INFRASTRUKTURA I EKOLOGIA TERENÓW WIEJSKICH
INFRASTRUCTURE AND ECOLOGY OF RURAL AREAS

Nr 12/2011, POLSKA AKADEMIA NAUK, Oddział w Krakowie, s. 17–30
Komisja Technicznej Infrastruktury Wsi
Commission of Technical Rural Infrastructure, Polish Academy of Sciences, Cracow Branch

Martina Vičanová, František Toman, Tomáš Mašíček, Petra Oppeltová

COMPARATIVE STUDY OF SOIL INFILTRATION CAPACITY AT SELECTED SITES

Summary

The study deals with definition and cross-comparison of soil infiltration capacity at two selected sites located in cadastral territories of Nosislav and Žabčice, Czech Republic. In order to assess the soil infiltration capacity in the areas of interest Niva and Kovál over the course of the 2010 growing season, four trips were made with three measurements taking place during each trip. A method of double-ring infiltration measurement was applied, based on the use of two concentric cylinders in field conditions and the subsequent data processing via geographical-empirical method according to Kostiakov. The soil infiltration capacity was assessed with regard to physical properties determined by an analysis of intact soil samples using Kopecky cylinders. The results indicate a reduced infiltration capacity due to soil compaction and also significant differences between the two sites, primarily caused by differences in soil type and, hence, different physical characteristics.

Key words: soil, infiltration rate, hydro-physical properties of soil, soil compaction

INTRODUCTION

Soil has a leading position in a landscape's hydrological cycle; the volume of water retained in the soil has great significance, as well as the volume flowing through the soil profile. An unbalanced water cycle in nature, particularly rapid runoff of water from the soil surface, results in alternating floods and droughts, which relates also to soil degradation. Increasing the ability of soil to accumulate and retain water in the landscape is a Europe-wide solution to the issue of water retention capacity of soil and landscape and their ecological functions. The aim of the ongoing research, which is part of a stage of the research programme *Biological and technological aspects of sustainability of controlled* *ecosystems and their adaptation to climate change* at the Faculty of Agronomy is to map the course of infiltration at selected locations in the Žabčice area and identify accumulation and retention of water in landscape.

MATERIALS AND METHODS

Characteristics of the territory

The studied area includes the following two sites: Niva and Kovál, Czech Republic (Fig. 1). Both sites are located on land held by an agricultural plant of the Žabčice School. Mendel University in Brno is the owner of the land. The Niva site is located on the Niva IV B allotment, which has a total area of 12.04 hectares and falls into the Nosislav cadastral territory. The Kovál site is located on the Nivky allotment, total area is 36.39 hectares, and it is part of the Žabčice cadastral territory. Both cadastral territories belong to the South Moravian Region (the Brno country district). The aerial photograph in Fig. 2 shows the two locations marked in red. The plots are a part of the Agricultural Land Resources. In both cases, we are dealing with arable land where winter wheat (*Triticum aestivum*) was grown in the reference year. A shallow soil preparation via disc tillers took place on the plot and organic (farm slurry) as well as chemical fertilizers (ammonium saltpeter with calcite and ammonium nitrate with urea) were used over the course of the year 2009.

Figure 1. Map of the Czech Republic showing the territory of interest (YMCA Brno)

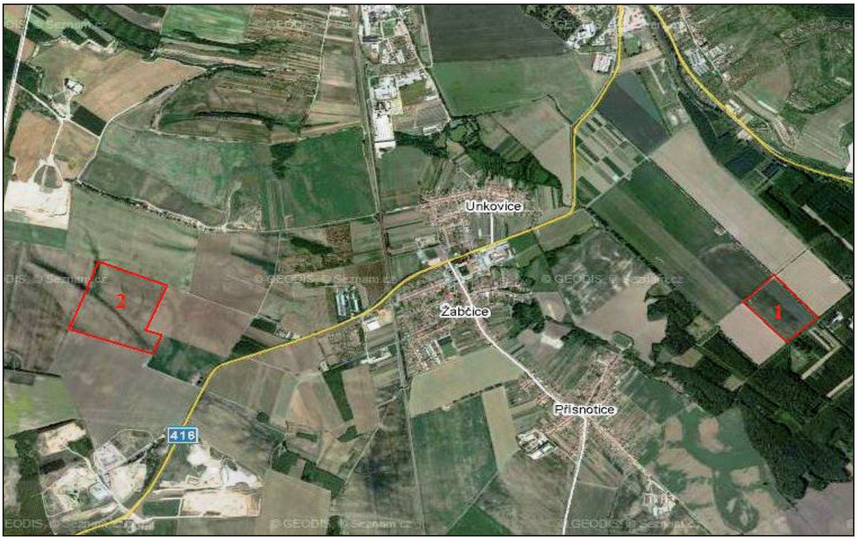

Figure 2. Aerial photo with sites of interest highlighted: 1 – Niva, 2 – Kovál (Geodis)

According to the bio-geographic classification of the Czech Republic (Culek, 1996), the two sites of interest are located on the edge of the Lechovice bio-region of Northpannonian subprovince in the vicinity of the border with Dyje-Morava bio-region. The geological bedrock consists of unconsolidated marine Neogene sediments – clays, sands, gravels, in some areas tightly bound and calcareous in varying degrees. However, these sediments are for the most part buried beneath a Pleistocene terraced gravel-sand. Both types of the rock are largely covered by thin layers of loess. According to the classification of climatic zones taken from the Climate Atlas of Czechoslovakia 1958 (Tolasz et al., 2007), the location falls within the A2 warm area, the dry sub-area, which indicates a warm, dry district with mild winters and less sunlight. Rožnovský and Svoboda (1995) deal with a detailed description of the Žabčice area from agro-climatic perspective, based on climatic data of the 1961–1990 period. Average annual precipitation reaches 480 mm. Most of the area's precipitation falls in June (total average rainfall of 69 mm), March shows the lowest average of 23.9 mm. In the vegetation season, total rainfall ranges from 219 mm to 420 mm, with an average of 312 mm. The dry season starts in mid-July and ends at the beginning of October. In some years, drought is typical for spring, in particular April and May.

According to the real estate cadastre, the valued soil-ecological unit (BPEJ) code is 0.59.00 for the Niva site and 0.04.01 for the Kovál site. In compliance with the Ministry of Agriculture Decree No 327/1998 Coll., as amended by Decree No 546/2002 Coll., these codes represent the following soil properties:

Niva: 0.59.00

- climate region: very warm, dry
- main soil unit: Gleyic Fluvisol on alluvial deposits, heavy and very heavy, no skeleton, moisture conditions are unfavourable, requiring water regime regulation
- gradient: full plane / plane
- exposition: omnidirectional
- skeleton: soil free of skeleton, includes ingredient
- depth: deep soil

Kovál: 0.04.01

- climate region: very warm, dry
- main soil unit: Arenic Chernozem on sands or shallow loess (up to maximum overlay of 30 cm) stored on sands and gravel sands, light grain, free of skeleton, highly permeable soils exposed to drying
- gradient: full plane / plane
- exposition: omnidirectional
- skeleton: soil free of skeleton, includes ingredient, contains low amount of skeleton
- depth: deep / medium deep soil

According to the Soil Atlas of the Czech Republic [Kozák et al., 2009], Gleyic Fluvisol soil type is located on the Niva site and Arenic Chernozem soil type on the Kovál site. In both cases, the deep unconsolidated (poorly consolidated) sediments represent the soil-forming substrate. It is the carbon-free alluvial deposit on the Niva site and loess on the Kovál site.

The two sites of interest differ in soil classes. According to the Novák's grain size classification (Jandák et al., 2009), which reflects the weight ration of clay particles (< 0.01 mm), the soil on Niva site ranks among heavy-textured clay-loam soil classes; the Kovál site represents medium heavy-textured sandy loam.

METHODS

The concentric cylinders method by Vališ and Šálek (1976) was used to assess the infiltration capacity of soil on the studied area. Absorption capacity was observed on the soil surface in the reference stand. The outer cylinder provides vertical and lateral infiltration, the inner cylinder vertical filtering in the core of observation (Fig. 3). Survey results from inner cylinder were used for the evaluation itself. The diameters of the outer and inner cylinders were 55 cm and 30 cm respectively. Three measurements were performed each time to comply with measurement requirements.

Kostiakov equations were used to evaluate the double-ring infiltration. The field measurements defined the time dependence of infiltration rate, $v(t)$, as well as time dependence of cumulative infiltration, $i(t)$. Representation of this dependence via Kostiakov empirical equations is dealt with in detail by Vališ, Šálek (1976), Velebný and Novák (1989).

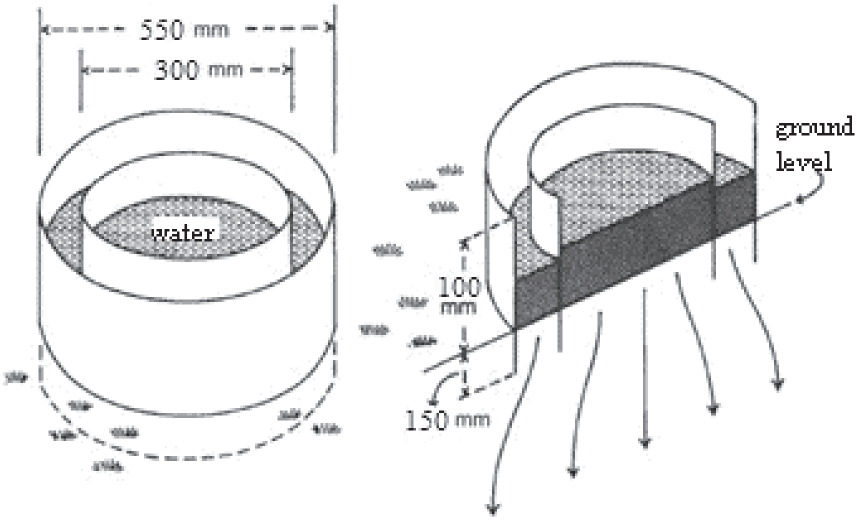

Figure 3. Double-ring infiltrometer [Sedláčková, 2007]

As part of each measurement, soil samples were collected at a site based on the usage of Kopecky physical rolls. Samples were taken from the depth of 10, 20 and 30 cm, followed by laboratory processing and evaluation of selected hydro-physical properties of soil. The determined properties included bulk density, actual soil moisture, absorbability, water retention capacity, porosity, capillary, semi-capillary and non-capillary pores and soil aeration [Vičanová et al., 2010].

The procedure for taking intact soil samples using Kopecky rollers to determine physical properties of soil is described in detail in the methodological guide of Pokorný et al., 2007. Samples for determining the physical properties of soil were collected in three reruns from each depth. Selected hydro-physical parameters were determined in compliance with Jandák et al. (2009). The data on 2010 daily rainfall recorded by rain gauge stations in Žabčice was provided by the Department of Agrosystems and Bioclimatology, Mendel University in Brno.

RESULTS AND DISCUSSION

Results of soil analyses

In the reference year 2010, four field trips to the sites of interest took place during the June – October period. Delaying the date of the first trip until June (against the initial plan to carry out measurements over the course of the entire vegetation period) was caused by extremely bad weather conditions – especially heavy rain in April and May. A collection of intact soil samples was carried out during each trip. 36 soil samples were collected in total (each time from the depth of 10, 20 and 30 cm). The results are presented in the form of a table; to assess soil moisture conditions, the value of actual moisture was calculated in relation to the local precipitation totals and the set soil-moisture constants.

To assess the physical condition of soil at the time of measurement, a collation was carried out comparing the acquired values of reduced bulk and porosity with the critical values describing a damaging soil compaction by Lhotský et al. (1984). Also, the representation of individual categories of soil pores and soil aeration was taken into account. According to Jandák et al. (2009), the levels of soil aeration in arable land in good condition should range between 18 – 24 % of volume. For winter wheat (*Triticum aestivum*), which was grown on both sites during the reference period, the optimum value of soil aeration is 15 – 20 % of volume and the limit value is 10 – 15 % of volume (Kutílek, Kuráž, Císlerová, 2004).

The detected physical properties of soil have shown significant changes during the reference period revealing major differences between the two sites of interest. Mutual difference is mainly due to different soil class. The soil of the Niva site is a heavy-textured clay-loam, on the contrary, the Kovál site soil represents medium heavy sandy loam.

Table 1 shows the variability of actual soil moisture at both sites of interest over the entire reference period. Values that are highlighted show the situations when the actual moisture exceeded the water retention capacity of soil. Rainfall contributed to the increased values. The difference between the two sites is obvious. On the Niva site, the soil moisture has been always higher, irrespective of the precipitation. Heavy-textured soil with a higher proportion of capillary pores, which is located on the Niva site, has a greater capacity to hold water. On the contrary, medium-heavy soil at the Kovál site, with less capillary pores and a greater proportion of non-capillary pores, becomes dry more easily. In case of Niva, the increased values of moisture in lower layers of soil profile maybe caused also by higher groundwater levels.

Table 1. Comparison of actual moisture at the two sites of interest

Instantaneous soil moisture [vol. %]							
Locality		Niva			Kovál		
Depth		10 cm	20 cm	30 cm	10 cm	20 cm	30 cm
Measurement period	June	38.89	**39.24**	**41.12**	23.82	16.60	16.61
	July	19.35	31.45	**32.15**	16.65	10.94	14.15
	August	37.69	38.01	**39.91**	21.89	21.48	**21.67**
	October	31.65	**37.97**	**39.30**	21.68	23.71	11.98

Soil compaction is another important factor that influences the infiltration capacity. From the perspective of the properties researched, soil condition is reflected mostly by reduced bulk (Table 2) and porosity (Table 3). The tables show the difference between the two sites. The results exceeding the critical value defined by Lhotský as compaction that is harmful for the given soil type are highlighted. On the Niva site, there are significant differences between the upper layer of loosened mould and the deeper compact layers of soil profile. On the contrary, on the Kovál site, even the upper layers of soil profile tend to compaction. Higher average levels of bulk density and the corresponding lower values of porosity at the Kovál site are caused by differences in soil class.

Table 2. Comparison of reduced bulk density at the two sites of interest

Reduced bulk density [g.cm^{-3}]							
Locality		Niva			Kovál		
Depth		10 cm	20 cm	30 cm	10 cm	20 cm	30 cm
Measurement period	June	1.27	**1.40**	**1.42**	**1.57**	1.52	1.51
	July	1.37	**1.56**	**1.58**	**1.57**	**1.63**	**1.74**
	August	**1.51**	**1.83**	**1.53**	**1.58**	**1.71**	**1.84**
	October	1.28	**1.55**	**1.53**	**1.66**	**1.68**	1.49

Table 3. Comparison of porosity at the two sites of interest

Porosity [vol. %]							
Locality		Niva			Kovál		
Depth		10 cm	20 cm	30 cm	10 cm	20 cm	30 cm
Measurement period	June	51.96	**46.91**	**46.68**	**41.09**	43.08	44.04
	July	48.69	**42.01**	**41.07**	**40.20**	**38.13**	**34.68**
	August	**43.11**	**31.11**	**42.41**	**39.61**	**34.57**	**29.68**
	October	51.68	**41.69**	**42.53**	**36.34**	**35.33**	42.60

Non-capillary pores play an important role during infiltration. Thanks to these pores, water drains into deeper levels of soil profile. The soil on both sites of interest differs in these physical characteristics too, as shown by Table 4. The values when the share of non-capillary pores is less than 10 % of total porosity are highlighted. Ideally, the non-capillary pores should contribute 1/6, that is roughly 17% (Jandák et al., 2009) to total porosity. At the Niva site, the representation of non-capillary pores is extremely low in some cases; on the contrary, at the Kovál site, it is around the optimum value in most cases. Great differences between sites are caused mainly by different classes of soil.

Table 4. Comparison of representation of non-capillary pores at both sites of interest

Content of non-capillary pores (% volume) /share of non-capillary pores on total porosity (%)							
Locality		Niva			Kovál		
Depth		10 cm	20 cm	30 cm	10 cm	20 cm	30 cm
Measurement period	June	7.05/13.6	**3.66/7.8**	**2.77/5.9**	6.86/16.7	6.68/15.5	10.80/24.5
	July	**3.61/7.4**	5.20/12.4	6.33/15.4	8.26/20.5	4.77/12.5	5.55/16.0
	August	**0/0**	**0/0**	**0/0**	9.16/23.1	5.96/17.2	3.83/12.9
	October	9.46/18.3	**0.73/1.7**	**1.01/2.4**	6.11/16.8	5.51/15.6	17.47/41.0

Evaluation of soil infiltration capacity

Evaluation of soil infiltration capacity at both sites of interest has been carried out on the basis of data acquired during the on-site infiltration tests and processed in compliance with Kostiakov's method. 24 tests were carried out in total, each time three tests took place at each site. Results are presented in the form of a graph of time dependence of infiltration rate and cumulative infiltration, always showing the three tests carried out during one measurement. Infiltration characteristics were assessed with regard to soil physical properties, changing properties during the reference period.

The observed infiltration capacity of soil is different at the two sites. It differs both in terms of absolute values of infiltration characteristics (infiltration rate and cumulative infiltration) and their fluctuations during the reference period at individual sites.

During the June measurement, the detected infiltration capacity at both sites was very low; in case of Niva, the lowest results were recorded taking into account the entire reference period. In this measurement, a fully involved winter wheat crop was located on the two plots; the soil was in relatively good physical condition (compared to other measurements). The low level of infiltration in case of Niva is caused primarily by the increased soil moisture occurring due to rainfall. Fig. 4 shows the comparison of infiltration characteristics at both sites during the June measurement.

In contrast, the July measurement showed the highest infiltration capacity at both sites for the entire reference period. The values detected at the Niva site are significantly higher than those at the Kovál site; also, the results are several times higher than the other measurements at the Niva site. For the Kovál site, this difference is not significant. The following graph (Fig. 5) shows the differences in the observed infiltration characteristics.

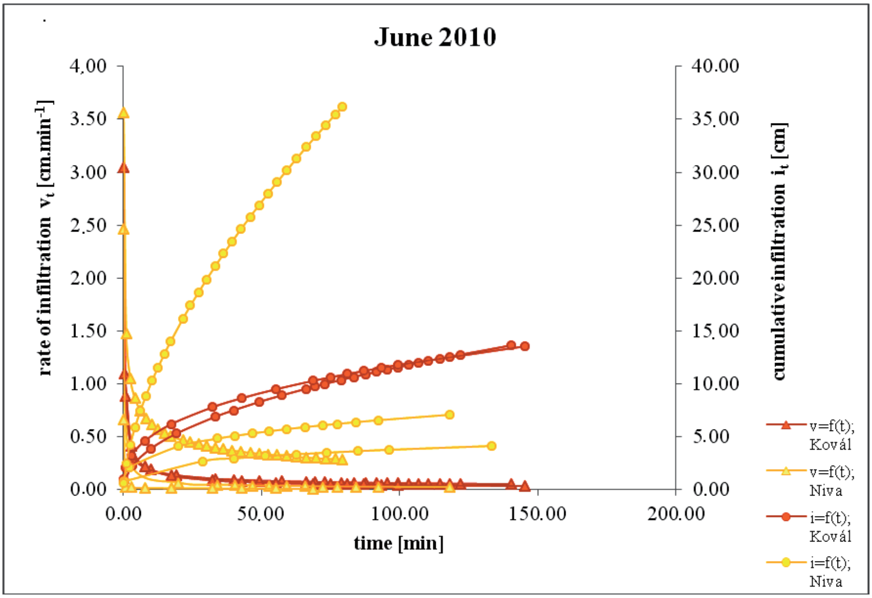

Figure 4. Time dependence of infiltration rate and cumulative infiltration, comparison of the Niva and Kovál sites, June 2010

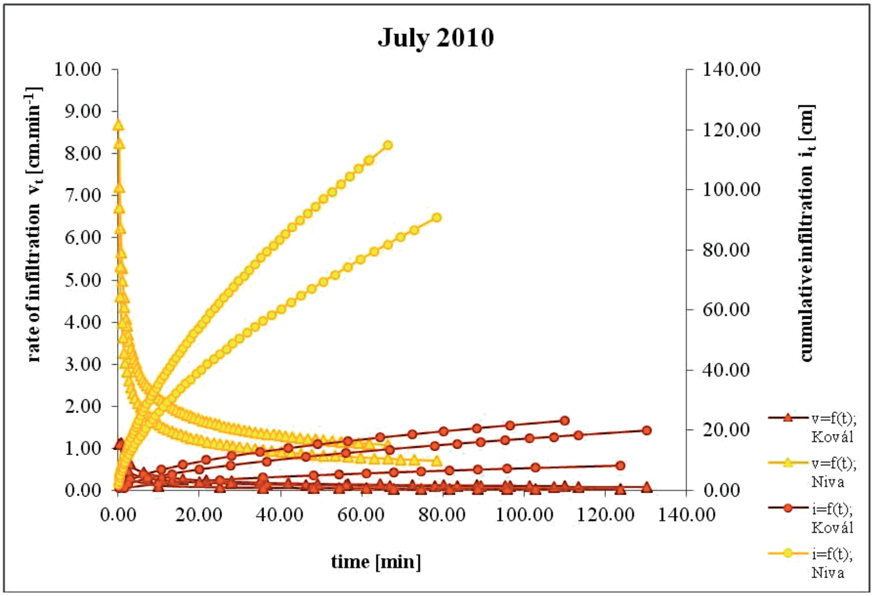

Figure 5. Time dependence of infiltration rate and cumulative infiltration, comparison of the Niva and Kovál sites, July 2010

The measurement carried out in August probably reflected the very poor physical condition of the soil observed at both sites. The soil infiltration capacity is very low due to compaction and the values observed at both sites show only minor difference, which is well illustrated in Fig. 6. The results for the Kovál site are approximately accordant with the July measurement; the obtained values are slightly higher in case of Niva.

The measurement carried out in October showed medium values for soil infiltration capacity at the Niva site. The obtained data was much higher than in case of the Kovál site, as illustrated in Fig. 7. This measurement revealed (especially in case of Niva) the influence of the increased initial moisture content, a typical feature for the end of the growing season. As for the Kovál site, the great variance between the results of individual infiltration tests makes it impossible to compare the data with other measurements carried out throughout the reference period.

The two following graphs, Figs. 8 and 9, show the results of infiltration tests carried out throughout the entire reference period. The test trials showing major deviations within the given measurement, (probably due to the occurrence of non-homogeneities in the soil profile) were not included in the graphs in order to keep clarity. The graphs confirm that the infiltration capacity of the soil at the Niva site shows greater variability over the reference period and reaches higher total levels than in case of Kovál. The infiltration at the Kovál site capacity results did not show significant fluctuations.

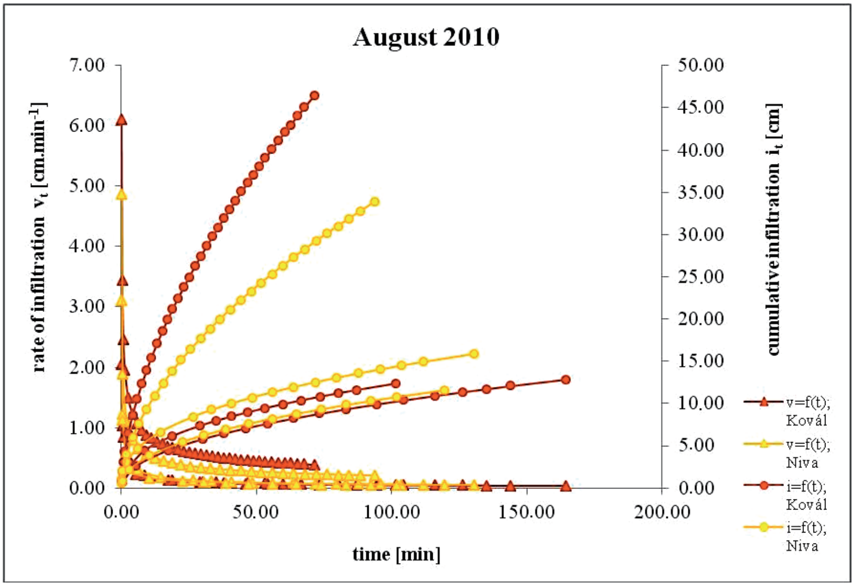

Figure 6. Time dependence of infiltration rate and cumulative infiltration, comparison of the Niva and Kovál sites, August 2010

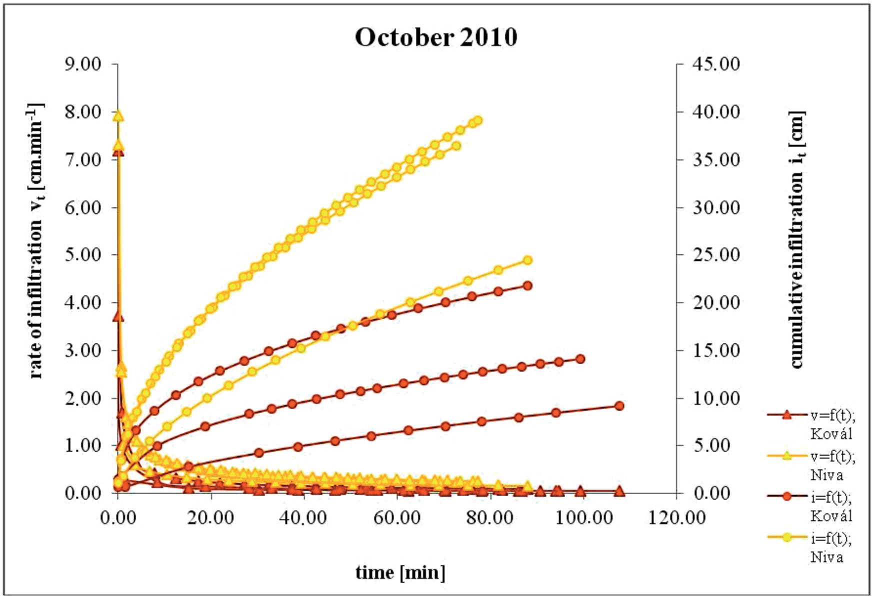

Figure 7. Time dependence of infiltration rate and cumulative infiltration, comparison of the Niva and Kovál sites, October 2010

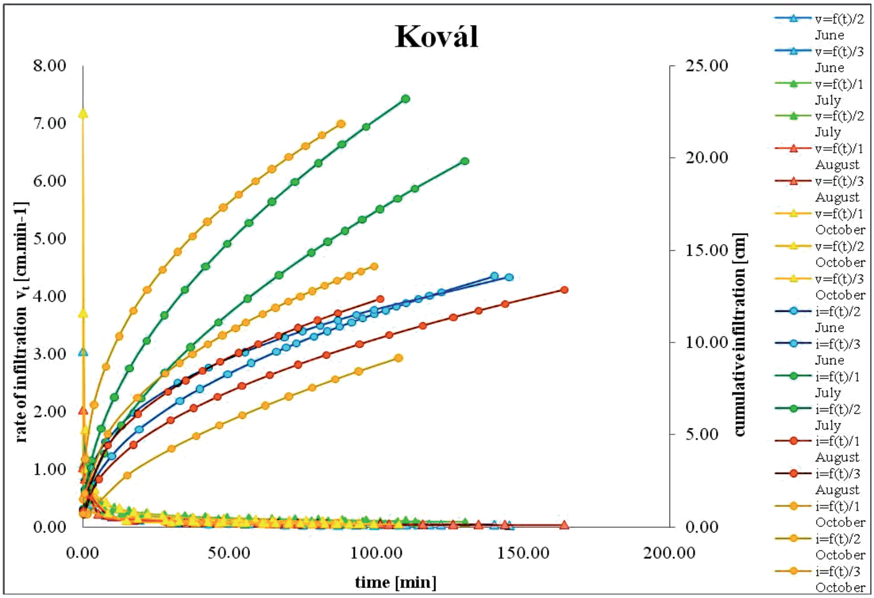

Figure 8. Time dependence of infiltration rate and cumulative infiltration, locality Niva, June – October 2010.

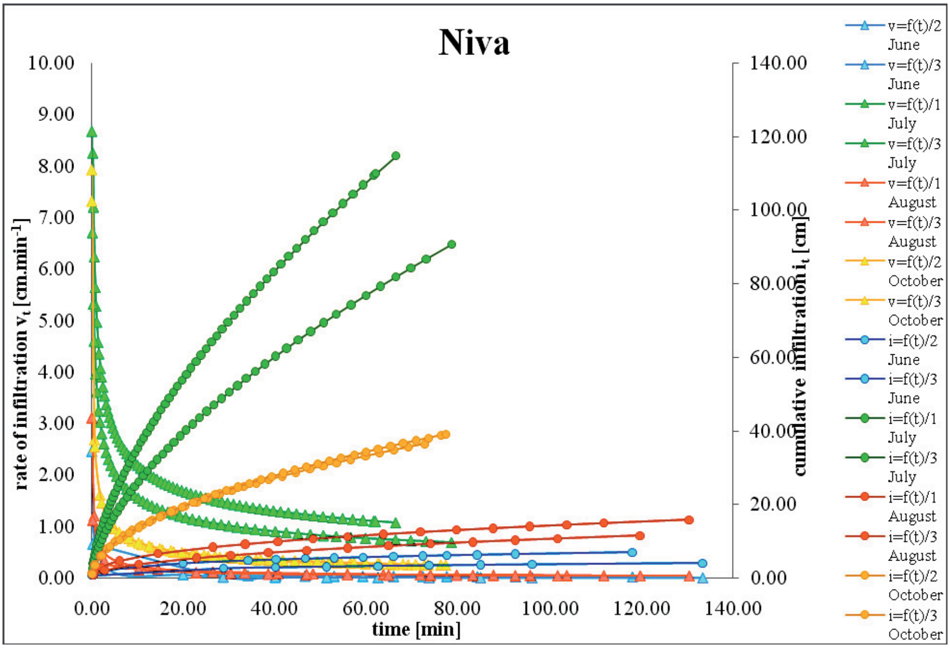

Figure 9. Time dependence of infiltration rate and cumulative infiltration, locality Kovál, June – October 2010

CONCLUSION

The initial assumption about the variability of soil infiltration capacity, depending on the time of measurement was that soil infiltration capacity is lower in spring and autumn and higher in summer (until harvest of the grown crop-plant). This assumption was based, inter alia, on the results of field measurements carried out at the Niva site (neighboring site IV A with the same soil class and a similar valued soil-ecological unit BPEJ) in the April–November period in 2008, which showed lower infiltration capacity of soil at the beginning and at the end of the reference period due to higher initial moisture content of the soil. This is caused in particular by reduced evapotranspiration, the influence of lower air temperatures and the absence of vegetation cover at the beginning and at the end of the growing season.

The field measurements carried out throughout the June – October period confirmed this assumption only partially. At the end of the period, which is the end of growing season, the infiltration capacity of soils was really low, in particular at the Niva site. At the Kovál site, the results of measurements showed only minor fluctuation over the entire monitored period; reduction in infiltration capacity of soils at the end of the growing season is not noticeable. In contrast, extreme fluctuations were detected at the Niva site. The physical condition of the soil, especially the damaging compaction of soil detected at both sites of interest on the basis of collection of intact soil samples, influences the results in a much greater extent than the term of measurement. Moreover, some results were also affected by rainfall occurring in the area shortly before the field measurements. Again, the influence of rainfall on the increased initial moisture was significantly manifested at the Niva site.

Another assumption was based on the comparison of the two sites of interest in terms of soil class. According to Gardner (1999), soil infiltration capacity would decline with the increasing proportion of clay particles. In case of a medium-heavy soil type with a higher representation of non-capillary pores (Kovál site), the total infiltration capacity should be higher than in case of heavy-textured soil (Niva site). The measurement results did not affirm this assumption. At the Niva site, the average soil infiltration rate was significantly higher during the monitored period than at the Kovál site. This may be caused by a higher degree of compaction of the upper plough layer at the Kovál site.

Soil compaction is a problem that manifests itself not only by reduced infiltration capacity of soils, but also causes many other phenomena having a negative influence on the overall soil quality and fertility.

Acknowledgements

The study was carried out with the support of Research Project No MSM6215648905 *Biological and technological aspects of sustainability of controlled ecosystems and their adaptation to climate change* issued by the Ministry of Education of the CR

REFERENCES

Culek M. et al. Biogeografické členění České republiky. Enigma, Praha 1996, 347 pp. ISBN 80-85368-80-3.

Jandák J. et al. Cvičení z půdoznalství. MUAF in Brno, Brno 2009, 92 pp. ISBN 80-7157-733-2.

Kozák J. et al. Atlas půd České republiky. CULS, Prague 2009, 150 pp. ISBN 978-80-213-2008-6.

Kutílek M., Kuráž V., Císlerová M. Hydropedologie 10. CTU, Prague 2004, 176 pp. ISBN 80-01-02237-4.

Lhotský J. et al. Soustava opatření k zúrodňování zhutněných půd. Methodics ÚVTIZ 14/1984, Prague 1984, 39 pp.

Pokorný E., Šarapatka B., Hejátková, K. Hodnocení kvality půdy v ekologicky hospodařícím podniku. Mehodics, ZERA, Náměšť nad Oslavou 2007, 28 pp. ISBN 80-903548-5-8.

Rožnovský J., Svoboda T. Agroklimatická charakteristika oblasti Žabčic. Folia, file A. MUAF, Brno 1995, 49 pp.

Tolasz R. et al. Atlas podnebí Česka. Praha: Czech hydrometeorological institute, Palacký University, Olomouc 2007, 255 pp. ISBN 978-80-86690-26-1 (CHMI), 978-80-244-1626-7 (UP).

Vališ S., Šálek J. Hydropedologické praktikum. ´BUT, Brno 1976, 183 pp.
Velebný V., Novák V. Hydropedológia. SVŠT, Bratislava 1989, 130 pp.
Vičanová M., Toman F., Stejskal B., Mašíček T., Knotek J., Kotovicová J. Rychlost vsaku vody do půdy na vybrané lokalitě v Žabčicích v průběhu vegetační sezony 2008. *Acta universitatis agriculturae et silviculturae Mendelianae Brunensis.* Brno 2010, sv. LVIII, č. 5, pp. 399-406. ISSN 1211-8516.
Decree No 327/1998 Coll. defining the characteristics of valued soil ecological units and the procedure for their keeping and updating, as amended by Decree No 546/2002 Coll.

Internet resources:
Gardner et al. Kategorizace infiltrační schopnosti a propustnosti půd při nenasycení vodou. 1999 [online] *http://www.env.cz* [March 18, 2011]
Geodis [online] http:/*/www.mapy.cz* [May 15, 2011]
Real estate cadastre [online] http://nahlizenidokn.cuczk.cz [May 15, 2011]
Sedláčková R. Change in physical properties and infiltration capacity of soil depending on the used processing system [online]
http://www.fce.vutbr.cz/veda/JUNIORSTAV2007/Sekce_3/Sedlackova_Radovana_CL.pdf [May 1, 2011]
YMCA Brno [online] *http://www.ymcabrno.cekit.cz/index.php?kat=ic&main=info/cestovani/cr* [June 25, 2011]

Ing. Martina Vičanová
martina.vicanova@mendelu.cz
Ing. Tomáš Mašíček, Ph.D.
tomas.masicek@mendelu.cz
Prof. Ing. František Toman, CSc
frantisek.toman@mendelu.cz
Ing. Petra Oppeltová, Ph.D
petra.oppeltova@mendelu.cz
Mendel University in Brno
Zemědělská 1
613 00 Brno
Czech Republic