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THE IMPACT OF DIFFERENT CROP MANAGEMENT ON THE SOIL WATER STORAGE AND EVAPOTRANSPIRATION: SIMULATION IN GLOBAL MODEL

Branislav Kandra, Milan Gomboš

The influence of selected crop species on the water content of the soil was assessed by analyzing the daily values of soil water storage, actual evapotranspiration and its partial processes, the actual transpiration and evaporation in the production and non-production part of the vegetation season 2006. The results of numerical simulations show that the average water consumption in the surveyed crops varied ranging from 7.9 to 22.1 % of available water capacity (188.85 mm). Actual transpiration totals were associated with the amount of yields of individual crops. The proportion of transpiration on the total evapotranspiration depended on the length of the production section of the growing season and agricultural cultivation of crops surveyed.

KEY WORDS: soil water storage, evapotranspiration, Eastern Slovak Lowland, numerical simulation, crop management

VPLYV RÔZNYCH PLODÍN NA ZÁSOBY VODY V PÔDE A EVAPOTRANSPIRÁCIU: SIMULÁCIA V MODELI GLOBAL. Vplyv vybraných druhov plodín na obsah vody v pôde bol hodnotený cez analýzy denných priebehov zásoby vody, aktuálnej evapotranspirácie a jej čiastkových procesov, aktuálnej transpirácie a evaporácie v produkčnom a mimoprodukčnom úseku vegetačného obdobia 2006. Zo získaných výsledkov numerickej simulácie vyplýva, že priemerná spotreba vody pri skúmaných plodinách kolíše oproti variantu bez plodiny v rozpätí 7,9 – 22,1 % využiteľnej vodnej kapacity (188,85 mm). Úhrny aktuálnej transpirácie sú spojené s výškou dosahovaných úrod jednotlivých plodín. Podiel transpirácie na celkovom výpare (evapotranspirácii) je závislý na dĺžke produkčného úseku vegetačného obdobia a agrotechniky pestovania skúmaných plodín.

KĽÚČOVÉ SLOVÁ: zásoba vody v pôde, evapotranpirácia, Východoslovenská nížina, numerická simulácia, agrotechnika plodín

Introduction

Vegetation cover forms an important interactive link with unsaturated soil zone within the hydrological cycle. During a vegetation period, plants go through different phonological phases. During these time-limited phases, plants have different requirements for water content available in soil. If the available water content is not sufficient in these critical phases, plants` growth and development is retarded. One of the indicators of optimal water provision for plants is their transpiration potential. This state is reached when the soil water storage is on the upper level of available water content, within the interval of field water capacity and treshold point. If the water content drops under this level, plants react to new stress conditions by lowering transpiration intensity or its total cessation. The unsaturated soil zone can be considered a third water source. It supplies the biosphere with water, interacts with atmosphere and ground water.

Plant cover is an important part of the system of atmosphere-plant cover-soil aeration zone-groundwater (Štekauerová et al., 2001). Among these subsystems there are complex interactions within the hydrological cycle, resulting in time and space distribution of water in the soil (Gomboš and Pavelková, 2010; Tall, 2007). Different crops have their individual physiological and crop management specifics, the research of which is significant for better understanding of the processes taking place between the soil and the plant. In relation to the water balance in the soil, the evapotranspiration is such process on the outflow side (Matejka et al., 2002).

Evapotranspiration consists of two partial processes, evaporation that depends on the physical properties of the environment and transpiration that is bound to the physiological properties of the plant (Allen et al., 1998). During the crop production process, the crops decrease the soil water content by transpiration but also by accumulation of water in plant tissue. It is necessary to obtain soil water storage development in a soil profile. There are two basic approaches to soil water research. Firstly, obtained field-data are monitored, processed and interpreted. Secondly, soil water regime is modelled by means of numerical simulation at soil water regime mathematical models. The results obtained by direct observation and monitoring shall be used for the verifycation of the mathematical simulation data. Correct input data are fundamental for numerical simulation. The data can be used not only for the simulation of past conditions but also for predicting future soil conditions, considering the input data for the corresponding period are available. Mathematical models, simulating the soil water regime, take into account this fact through input parameters of the plants (eg. leaf area index, roughness of root evaporating surface, root system depth, etc.).
The aim of the presented paper is to analyze the impact of selected crop growth stages on the water storage in the root zone of the soil to a depth of 1 m. For this purpose, the numerical simulation method by the mathematical model GLOBAL was used (Majerčák and Novák, 1994).

Material and methods

The impact of selected crops on the soil water storage (WS) in the root zone of the plants to a depth of 1 m was evaluated in this contribution. The analysis was based on data obtained via numerical simulation by the mathematical model GLOBAL. This model allows the simulation in the daily step. Necessary data base for the calculation was gained from Milhostov locality situated in the central part of Eastern Slovak Lowland (ESL) in the Trebišov region (GPS coordinates 48°40'11.08"N, 21°44'18.02"E). The research area is managed by the National Agricultural and Food Centre based in Michalovce. For this study, the field no. 9 (with area of 34 780 m^2) was selected. From a pedological point of view, it is characterized by a Fluvisol soil type with a content of clay particles 27–35 %. A higher content of clay (32 % in average) was found in the top layers (< 0.7 m) and lower content (27 %) was found in the bottom layers of the soil (> 0.7 m). For the high proportion of these clay particles with the size < 0.002 mm, the soil structure is typically two-domain with the formation of cracks during dry periods and therefore by specific outflow processes. Since 2000, there has been regular monitoring of groundwater level (GWL) in a nearby Slovak Hydrometeorological Institute (SHMÚ) probe and measuring of soil water storage to a depth of 0.8 m by gravimetric and TDR method. Soil water storage measurement by the method of TDR is performed in one probe located near the GWL probe. The weekly data from the monitoring and phenological characteristics of the crops were used to assess the influence of the plants on the soil water storage. This information served as input to the mathematical model GLOBAL, which allows simulation of individual elements of the soil water regime, calculation of the integral water content in the soil through the vertical direction, and calculation of the WS in the selected soil layer. As a further input to the model, the daily values of meteorological data obtained from SHMÚ measurements and hydrophysical characteristics of the soil were used. The moisture retention curve of the soil was expressed using the RETC program, which allows the calculations of van Genuchten's parameters (van Genuchten et al., 1991) to be based on the analysis of the measured points. Moisture retention curve gave hydrolimites and usable water capacity (AWC = 188.8 mm). The accuracy of the calculated values of investigated parameters was confirmed by the verifycation at the monitored values (Kandra and Pavelková, 2007). For the purpose of the above mentioned evaluation, the growing season (GS) 2006 was selected from the examined 39 years period (1970–2008). The selection was based on the fact that during this growing season, the average value of WS was nearest to the average of the 9 years period (2000–2008) during which the WS was monitored to a depth of 0.8 m (Fig. 1). The fig. 2 shows the daily total of rainfall and the average daily temperature in the evaluated period.
In the next step, the real crop of peas was replaced in the individual simulations by different crops. During simulation agrotechnical requirements and physiological or morphological features of crops have been taken into account. Table 1 shows the agrotechnical description of selected crops and their yields under conditions of Slovakia. By changing the crops grown, their individual effect on the daily values of the calculated water storages up to 1 m was monitored. The analysis was based on the comparison of simulated water storage with simulated actual evapotranspiration (ET_a) – the most important outflow parameter which consist of two partial processes, evaporation (E_{ea} – surface evaporation) and transpiration (E_{ta} – plant evaporation).

Results and discussion

The daily values of the actual evapotranspiration and its partial processes for each kind of the investigated crop are shown in figures 3–5. These charts well reflect the morphological and physiological differences of selected crop species during their phenological phases. They also reliably reflect the way these crops are used from crop management point of view. During the cultivation of the alfalfa, three harvests were conducted during the year (1. June, 3. August and 3. October).
At that time, the E_{ea} totals increased and E_{ta} values dropped. After harvest at the time of regrowth of phytomass, the leaf area index (LAI) also increased. This resulted in an increase in water discharge by

transpiration and, on the contrary, a decrease in discharge by evaporation. Differences are also seen in the increase in transpiration after individual harvest. Before the first harvest, which was the largest, the totals of E_{ta} were also highest. Before the next harvest, the totals of E_{ta} were decreasing.

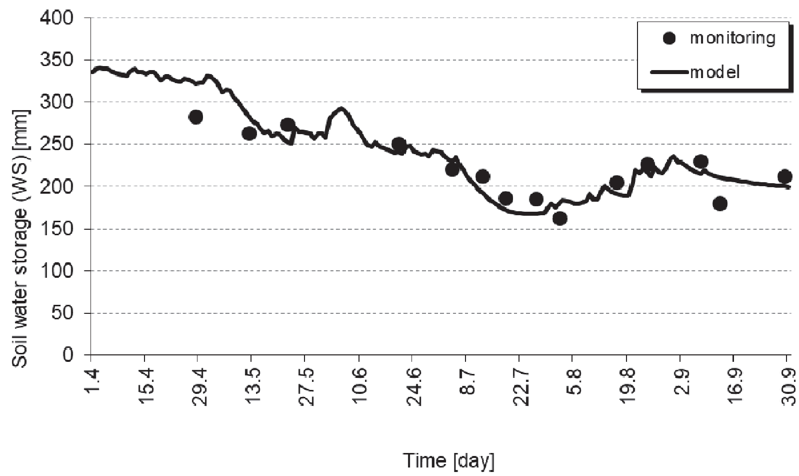

Fig. 1. The course of measured and simulated water storage up to 0.8 m for the growing season 2006.
Obr. 1. Priebeh meranej a vypočítanej zásoby vody do 0.8 m za vegetačné obdobie 2006.

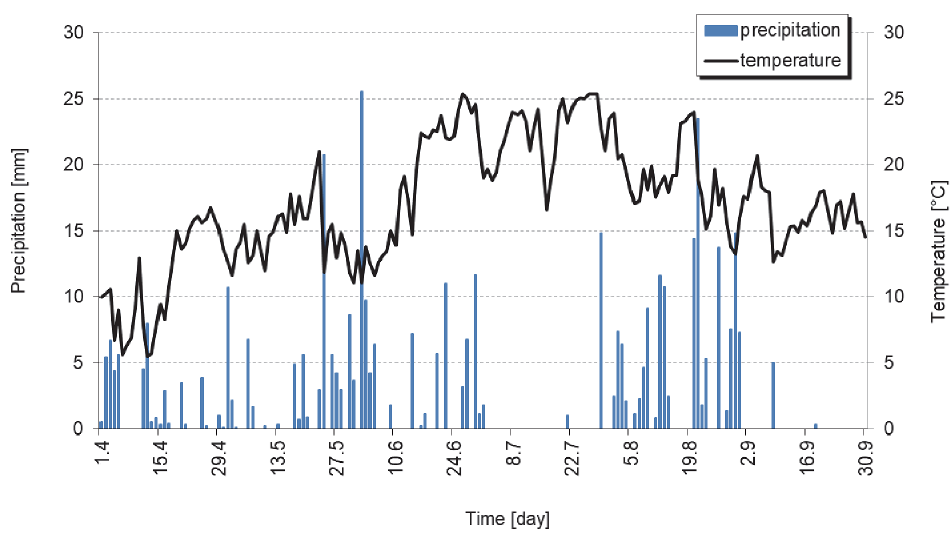

Fig. 2. Daily precipitation and average daily temperature in the growing season 2006.
Obr. 2. Denný úhrn zrážok a priemerná denná teplota vzduchu vo vegetačnom období 2006.

Table 1. Agrotechnical specification of the evaluated crops
Tabuľka 1. Agrotechnická špecifikácia hodnotených plodín

Crop	Date of seeding	Date of harvesting	Row spacing [m]	Yield grain/seed [$t.ha^{-1}$]	Yield hay/straw [$t.ha^{-1}$]
Alfalfa	15. September	1. June, 3. Aug., 3. Oct.	0.125	-	8.0–10.0
Maize	25. April	6. September	0.700 x 0.180	4.5–7.0	4.1–7.0
Peas	15. March	24. July	0.180 x 0.040	1.5–3.2	2.6–5.0

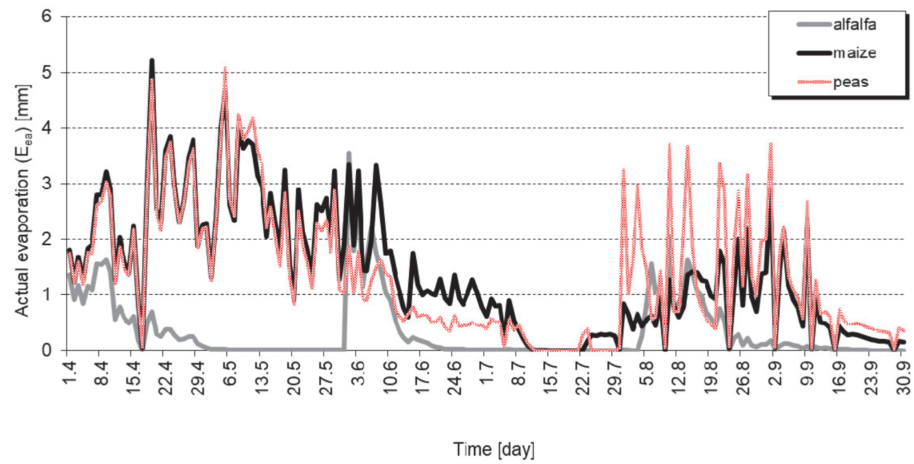

Fig. 3. *Simulated daily totals of actual evaporation for the growing season 2006.*
Obr. 3. *Denné úhrny aktuálnej evaporácie za vegetačné obdobie 2006.*

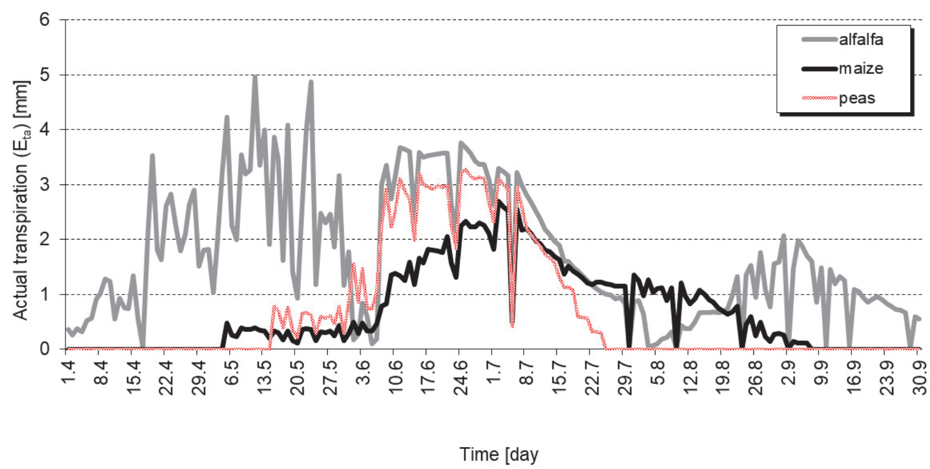

Fig. 4. *Simulated daily totals of actual transpiration for the growing season 2006.*
Obr. 4. *Denné úhrny aktuálnej transpirácie za vegetačné obdobie 2006.*

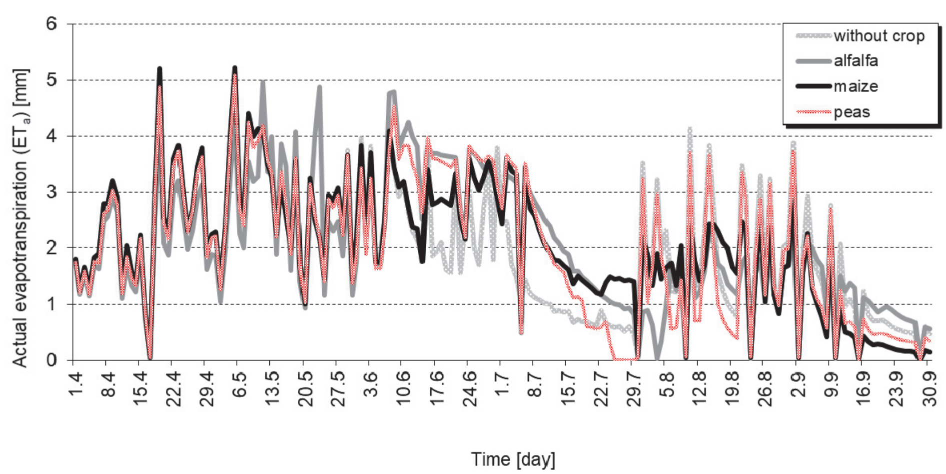

Fig. 5. *Simulated daily totals of actual evapotranspiration for the growing season 2006.*
Obr. 5. *Denné úhrny aktuálnej evapotranspirácie za vegetačné obdobie 2006.*

In the case of maize, seeding was performed at the end of April. Transpiration gradually grew with the peak reaching at the beginning of July. Later, at the time of ripening until the harvest, totals of E_{ta} decreased. Before seeding and after harvesting of maize, the value of evaporation was maximum. A similar course was also observed in the case of peas but with some shifts due to the difference in the agrotechnical term of seeding and harvesting. With a wider rows spacing in maize and peas, there is a higher evaporation during vegetation and, on the other hand, lower evaporation with a narrower rows spacing in the alfalfa. The average values of the individual parameters for the analyzed plants are shown in table 2. In the variant without crop, $ET_a = E_{ea}$.

Figure 6 presents the daily values of the WS to the 1 m of soil depth obtained by numerical simulation. The highest loss of water from the soil was due to the growth of the alfalfa and, on the other hand, the lowest water loss was due to the peas. The variant without crop provided a reference course for the evaluated plants. Similarly, figure 7 shows average WS values and ET_a totals for individual crops. The average loss of WS under the crops compared to variant without crop was as follows: alfalfa (41.7 mm = 22.1% of AWC), maize (25.8 mm = 13.7% of AWC) and peas (15 mm = 7.9% of AWC, where 1 mm = 1 liter of water.m^{-2}). The highest evapotranspiration totals were observed in alfalfa (374.1 mm) and maize (374.7 mm), lower in peas (370.9 mm) and lowest in soil without crop (358.4 mm). The totals of E_{ta} and E_{ea} calculated by numerical simulation in the evaluated crops during the analyzed growing season were as follows: alfalfa (313.8 mm, 60.1 mm), maize (123.7 mm, 251 mm), peas (121.1 mm, 249.7 mm). When assessing the influence of the crop on the water content in the soil, it is necessary to consider not only the amount of water that the plant transpirates but also the water bound in its fytomass. This can be quantified via the achieved harvest (Liu et al., 2002). An important indicator is also the ability of the plant to manage water (Zhang et al., 2004, Blum, 2009, Parry et al., 2007). From this point of view, maize is more thrifty than alfalfa.

Table 2. Simulated average daily values of analyzed parameters for the growing season 2006
Tabuľka 2. Priemerné hodnoty skúmaných ukazovateľov za vegetačné obdobie 2006

Crop	Average E_{ea} [mm]	Average E_{ta} [mm]	Average ET_a [mm]	Average WS [mm]
Without crop	1.96	0.00	1.96	322.5
Alfalfa	0.33	1.72	2.05	280.8
Maize	1.37	0.68	2.05	296.7
Peas	1.36	0.66	2.02	307.5

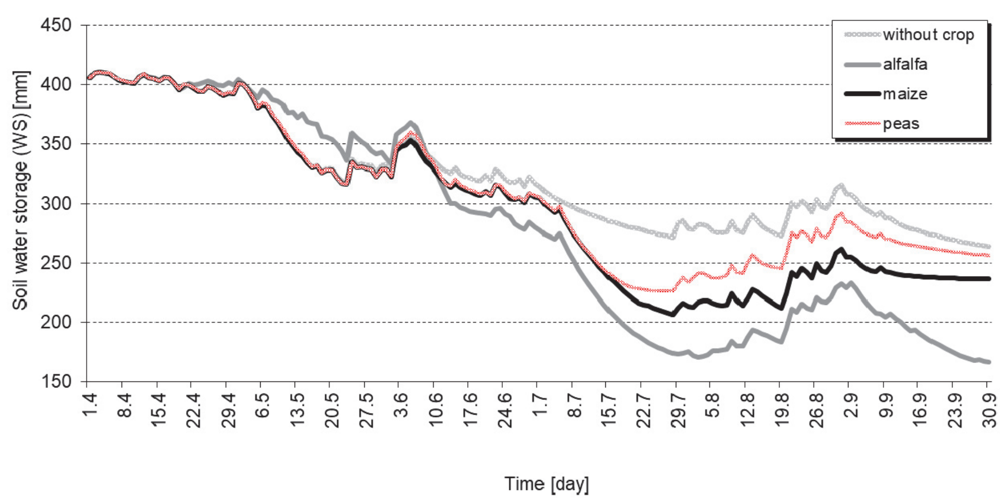

Fig. 6. Simulated daily soil water storage up to 1 m of soil depth for the growing season 2006.
Obr. 6. Vypočítaná zásoba vody v pôde do hĺbky 1 m za vegetačné obdobie 2006.

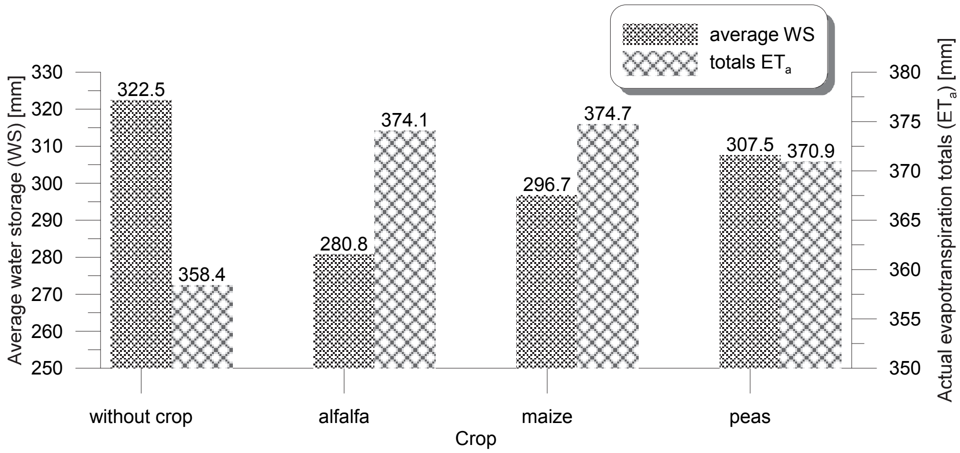

Fig. 7. Simulated daily average WS and totals of ET_a for the growing season 2006.
Obr. 7. Vypočítaná priemerná WS a suma ET_a za vegetačné obdobie 2006.

Conclusion

In this contribution the impact of selected field crops on the water storage in the root zone of the soil profile located on the Milhostov site was evaluated. The daily courses of WS to a depth of 1 m and the daily evapotranspiration totals were obtained using the numerical simulation method on the mathematical model GLOBAL. The results clearly demonstrate the significant impact of crop diversity on the soil water content. The crops with the longest vegetation time and the largest production of total biomass showed the most significant water consumption during the growing season 2006. On the other hand, the highest soil water storage was observed in the soil without crop or in the crop with a lower production of fytomass. The production of plant dry matter is closely related to the process of transpiration, and therefore crops producing larger quantities of dry matter have to transpirate larger amounts of water. Similarly it is also with the water accumulating in plant fytomass. Plants are mostly composed of water (80–90 %), and therefore higher water consumption by plants also increases the water consumption from the soil. The proportion of transpiration on the total evapotranspiration is determined by the physiology of plants during the phenological growth phases and agricultural crop management practices (row spacing, agrotechnical date of harvest, mode of utilization and crop yields). For example, in the case of crops with narrow row spacing, transpiration will dominate and vice versa, with widely spaced crops, considerable evaporation will also occur.

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VPLYV RÔZNYCH PLODÍN NA ZÁSOBY VODY V PÔDE A EVAPOTRANSPIRÁCIU: SIMULÁCIA V MODELI GLOBAL

V príspevku bol hodnotený vplyv vybraných druhov poľných plodín na zásobu vody v koreňovej zóne pôdneho profilu nachádzajúceho sa na lokalite Milhostov. S využitím metódy numerickej simulácie na matematickom modeli GLOBAL boli získané denné priebehy zásoby vody do hĺbky 1 m a priebehy denných úhrnov evapotranspirácie. Výsledné priebehy jasne dokumentujú výrazný vplyv druhovej odlišnosti pestovaných plodín na obsah vody v pôde. Najvýraznejšiu spotrebu vody počas vegetačného obdobia roku 2006 preukázali plodiny s najdlhšou vegetačnou dobou a najväčšou produkciou celkovej biomasy. K týmto plodinám patrila lucerna siata (22,1 % z využiteľnej vodnej kapacity (AWC), AWC = 188,8 mm) a kukurica (13,7 % z AWC). Naopak najvyššia zásoba vody v pôde bola zaznamenaná na pôde bez porastu alebo pod plodinou s nižšou produkciou rastlinnej hmoty (hrach siaty, spotreba vody 7,9 % z AWC). Produkcia rastlinnej sušiny je úzko spojená s procesom transpirácie a teda plodiny produkujúce väčšie množstvá sušiny musia vytranspirovať väčšie množstvá vody. Podobne je to aj s množstvom vody, ktorá sa akumuluje v rastlinných pletivách. Rastliny sú z väčšej časti tvorené vodou (80 – 90 %) a preto pri vyššej produkcii sa odčerpá a akumuluje väčšie množstvo vody z pôdy. Podiel transpirácie na celkovom výpare je podmienený fyziológiou rastlín počas fenologických fáz rastu a agrotechnikou pestovania (spon riadkov, agrotechnický termín sejby a zberu, spôsob využitia či výška úrody). Napríklad pri hustosiatych plodinách bude prevládať transpirácia a naopak pri plodinách s väčšou medziriadkovou vzdialenosťou bude značný aj výpar z pôdy (evaporácia). Celkové úhrny aktuálnej transpirácie (E_{ta}) a evaporácie (E_{ea}) pri hodnotených plodinách počas analyzeváného vegetačného obdobia získané numerickou simuláciou boli nasledovné: lucerna (313,8 mm, 60,1mm), kukurica (123,7 mm, 251mm), hrach (121,1 mm, 249,7 mm).

Ing. Branislav Kandra, PhD.
Ing. Milan Gomobš, CSc.
Ústav hydrológie SAV Bratislava
Výskumná hydrologická základňa Michalovce
Hollého 42
Michalovce 071 01
Tel.: +42156 6425 147
E-mail: kandra@uh.savba.sk
gombos@uh.savba.sk