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The Effect of Land Management on the Retention Capacity of Agricultural Land in the Conditions of Climate Change – Case Study

Jana Podhrázská [1,2*], Josef Kučera[1,2], Petr Karásek[1,2], Jan Szturc[2], Jana Konečná[1]

[1] Research Institute for Soil and Water Conservation, v.v.i., Department of Land Consolidations and Landscape Use, Lidická 25/27, 602 00 Brno, Czech Republic

[2] Faculty of Agronomy, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic

[*] Corresponding author's e-mail: podhrazska.jana@vumop.cz

ABSTRACT

The water retention capacity of a territory is mainly defined by the land conditions, type of soil cover and manner of land management. The manifestations of the climate change reflect the need for better water capture from precipitation in agricultural catchment areas. The effect of the soil cover on the water retention capacity was studied in two localities with different soil types (chernozem and cambisol). The results have shown significant effects of permanent grass covers on increasing the water retention capacity. The mean retention capacity measured at permanent grass covers was 1.7-fold higher than at arable land. The soil type did not play a significant role. To some extent, the retention capacity is also influenced by the used agro-technology. After stubble-tillage, the water from precipitation was better infiltrated by arable land than by permanent grass cover. However, during a major part of the vegetation period, arable land is at the rest, and the short-term increase of its retention capacity has no impact on the overall outcome.

Keywords: climate change, Infiltration capacity, rainfall simulator

INTRODUCTION

The climate and its changes both in central Europe and worldwide are gradually becoming a topic of interest to the general public. The shares of the civilization factors involved and the natural climatic variability have not been fully resolved. The available data suggest that in previous centuries, the Bohemian countries also experienced periods of extreme droughts (Brázdil et al. 2015, Beranová et al. 2018). These dry episodes resulted in poorer quality of life of the inhabitants, extensive losses of crops leading to a significant increase of prices of food, and necessity to adopt the emergency measures to eliminate the impacts of the extreme droughts. The analyses of trends in the development of temperature and humidity characteristics from the past years document a gradual elevation of the temperature at our territory, fluctuations in precipitation sums, and deepening the soil moisture deficit (Rožnovský, 2019). The prospective climatic scenarios presenting the potential consequences of the climate change for the years 2050 and 2100 in the Czech Republic show the possible impacts of these continuing trends in the climate development (Trnka et al. 2018).

The prospects of climate change in the central European region for the 21st century, which signal a risk of long-lasting and more intensive episodes of drought, namely in the period of April-September, show the expectations of essential adverse impacts on the spheres of agriculture, forestry, as well as water management (Naveen et al. 2007, Trnka et al. 2016).

The extent of agricultural drought consequences is growing not only due to the unfavourable development of climate conditions, but also in association with the degradation of agricultural land and loss of its surface area. Agricultural land comprises about 53.5% of the Czech Republic (CR) territory, 38% of which consists of arable land (20% of the CR territory). An additional 34% of the CR territory is represented by woodlands (Janků, 2016). Absorption of precipitation water by soil and its subsequent retention in the soil environment is one of important extra-production functions of agricultural land, particularly with regard to reducing the consequences of drought and flash floods (Humann,M et al. 2011, Geroy et al. 2011)

The landscape character and use also play some role in the climate variability. During the 20th century, the Czech landscape underwent dramatic changes associated with the manner of management of agricultural and forest land and with dynamic development (Sklenička et al. 2004, 2014). The increasing temperatures and growing frequency of dry periods are greatly enhanced by agricultural management on large blocks of arable land sown with monocultures (Kiryluk, 2016). In addition, the soil is threatened by a number of degradation processes. The most important risk is erosion by water, which threatens about 60% of land (approximately 12% of which is already degraded), 14% is at risk of erosion by wind; other degradation processes include compaction, lack of organic matter, and soil acidification (SOWACGIS).

The change of this alarming state is possible only by modifying the manner of land management, which is particularly relevant regarding agricultural subjects. Agriculture, as a tool for maintenance of the quality and quantity of water and land condition, can employ additional anti-erosion measures, i.e. introduction of novel land-protecting technologies and support of application of complex land adaptations (Vitikainen, 2014). Adaptations of the structure of land blocks should contribute to increasing the water retention capacity of the landscape and decrease the risk of erosion, or optionally allow the construction of water management facilities. During zone planning, emphasis is placed among other factors on increasing the coefficient of ecologic stability, in association with the adaptation to the climate change.

This study was aimed at finding the differences in the water retention capacity of various land types – permanent grass cover and arable land – in the experimental areas: Hustopeče/Starovice and Němčice, located in the South Moravian region, territory at the highest risk of climate change impacts, i.e. increasing temperatures and agricultural drought.

METHODOLOGY AND DATA

Model locality Micmanice

In order to simulate natural rain and measure the speed and amount of infiltrated water, including surface runoff, we used an adapted portable rainfall simulator – infiltrometer of the US Geology Service (Mc QUEEN, 1963, Janeček 1989). In our project, the device for capturing the surface suspension has been rearranged. In the original simulator, the surface suspension was aspirated, while after adaptation, the suspension freely flowed to the collecting vessel (Fig. 1).

This type of rainfall simulator met the requirements of usability under the field conditions, i.e., low demands on material technical support (the locality has no access to water and energy supplies) as well as relatively easy installation, operation and transport.

This apparatus consists of: a spray head (dripper), a holding tank with a regulator, a stand with anti-wind protection, and an overflow device for collecting surface runoff. Distilled water is used to simulate the rainfall. The volume of water in the tank (ca 20 l) is sufficient to create a sum of rainfall of 120 mm. Drops fall to the collecting area from the height of 1.6 m inside an organic glass column. A metal ring in the form of a reversed truncated cone of 200 mm inner diameter is used to delineate the collecting area. At the soil surface level, this ring contains a hole (outlet) by which the suspension of eroded soil flows to a graduated cylinder. The simulator was used at two experimental localities, both on a permanent grass cover and on arable land. We investigated the following data: duration of precipitation, total sum of precipitation, total intensity of precipitation, total infiltration, total infiltration intensity, mean infiltration intensity, infiltration coefficient, total surface runoff, total intensity of surface runoff, mean intensity of surface runoff, and runoff coefficient.

Characteristics of study localities

The Hustopeče/Starovice area (Fig. 2) is part of a small agricultural catchment with a distinct talweg ended by a dry reservoir with an outlet to the Starovice Brook at the border of a built-in area. According to the overall climate

Fig. 1. Collecting device of the simulator and setup of the field rainfall simulator

character, Hustopeče with its surroundings belongs to the natural region of Hustopeče Highlands with favourable climatic conditions. The geomorphological unit makes a part of a warm region, warm and dry district with moderate winters and relatively short sunlight. The mean annual temperature is 9.2°C. The mean precipitation reaches 563 mm per year with a maximum in July and minimum in February.

Representation of soil types in the studied locality (experimental area):

- Modal chernozem (CEm)
- Washed-off modal chernozem (CEm)

The Němčice study area (Fig. 3) is located in the catchment of the Němčice Brook and climatically belongs to a moderately warm region, moderately humid district. The mean annual temperature fluctuates around 6°C; the mean annual sum of precipitation reaches 652 mm. The relief of the experimental catchment forms moderately broken, long gentle slopes of the Drahanské Highlands. The water divide at the highest point crosses the altitude of 656 m; the catchment closure is situated at the altitude of 556 m and the mean catchment altitude is 606 m.

RESULTS

Field surveys were always conducted in the spring and autumn seasons (before and after the crop growth). During the project, 24 simulated rainfall processes were conducted by a field rain simulator and the results of the experiments on permanent grassland and arable land were compared. An example of determining the quantities above is presented in table 1 and in Figs. 4 to 6.

On the basis of the measurement results of the ratio of simulated precipitation and runoff for all the investigated years, the infiltration and runoff coefficients were established. The infiltration coefficient (ratio of the infiltrated amount of precipitation to the precipitation volume) for all investigated localities and land types as an indicator of the soil infiltration capacity is presented in Figures 7 and 8. The overall evaluation of the infiltration capacity based on all measurements is presented in Figure 9.

The results of the experiments showed higher infiltration capacity of permanent grass covers compared to arable land by 34.5%, while the permanent grass cover infiltration capacity on cambisols exceeded that of arable land by 35.2% and that on chernozems by 33.8%. These findings correlate with those by Van Dijk et al. (1996),

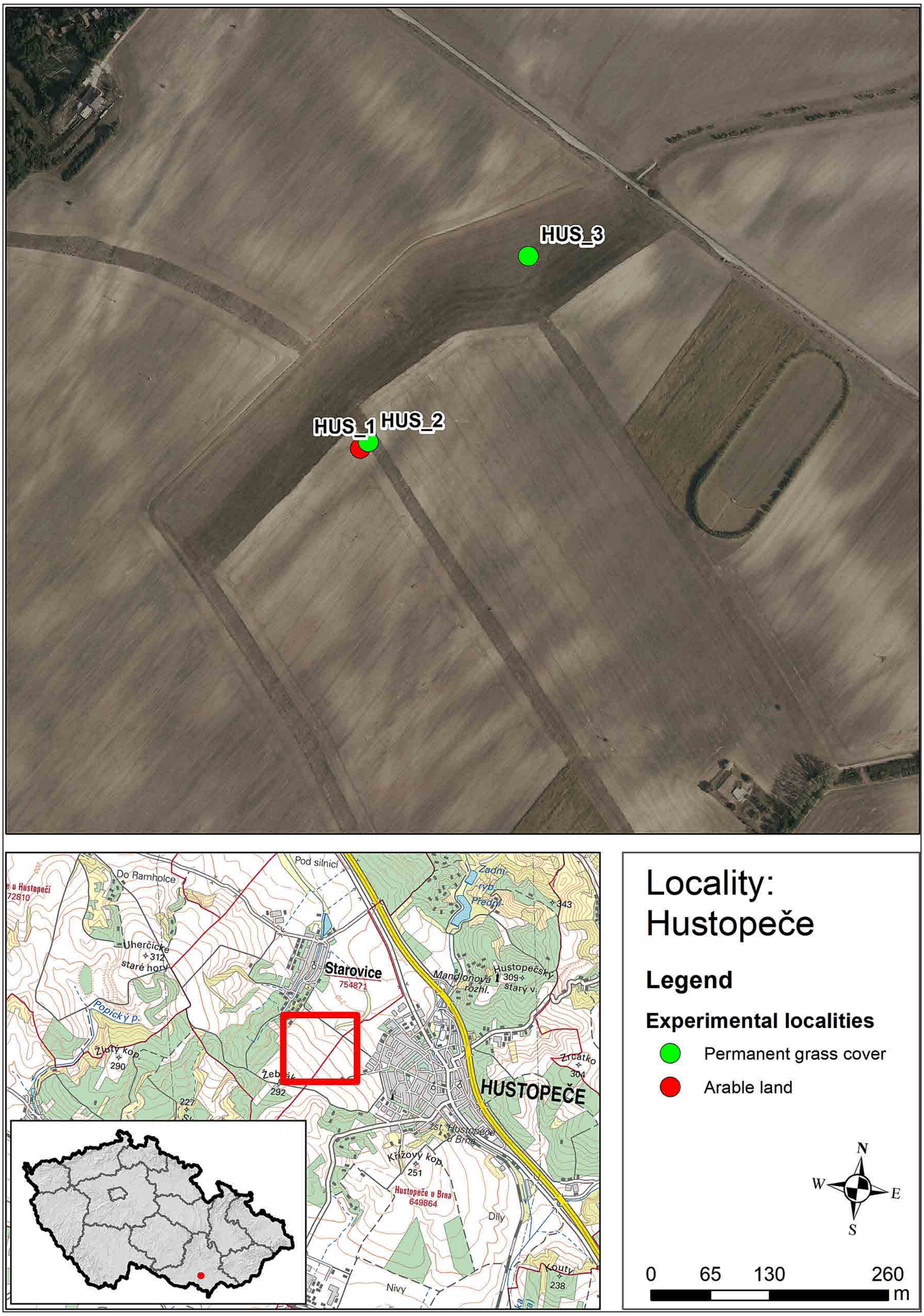

Fig. 2. Hustopeče/Starovice measuring points

who tested the infiltration capacity of grass strips with the width of 1.4–5.0 and 10 m. These strips were capable of infiltrating precipitation and retaining the erosion washout sediment to the extent of 50% to 90%. The infiltration coefficient of arable land on chernozems was 52% and on cambisols 57%. However, the infiltration rate is dependent on the soil condition (Otalvaro et al.

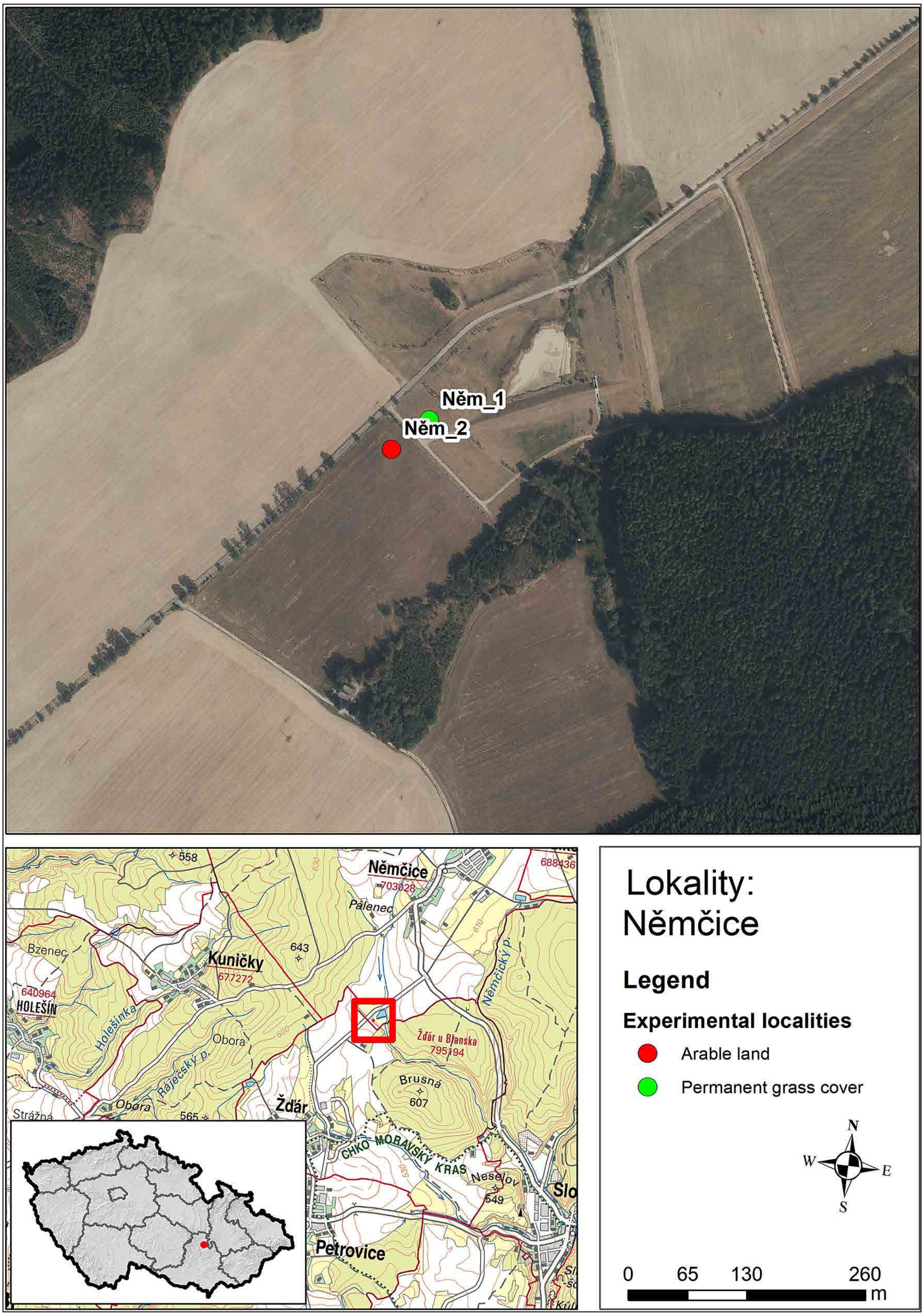

Fig. 3. Němčice measuring points

2016), amount of organic matter (Minasny et al. 2017, Hollis et al. 1977), manner of cultivating crops, and agro-technical operations (Kintl et al. 2018, Manojlovič et al. 2008). These findings are also documented by the results of the experiments performed in our model localities; e.g., in the Hustopeče/Starovice locality, on September 11th, 2019 the infiltration experiments were conducted

Table 1. Rated for rainfall simulation

Duration of sim. precipitation:	35.0	[min]	duration	Precipitation
Total sum of sim. precipitation:	79.1	[mm]	height	
Total sum of sim. precipitation:	2241.7	[ml]	volume	
Total precipitation intensity:	2.3	[mm/min]	intensity	
Mean precipitation intensity:	2.2	[mm/min]	intensity	
Total sum of infiltration:	691.7	[ml]	volume	Infiltration
Total infiltration intensity:	0.7	[mm/min]	intensity	
Mean infiltration intensity:	1.0	[mm/min]	intensity	
Infiltration coefficient:	30.9	[%]	ratio	
Total surface runoff:	1550.0	[ml]	volume	Runoff
Total intensity of surface runoff:	1.6	[mm/min]	intensity	
Mean intensity of surface runoff:	1.2	[mm/min]	intensity	
Runoff coefficient:	69.1	[%]	ratio	

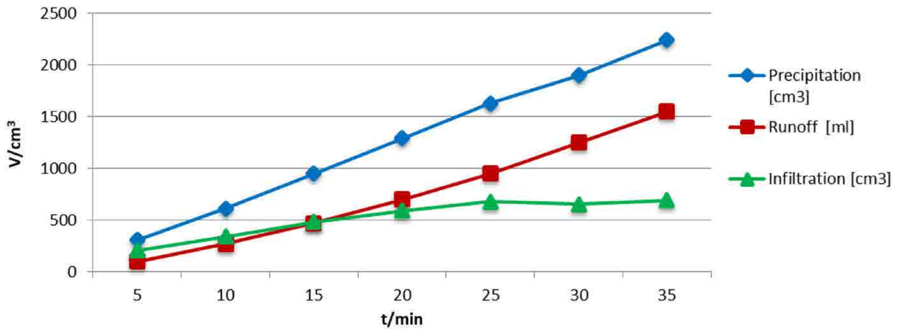

Fig. 4. Time course of precipitation, runoff and infiltration values

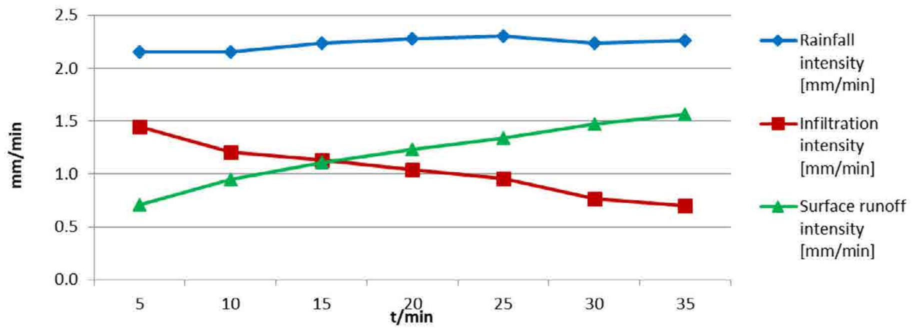

Fig. 5. Time course of the precipitation, runoff and infiltration intensity

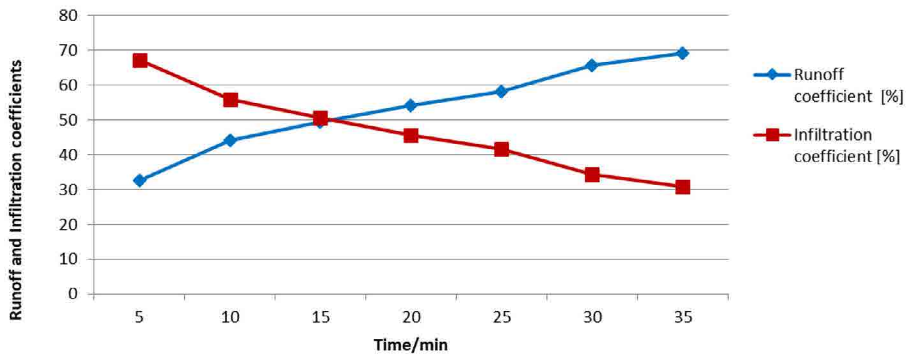

Fig. 6. Time course of the runoff and infiltration coefficients

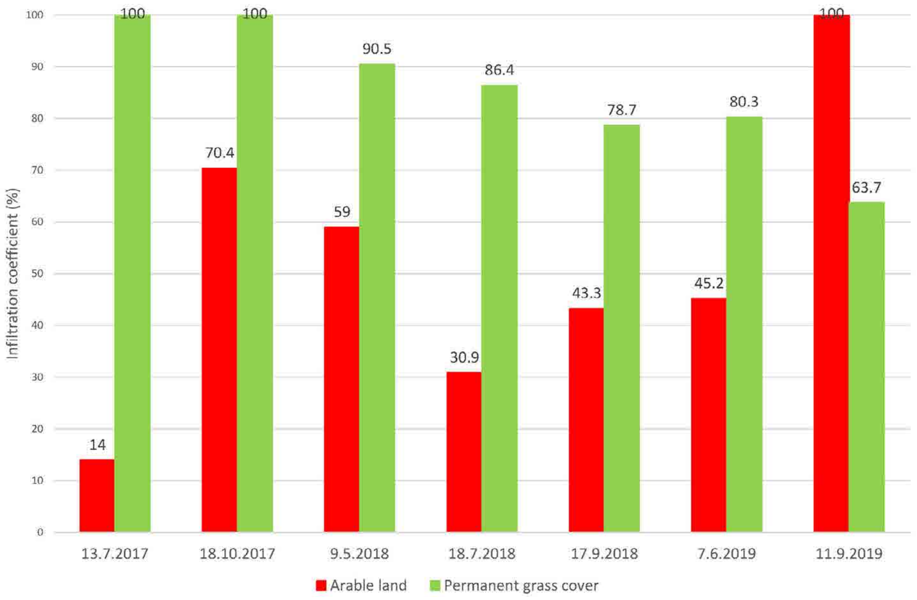

Fig. 7. Infiltration capacity of the soil in the Hustopeče/Starovice locality

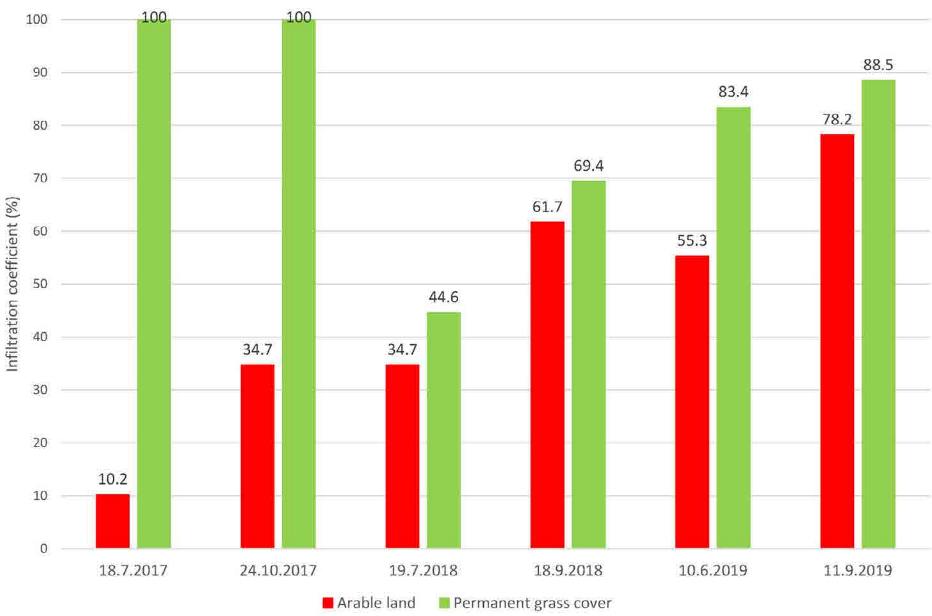

Fig. 8. Infiltration capacity of the soil in the Němčice locality

directly after loosening the soil by stubble-tillage and the infiltration coefficient was higher than that of the permanent grass cover. The differences in the infiltration capacity of arable land at both localities are also influenced by the cultivated crops – the locality of Hustopeče/Starovice is mainly occupied by broadcast crops (Zea mays), the manner of cultivation and treatment of which has negative impacts on the surface runoff. The Němčice locality is sown exclusively by narrow-row crops (cereals, fodder crops), which provide good coverage and contribute to higher water retention capacity of the land.

CONCLUSIONS

Our experiments have shown the effects of permanent grass cover on increasing the water retention capacity of soil. The average infiltration coefficient (ratio of the infiltrated amount of precipitation to the precipitation volume) was 1.7-fold higher than at permanent grass cover (further referred to PGC) than at arable land. When comparing the median infiltration coefficients (PGC = 48.51%, arable land = 86.03%), the infiltration coefficient at PGC is again higher, by 37.51%. The minimum infiltration values also

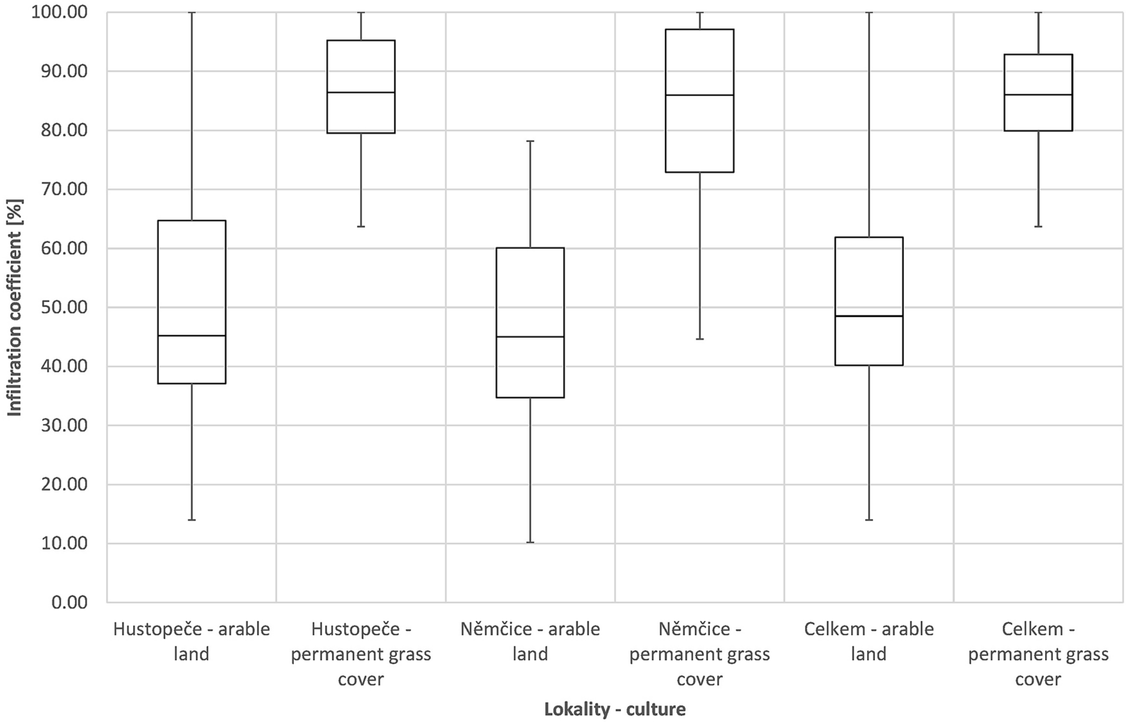

Fig. 9. Maximum, minimum and median values of the measurements performed in arable land and grassland at the Hustopeče/Starovice and Němčice localities

confirm the higher values of the infiltration coefficient at PGC (PGC = 63.70%, arable land = 14%).

These data should be taken into account when designing the measures of agricultural management aimed at enhancing the water retention capacity of soil. A significant role may be played by grassed soaking strips, grassed talwegs, and grassing of sloped positions.

A land block of 100 ha surface was used as arable land until 2015. Gradually, a grassed talweg of 5.4 ha surface area and grassed soaking strips of total surface area of 2.2 ha have been implemented, as introduced in Fig.9. In total, a surface area of 7.6 ha has been grassed. The infiltration coefficient at arable land is 51.8%, i.e., 48.2% of the precipitation volume runs off from the land block. The infiltration coefficient at PGC is 85.7%, i.e., only 14.3% of the precipitation volume is not captured by the cover. It means that before grassing, almost half of the precipitation ran off from the surface area of 100 ha. After grassing, the loss of arable land represented 7.6% and the potential retention of the entire area increased by 2.6%. The application of grassing also plays a non-negligible role as a guideline for the manner of land management and as a transformation space and barrier to the surface runoff.

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