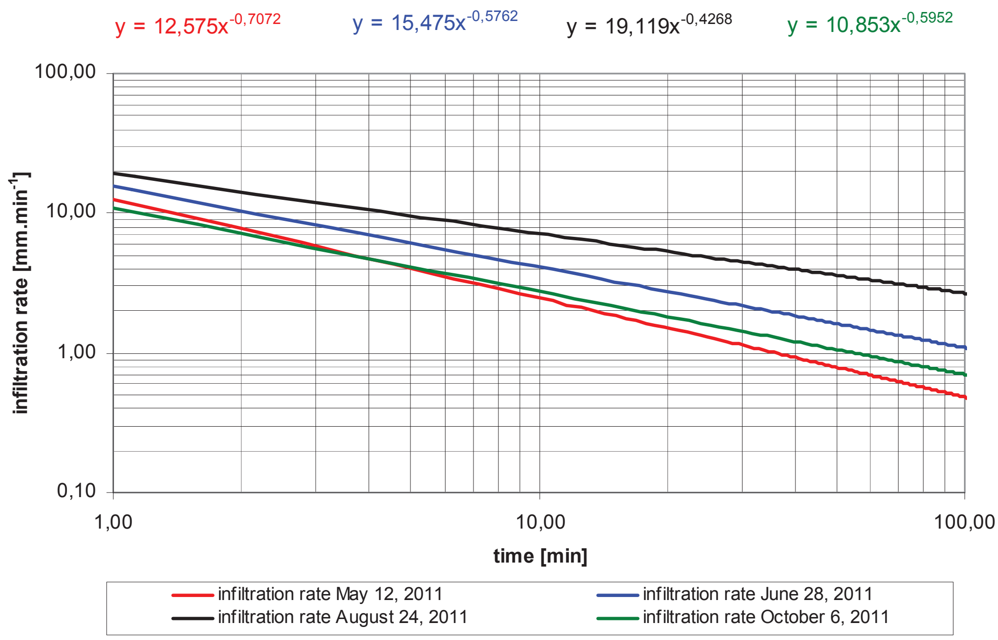
The course of infiltration attempts in selected stand types during the 2011 growing season is shown in the graphs in Fig. 2 to 5. The graphs show the average infiltration rate ($mm.min^{-1}$) and cumulative infiltration (mm) in each measurement, depending on time. The course of infiltration rate and cumulative infiltration is shown from 1 to 100 minutes from the start of measurement.

Infiltration experiments carried out within one day were characterized on some days by a considerable heterogeneity, which is mainly due to preferential pathways (cracks, pathways in mezoedafon and macroedafon) or obstacles in the way of absorbing water (stones, air enclosed in the pores, etc.). Such measurement experiments, deviating from the remaining ones, were not deemed as representative and therefore were not included in calculating the average infiltration rate and cumulative infiltration on a given date.

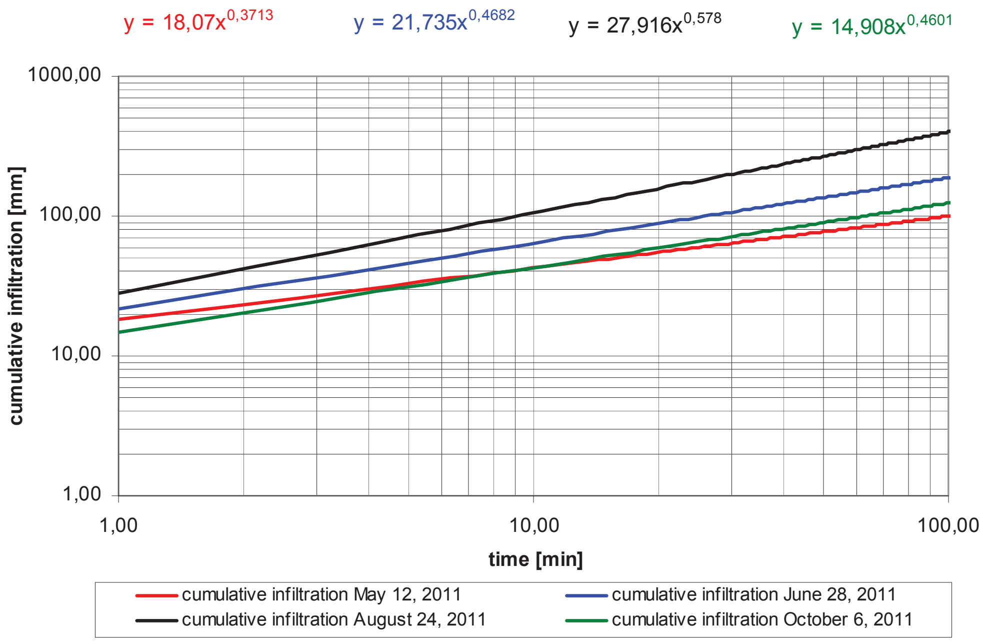
The graphs on Fig. 2 and 3 comparing representative values of infiltration rate and cumulative infiltration on individual dates of measurement of the 2011 growing season in PG clearly show that a gradual increase of all indicators monitored is occurring in the May – August period with the maximum values attained in August (August 24). The aforementioned trend corresponds with gradually declining initial water content of soil profile over the given period. The lowest values of infiltration rate and cumulative infiltration together with the initial water content of soil were recorded at the start (May 12) and the end (October 6) of the growing season. The influence of reduced volume weight as indicator of soil compaction did not prove to be decisive in case of PG. The highest volume weight has been recorded during the period with the highest infiltration rate.

The lowest rate of water infiltration into soil, same as in case of PG, has been recorded in arable land during the first measurement (Fig. 4 and 5). Infiltration capacity grew at the second measurement followed by a slight decline in August. The soil showed the highest rate of infiltration and cumulative infiltration during the last measurement (October 6) in contrast to PG. This situation is due to previous agro-technical intervention (stubble under-ploughing, ploughing). In case of arable land, in contrast to PG, the soil's reduced volume weight has been the decisive factor determining the rate of infiltration and cumulative infiltration as based on the analysis of physical properties of soil. The highest values of volume weight were recorded during the first measurement date (the lowest rate of water infiltration into soil) and, on the contrary, the lowest values were recorded during the last autumn measurement (the highest rate of water infiltration into soil). The influence of actual soil moisture on water infiltration has been suppressed by the aforementioned agro-technical operations and the development stage of the stand grown affecting the soil's volume weight.

The comparison of average rates of infiltration and cumulative infiltration values during individual measurements in arable land and PG shown in the graphs in Fig. 2 to 5 clearly indicate that the indicators observed during the growing season demonstrate a greater balance in grassland compared to measurements performed in arable



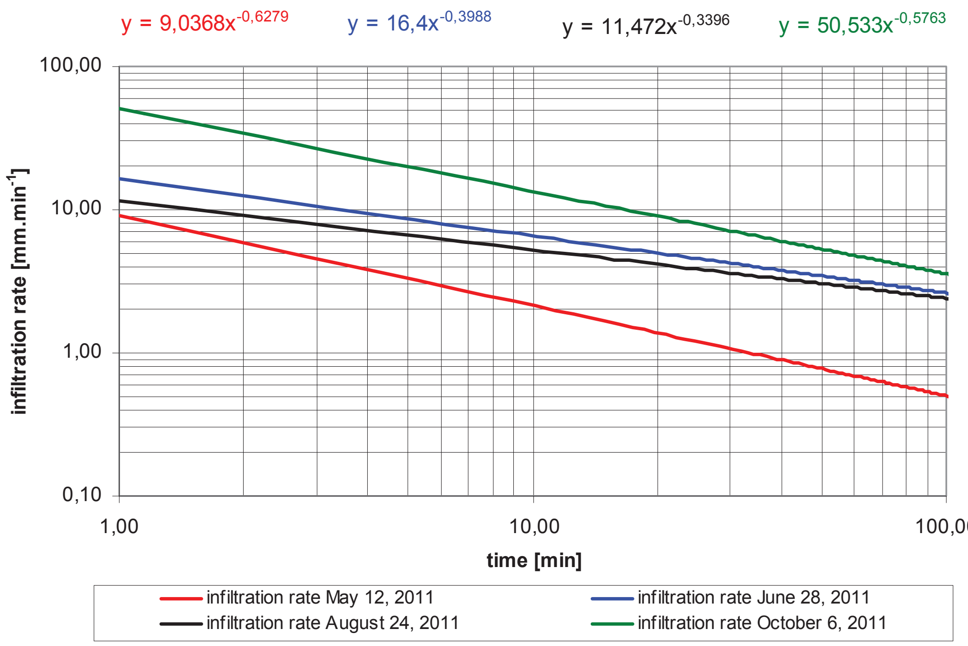
2: *Dependence of infiltration rate on time in PG during the 2011 growing season*



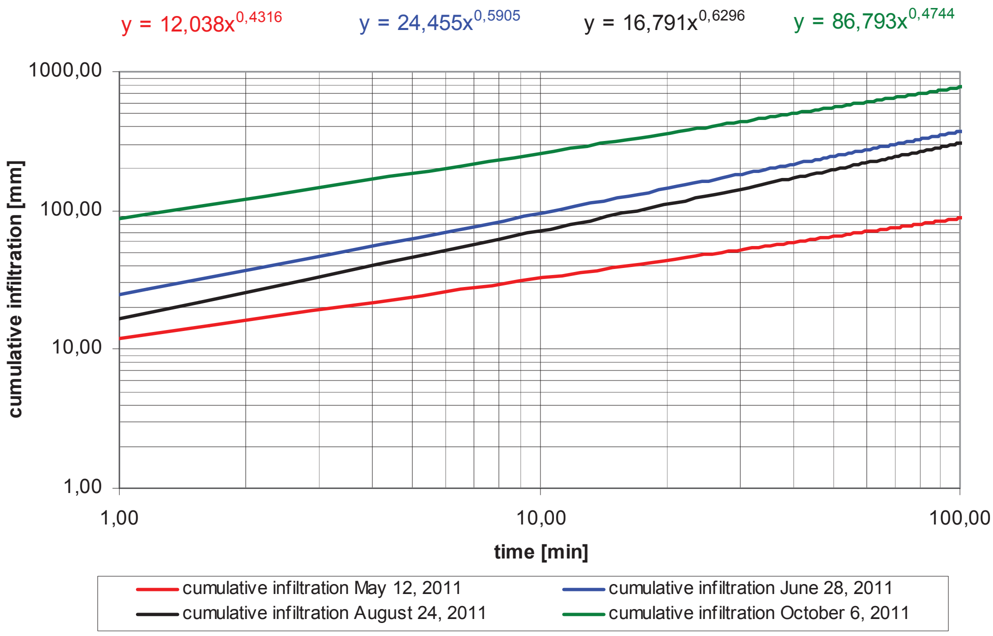
3: *Dependence of cumulative infiltration on time in PG during the 2011 growing season*

land. This condition is caused by the kind of crop and the corresponding soil tillage. The observed greater dispersion between the values of cumulative infiltration and infiltration rates during the growing season in arable land is a reflection of dynamic changes in physical properties of soil profile due to the development stage of the stand and the applied agro-technical interventions. These findings confirm the results of infiltration experiments by Dumbrovský *et al.* (2011) monitoring the infiltration rate and cumulative infiltration in soils with different soil tillage technologies. In conventional tillage, the abovementioned author has proven a significant inhomogeneity of the measured values and in the event of using minimization technologies (similar to PG), a greater conformity of values has occurred.

Comparison of the average rate of infiltration and cumulative infiltration during the 2011 growing season in PG and arable land is shown in the graphs in Fig. 6 and 7. Also, this comparison corresponds to the results by Dumbrovský *et al.* (2011), where a significantly higher suction capacity of upper soil layers has been demonstrated in the event of conventional tillage compared to minimization



4: *Dependence of infiltration rate on time in arable land throughout the 2011 growing season*

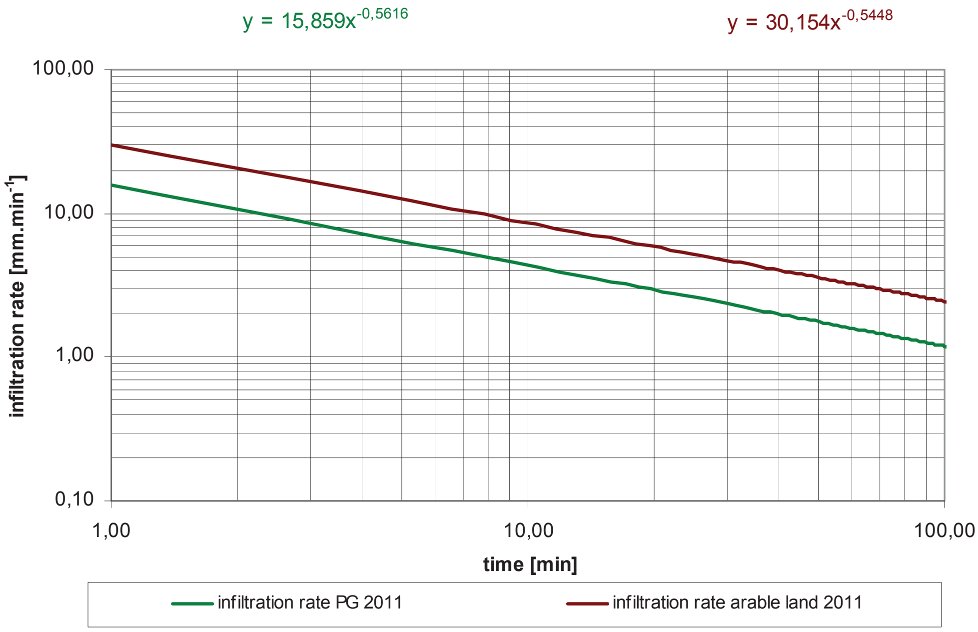


5: *Dependence of cumulative infiltration on time in arable land throughout the 2011 growing season*

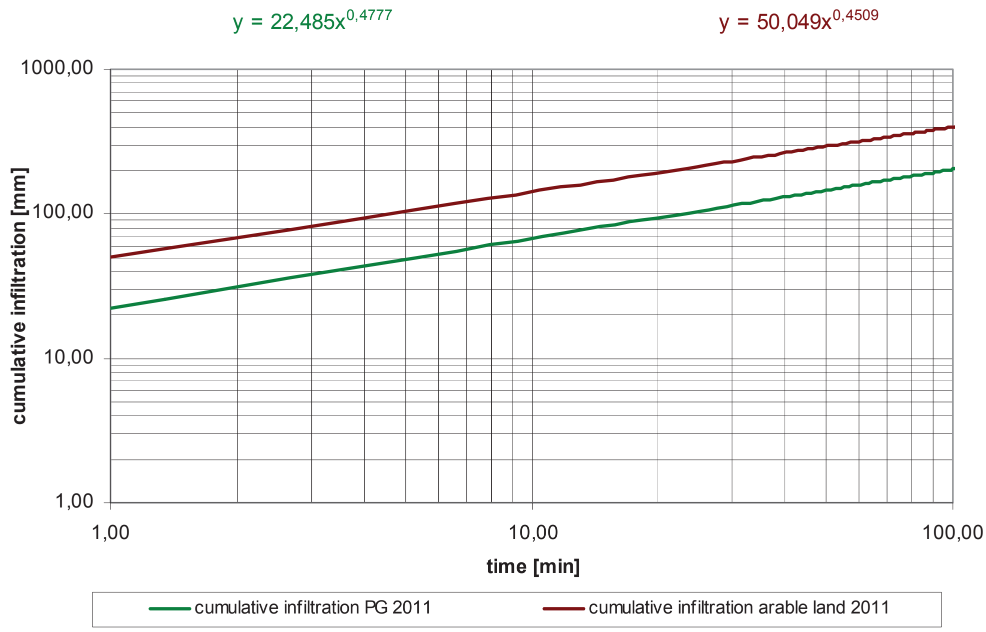
soil tillage technologies, in which case the suction capacity reached approximately 50%. In case of PG, comparable to minimization technologies, the identified rate of infiltration and cumulative infiltration reached half the level compared to the rate of water suction and cumulative infiltration in arable land. (Actual rate in 10 min in PG 4.35 $mm.min^{-1}$, in arable land 8.60 $mm.min^{-1}$, in 60 min in PG 1.59 $mm.min^{-1}$, in arable land 3.24 $mm.min^{-1}$. Cumulative infiltration in 10 min in PG 67.54 mm, in arable land 141.35 mm, in 60 min in PG 158.97 mm, on arable land 317.08 mm).

CONCLUSION

Soil is a very complex and complicated system, where water movement is always affected by the mutual interaction of many factors. The process of evaluating infiltration attempts has been burdened by unbalanced courses of water infiltration rates into soil and cumulative infiltration between individual repetitions performed within one day of measurement. The variance of observed indicators significantly affected the heterogeneity of soil condition. Despite the facts described, it is



6: *Comparing the dependence of average infiltration rate on time in PG and in arable land during the 2011 growing season*



7: *Comparing the dependence of average cumulative infiltration on time in PG and in arable land during the 2011 growing season*

possible to trace patterns of water movement in soil depending on soil physical properties, type of crop and the agro-technical interventions used.

A faster water infiltration into soil and a higher cumulative infiltration during the growing season were found on average in arable land despite a higher proportion of clay particles in the soil profile. The actual soil moisture in PG and the volume weight in arable land reduced as an indicator of its compaction have proven to be the crucial factors. The PG showed a more balanced course of infiltration rate and cumulative infiltration values during the growing season. Arable land is characterized by a greater dispersion of measured values between individual measurement dates. This situation reflects the nature of the crop, its development stages and the agro-technical operations performed.

Based on results of experiments, arable land showed more favourable conditions for water infiltration into soil. Therefore, from this perspective, the PG is not always and under all circumstances a better option for supporting water infiltration into soil. However, this situation was largely influenced mainly by much higher infiltration capacity of arable land during the last measurement attempt carried out after stubble under-ploughing and ploughing. From the perspective of protection of soil surface layer against its loss caused by erosion as a result of flowing water from torrential rainfall, it is important to arrange for an unbroken stand cover for the longest possible period of the year, which is provided by PG.

SUMMARY

The aim of the presented paper was to compare the infiltration rate and cumulative infiltration in permanent grassland (PG) and in arable land in the cadastral area of Sazomín during the 2011 growing season. In order to assess the infiltration capacity of soils on experimental plots, four measurements were carried out, each including three repetitions. Infiltration attempts were held on May 12, June 28, August 24 and October 10, 2011.

The measurement of water infiltration into soil was carried out by ponded infiltration method according to Vališ and Šálek (1970) using two concentric cylinders. In order to ensure statistical significance and minimize deflection in measurements, three sets of concentric cylinders were used for each measurement attempt. Kostiakov equations were applied to evaluate the ponded infiltration method (Kutílek, Kuráž and Císlerová, 1993; Vališ and Šálek, 1970; Velebný and Novák, 1989). Based on field measurements, the dependence of infiltration rate *v* on time *t* was determined and also the dependence of cumulative infiltration *i* on time *t*.

Along with infiltration experiments, at each of the measurements, undisturbed soil samples were taken at the locality by means of Kopecký physical cylinders from the soil depth of 10, 20 and 30 cm, always in three repetitions in each soil depth. Based on the analysis of collected soil samples, selected physical properties of soil were evaluated in compliance with the methodology (reduced volume weight, porosity, capillary, semi-capillary and non-capillary pores, actual soil moisture and aeration) and a grain size analysis was conducted. The proportion of humus was determined using the disturbed soil samples collected (Zbíral *et al.*, 2004).

A faster water infiltration into soil and a higher cumulative infiltration during the 2011 growing season were found on average in arable land despite a higher proportion of clay particles in the soil profile. In comparison to arable land, the indicators monitored showed half the values in case of PG. The actual soil moisture in PG and the volume weight in arable land reduced as an indicator of its compaction have proven to be the crucial factors affecting the rate of water infiltration into soil. The PG showed a more balanced course of infiltration rate and cumulative infiltration values during the growing season. Arable land is characterized by a greater dispersion of measured values between individual measurement dates. This situation reflects the nature of the crop, its development stages and the agro-technical operations performed which overall manifest themselves in physical properties of soil.

Acknowledgement

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