Soil Water Regime Estimated from the Soil Water Storage Monitored in Time

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Abstract: During the vegetation season, the water storage in the soil aeration zone is influenced by meteorological phenomena and by the vegetated cover. If the groundwater table is in contact with the soil profile, its contribution to water storage must be considered. This impact can be either monitored directly or the mathematical model of the soil moisture regime can be used to simulate it. We present the results of monitoring soil water content in the aeration zone of the East Slovakian Lowland. The main problem is the evaluation of the soil water storage in seasons and in years in the soil profile. Until now, classification systems of the soil water regime evaluation have been mainly based upon climatological factors and soil morphology where the classification has been realized on the basis of indirect indicators. Here, a new classification system based upon quantified data sets is introduced and applied for the measured data. The system considers the degree of accessibility of soil water to plants, including the excess of soil water related to the duration for those characteristic periods. The time span is hierarchically arranged to differentiate between the dominant water storage periods and short-term fluctuations. The lowest taxonomic units characterize the vertical fluxes over time periods. The system allows the comparison of soil water regime taxons over several years and under different types of vegetative cover, or due to various types of land use. We monitored soil water content on two localities, one with a deep ground water level, one with a shallow ground water level. The profile with a shallow ground water level keeps a more uniform taxons and subtaxons of soil water regime due to the crop variation than the profile with a deep ground water level.

Keywords: ecology classification; soil water regime; soil water content monitoring; soil water storage

The soil water storage W_p (mm) is

$$W_p = \int_0^Z \theta dz \tag{1}$$

where:
- θ – volumetric soil water content
- z – vertical coordinate in cm
- Z – total depth to which the soil water content is measured in 10 cm thick layers; in our research Z = 80 cm

W_p is permanently influenced by the fluxes through the boundaries of the unsaturated zone: at the top, it is the soil-atmosphere interface, and at the bottom, it is the ground water level in simple cases, as we are dealing with in our research. Monitoring of soil water content (Šútor 1999; Šútor *et al.* 1999) and numerical solution (Štekauerová *et al.* 2002) yield a great number of time series of data, which are further visualised as follows:

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(i) by θ (z) point plots,
(ii) by θ (z) continuous graphs,
(iii) by continuous θ (t) in soil horizons,
(iv) by chronoisoplets of soil water content, θ (z, t),
(v) by continuous graphs of integral soil water storage $W_p(t)$.

None of those procedures evaluates the soil water regime; rather each is simply a documentation of data. For evaluation of water storage $W_p(t)$ we use a procedure leading to an objective classification of the soil water regime of the monitored site. There exist two basically different approaches, the first is hydrological classification, and the second one is the ecological classification.

In hydrological classification, the main criterion is the predominant direction of flow of water in the soil profile as related to hydrological cycles. In ecological classification, the dominant aspect is the amount of water stored in the soil profile (Šútor *et al.* 1999), its availability to vegetation and its variation with time and depth (Štekauerová & Nagy 2002). This type of classification was proposed and documented by Kutílek (1970), Kutílek and Nielsen (1994) and modified by Němeček *et al.* (1990). Here we apply evaluation of monitored data in one region of the East Slovakian Lowland that displays with soil water storage variation and depths to ground water level.

MATERIALS AND METHODS

Classification of soil water regime in seasonal monitoring

The classification of soil water regime was successfully used for the evaluation of water content data collected for several seazons in the ranges between 2 to 4 years in Czech and Slovak soils (Kutílek 1978; Němeček *et al.* 1990; Šútor *et al.* 1999).

The range of W_p between full saturation and zero storage is divided into six intervals defined by soil-water characteristics: FS – full saturation, FWC – field capacity, PDA – point of decreased availability with water content at pressure head h = –2000 cm, WP – wilting point, HC – hygroscopic coefficient i.e. soil moisture in equilibrium with partial pressure of water vapor, p/p_0 = 0.95.

The system is based upon the hierarchical scheme: Class – Order – Suborder – Type.

The classes are identical with intervals of soil water storage:

(1) – Aquatic class: W_p is at full saturation FS.

(2) – Umidic class: W_p is in the range between FS and FWC.

(3) – Uvidic class: W_p is in the range between FWC and PDA.

(4) – Semiarid class: W_p is in the range between PDA and WP.

(5) – Arid class: W_p is in the range between WP and HC.

(6) – Hyperarid class: W_p is below HC.The orders specify in which direction W_p develops in the season. We realized the monitoring within the vegetational season. The classificatioon system is therefore modified and the lengths of intervals differ slightly from the original classification system of the whole year monitoring as follows:

(A) – Permanent orders with a dominant interval duration equal to (or greater than) 150 days. The subdominant interval is equal to or less than 30 days.

(B) – Temporary orders with dominant interval duration over 90 days and less than 150 days. The subdominant interval has the duration of 30 to 90 days and the inferior interval is less than 30 days. Intervals of duration less than 14 days are neglected.

(C) – Indifferent orders in which all intervals have a duration of less than 90 days.

Suborders are classified in relation to the part of the season where the subdominant interval exists.

Types are classified according to the soil water regime classification in the topsoil and subsoil. We did not classify the types.

The detailed classification system is in the Table 1. The six classes are denoted by arabic numbers and them related terms. The orders are denoted by capital letters, where A is for permanent, B for temporary and C for indifferent order. Suborders are in paranthesis where the subdominant intervals are written in arabic numbers identical to classes. Example of the evaluation of the soil water storage regime in Chernozem on loess in two subsequent years is 3C(2,4) and 3B(2), see Němeček *et al.* (1990).

Monitoring of the soil water storage

Soil water content was measured gravimentrically in two weeks intervals for 10 cm layers up to a depth 80 cm. Core samples were taken in three repetitions and the water content was determined by drying. The mean value θ from each layer was used for calculation of soil water storage of the whole soil profile, for z = 0 to z = 80 cm at each sampling time. Soil water storage regime was evaluated in two different ways. First, the mean value of water storages was computed for sampling dates over the whole vegetation season (April–September). Then the water storage was computed for sampling dates and plotted against time and evaluated as the soil water regime.

The limiting values of the soil water storage were determined on all experimental plots: Water storage at field water capacity (FWC), at point of decreased availability (PDA) and at wilting point (WP), where FWC was determined as the soil water content at the pressure head h = –200 cm, PDA was at h = –2000 cm, and WP was at h = –15000 cm.

Localities

Soil water content monitoring was realized in long-term stationary field trials in the experimental centre of the Regional Agroecological Research Institute of Michalovce (East Slovakian Lowland), in Milhostov and in Vysoká nad Uhom.

In Milhostov the soil texture was clay loam, FAO classification was Fluvisol, mean ground water level (GWL) at 110–150 cm. The following crops were planted in 2003: maize, beans, winter wheat, spring barley, clover, soya, sugar beet, sunflower on 10 plots.

In Vysoká nad Uhom the soil texture was loam, FAO classification was Fluvisol, mean ground water level (GWL) at 150–200 cm. The planted crop was maize in years 1972 to 1976, and from 1998 to 2003 on locality No 1. For the comparative study, the following crops were planted on 10 plots on locality No 2 in 2003: alfalfa, wheat, peas, barley, sugar beet, soya, sunflower. The two localities differed slightly in soil water retention curves, all other parameters (horizons, texture) were identical. The difference is projected into different values of soil water storage at WP, PDA and FWC, see the Figure 1 and 2.

Model crops alfalfa, wheat, peas, barley, maize, sugar beet, soya, sunflower, beans, winter wheat, alfalfa, clover, and spring barley were grown with the use of classic techniques consisting of normal agrotechnical measures (stubble breaking, ploughing, harrowing, sowing).

RESULTS

Values of the soil water storage in the vegetation seasons are presented in Figures 1–4.

Figure 1 shows the mean soil water storage W_p in the soil aeration zone during vegetation season (April to September) at the locality Vysoká nad Uhom from 1972 to 1976 and from 1998 to 2003. The ground water level is at position between 150 to 200 cm, substantially lower than at the locality Milhostav. The quoted data were taken under the maize growth. When the soil water storage measured at 14 days interval was plotted as the

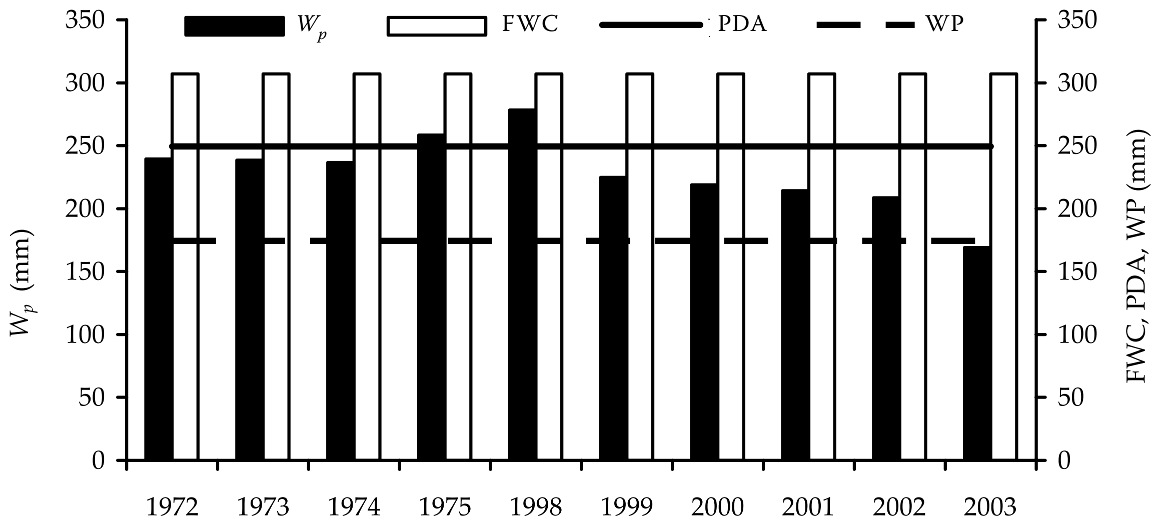

Figure 1. Mean soil water storage W_p during vegetative period (April to September) under maize growth at locality No. 1, Vysoká nad Uhom, from 1972 to 1976, and from 1998 to 2003; GWL = 150–200 cm; FWC – field water capacity; WP – wilting point; PDA – point of decreased availability

Table1. Classification of soil water regime

Class	Order	Duration (in days) of the interval of soil water storage			
		≥ 150	150–90	90–30	≤ 30
1	A	FS	–	–	–
Aquatic	A(2)	FS	–	–	FS–FWC
	B(2)	–	FS	FS–FWC	–
	B(2,3)	–	FS	FS–FWC	< FWC
2	A	FS–FWC	–	–	–
Umidic	A(1)	FS–FWC	–	–	FS
	A(3)	FS–FWC	–	–	< FWC
	A(1,3)	FS–FWC	–	–	FS and < FWC
	B(1)	–	FS–FWC	FS	–
	B(3)	–	FS–FWC	FWC–PDA	–
	B(1,3)	–	FS–FWC	FS	< FWC
	B(3,1)	–	FS–FWC	< FWC	FS
	B(3,4)	–	FS–FWC	FWC–PDA	< PDA
	C	length of each of intervals FS, FS–FWC, FWC–PDA is < 90 days			
3	A	FWC–PDA	–	–	–
Uvidic	A(2)	FWC–PDA	–	–	> FWC
	A(4)	FWC–PDA	–	–	< PDA
	A(2,4)	FWC–PDA	–	–	> FWC and < PDA
	B(2)	–	FWC–PDA	FS–FWC	–
	B(4)	–	FWC–PDA	PDA–WP	–
	B(2,1)	–	FWC–PDA	FS–FWC	FS
	B(2,4)	–	FWC–PDA	> FWC	< PDA
	B(4,2)	–	FWC–PDA	< PDA	> FWC
	B(4,5)	–	FWC–PDA	PDA–WP	< WP
	C	length of each of intervals FS–FWC, FWC–PDA, PDA–WP is < 90 days			
4	A	PDA–WP	–	–	–
Semiarid	A(3)	PDA–WP	–	–	> PDA
	A(5)	PDA–WP	–	–	< WP
	A(3,5)	PDA–WP	–	–	> PDA and < WP
	B(3)	–	PDA–WP	FWC–PDA	–
	B(5)	–	PDA–WP	WP–HC	–
	B(3,2)	–	PDA–WP	FWC–PDA	> FWC
	B(3,5)	–	PDA–WP	> PDA	< WP
	B(5,3)	–	PDA–WP	< WP	> PDA
	B(5,6)	–	PDA–WP	WP–HC	< HC
	C	length of each of intervals FWC–PDA, PDA –WP, WP–HC is < 90 days			
5	A	WP–HC	–	–	–
Arid	A(4)	WP–HC	–	–	> WP
	A(6)	WP–HC	–	–	< HC
	A(4,6)	WP–HC	–	–	> WP and > HC
	B(4)	–	WP–HC	PDA–WP	–
	B(5)	–	WP–HC	< HC	–
	B(4,3)	–	WP–HC	PDA–WP	> PDA
	B(4,6)	–	WP–HC	> WP	< HC
	B(6,4)	–	WP–HC	< HC	> WP
	C	length of each of intervals PDA–WP, WP–HC, < HC is < 90 days			
6	A	< HC	–	–	–
Hyperarid	A(5)	< HC	–	–	> HC
	B(5)	–	< HC	WP–HC	–
	B(5,4)	–	< HC	WP–HC	> WP

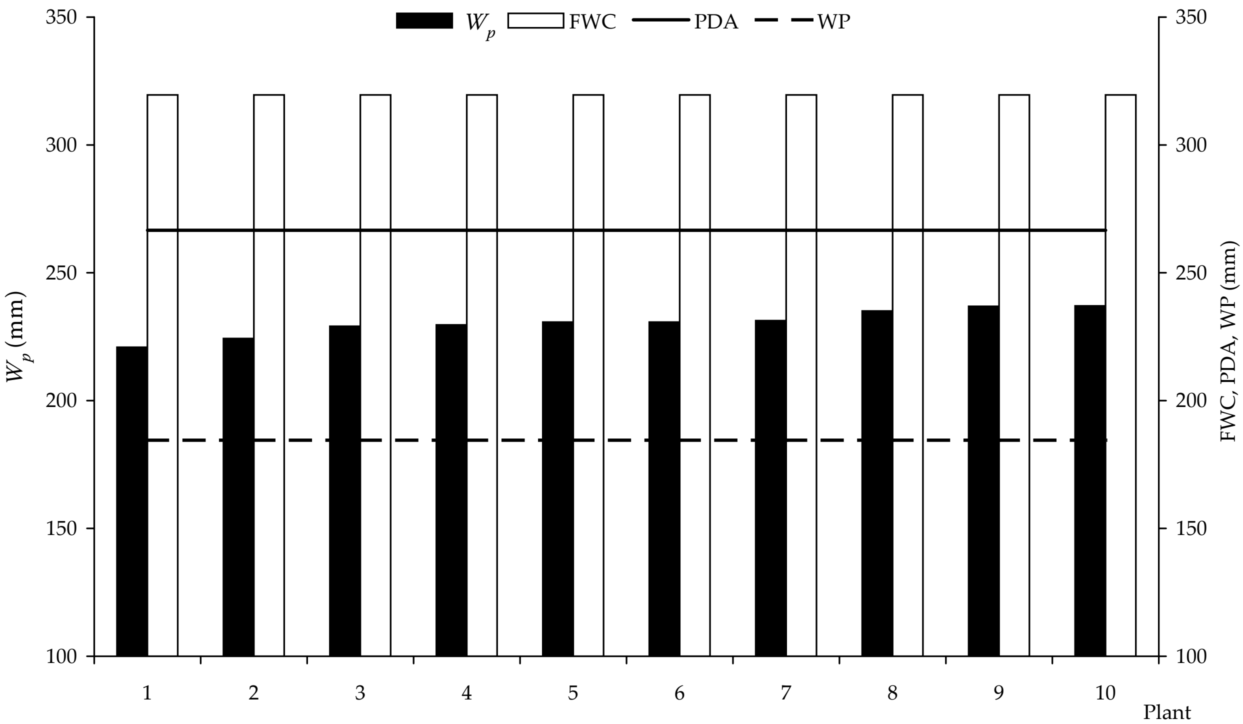

Figure 2. Mean soil water storage W_p during vegetation period under growths of ten crops at the locality No. 2, Vysoká nad Uhom in 2003; crops: 1 – alfalfa 2, 2 – wheat, 3 – wheat, 4 – alfalfa 4, 5 – peas, 6 – barley, 7 – maize, 8 – sugar beet, 9 – soya, 10 – sunflower; GWL = 150–200 cm; FWC – field water capacity; WP – wilting point; PDA – point of decreased availability

function of time, we obtained following soil water regime taxons in individual years:

1972–1974, 1999–2002: Uvidic class, temporary order, semiarid suborder, 3B(4).

1975, 1998: Uvidic class, permanent order, semiudic suborder, 3A(2).

2003: Uvidic class, temporary order, semiarid/arid suborder, 3B(4,5).

In Figure 2 the role of crops upon the mean value of soil water storage is demonstrated for locality No. 2 at Vysoká nad Uhom. The planted crops were alfalfa, wheat, peas, barley, maize, sugar beet, soya, sunflower. When the soil water storage measured at 14 days interval was plotted as the function of time, we obtained following soil water regime taxons for individual crops:

- alfaalfa, wheat: Semiarid class, temporary order, uvidic suborder, 4B(3),
- peas, barley, maize, sugar beet: Uvidic class, temporary order, semiarid suborder, 3B(4),
- soya, sunflower: Uvidic class, temporary order, semiarid/arid suborder, 3B(4,5).

During 2003, the crops grown on individual research plots in Milhostov were exposed to the effect of the same precipitation as at Vysoká nad Uhom and the oscillation of groundwater table took place approximately in the same intervals, but the depth 110–150 cm at this location was much shallower, compared to Vysoká nad Uhom. The quantitative effect of individual crops on mean soil water storage is in Figure 3. Mean values are between PDA and WP values. The lowest mean value of W_p was observed in maize. With regard to this crop, the values corresponding to the rest of crops rank in an increasing order. The greatest difference was observed between the maize and sunflower. This difference is about 17 mm. When the soil water storage measured at 14 days interval was plotted as the function of time, we obtained following soil water regime taxons for individual crops:

- maiz, beans, winter wheat, spring barley: Uvidic class, permanent order, umidic/semiarid suborder,

← Explanation to Table 1

FS – full saturation; FWC – field water capacity; WP – wilting point; HC – hydroscopic coeffecien; PDA – point of decreased availability

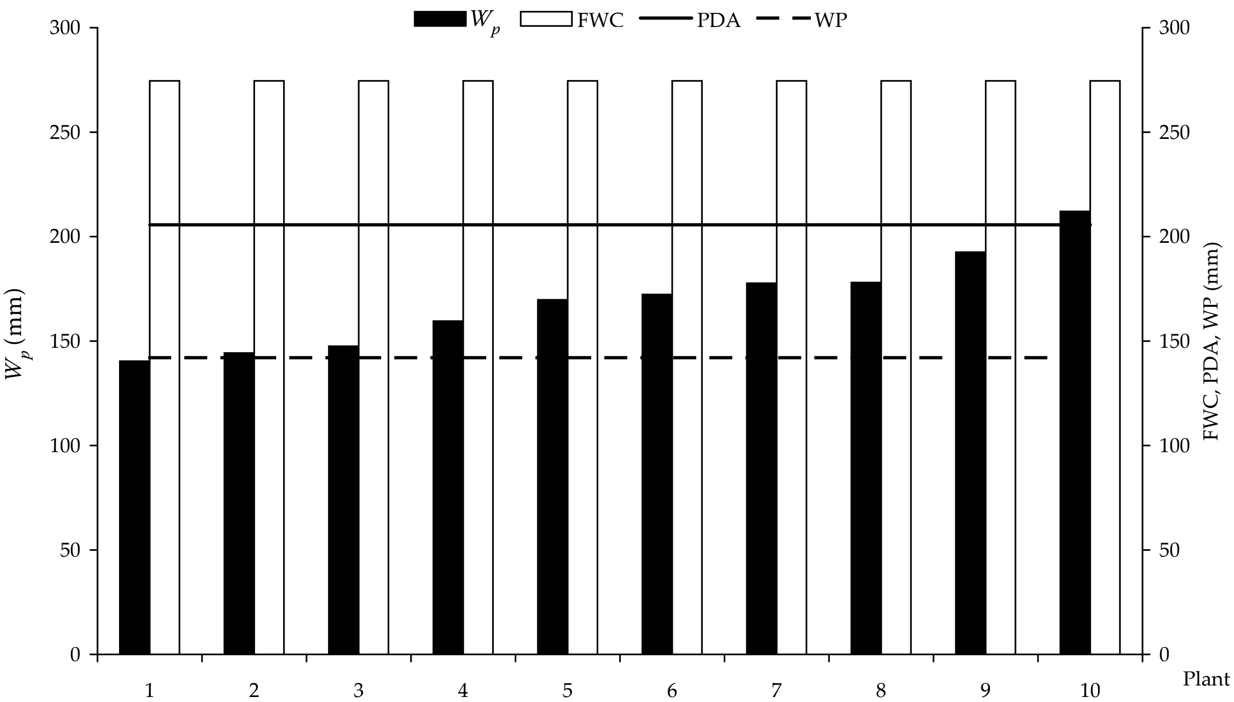

Figure 3. Mean soil water storage W_p during vegetative period under growth of ten crops at the locality Milhostov in 2003; crops:1 – maize, 2 – beans, 3 – winter wheat, 4 – spring barley, 5 – clover, 6 – soya, 7 – sugar beet, 8 – winter wheat, 9 – clover 2, 10 – sunflower; GWL = 110–150 cm; FWC – field water capacity; WP – wilting point; PDA – point of decreased availability

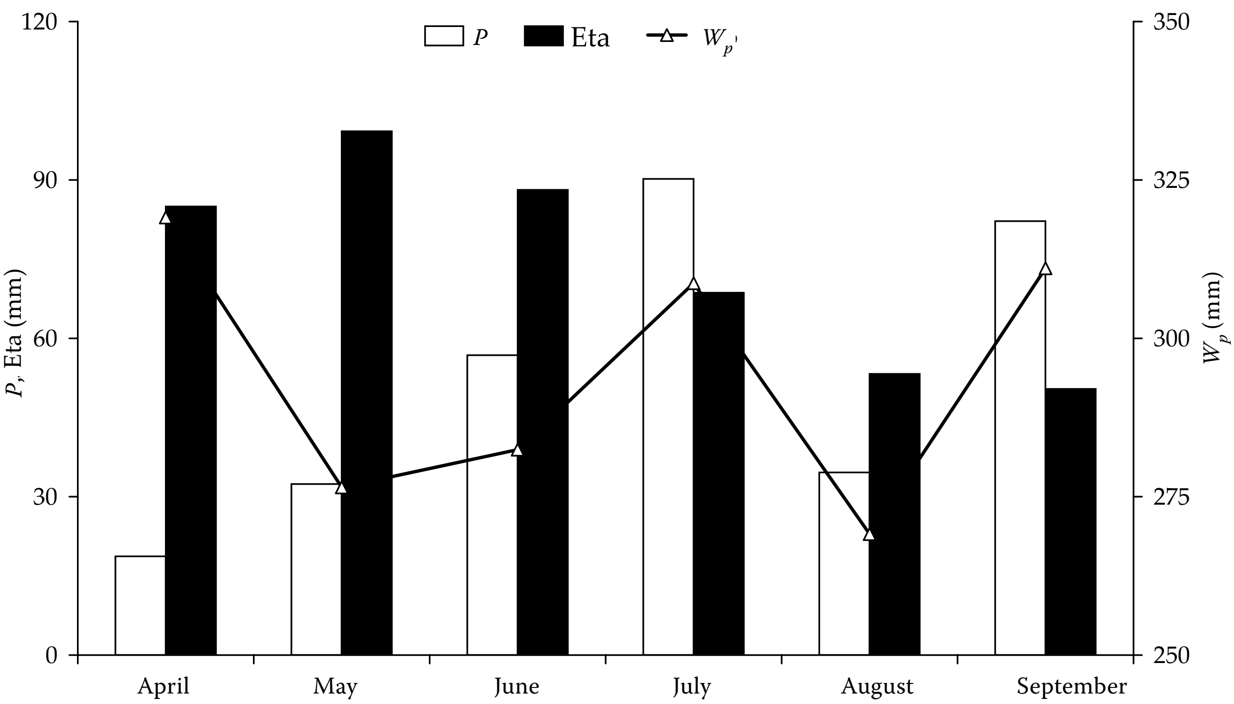

Figure 4. Monthly precipitation totals (P) actual evapotranspiration (Eta) and the regime of the mean monthly values of soil water storage (W_p) in individual months of 2003 vegetation period under the maize growth at the locality Milhostov; GWL = 110–150 cm; WP – wilting point

3A(2/4),
– sugar beet, clover, sunflower: Uvidic class, permanent order, semiarid suborder, 3A(4).

We compared the directly measured data with the computational procedures by the assessment of actual evapotranspiration (Eta) for meteorological conditions and for oscillation of the groundwater table in 2003 for maize. The numerical simulation by HYDRUS-ET (Šimůnek *et al.* 1997) was applied. The obtained results are presented in Figure 4.

The total Eta value and its components Ta (transpiration) and Eta (evapotranspiration) for maize during vegetation season is 445 mm, precipitation 350 mm and mean W_p value equals 278 mm. It is evident that the difference between the direct measured W_p and the computed W_p is not negligible. The main source of errors was not found.

DISCUSSION

Soil water regime as well as the documented mean soil water storage in the soil aeration zone at localities Milhostov (Figure 3) and Vysoká nad Uhom (Figure 2) in 2003 vegetation season is significantly different due to the difference in the depth of the ground water level, since all other factors as meteorology, soil texture and soil type and even the majority of crops are identical for both localities.

In locality with deep ground water level (Vysoká nad Uhom), the meteorologic data of individual years influence substantially the soil water regime. The highest soil water regime taxon, the uvidic class is kept all over the periods of measurement. The change in meteorologic data is reflected by the shift in suborder either to wetter or to drier next subtaxon of the classification system, when the crop is kept still the same, i.e. maize. For extremely wet meteo situations the order is changed from temporary to permanent one, still in the uvidic class. The climatic change as defined by Intergovernmental Panel for Climatic Change was not projected into a change in the soil water regime, even if some speculation could arize from a simple observation of Figure 1. However, the time related regime is more objective than simple mean values. The long term monitoring of soil water storage in locality with a shallow ground water level (110–150 cm) was not realized.

The role of crops upon the soil water regime was studied in both localities and the role of ground water level position could be estimated, too. The monitoring was evaluated for one year, only. The crops influence the soil water regime more distinctly in profile with a deep ground water level than in profile with a shallow ground water level. See also Figures 2 and 3. A relatively not too much changing soil water regime is in the profile with a shallow ground water level (110–150 cm) where we classified uvidic class of permanent order. A more variable situation was in the profile with a deep ground water level (150–200 cm) where the dominant uvidic class of majority crops was changed to semiarid class for two crops, alfalfa and wheat.

The results of numerical modeling with estimates on evapotranspiration did not bring an improvement in estimates on soil water regime, when compared with regular monitoring.

CONCLUSIONS

The classification of soil water regime based upon the evaluation of time dependent soil water storage was successfully tested for the monitored soil water content on two localities, one with a deep ground water level, one with a shallow ground water level. The profile with a shallow ground water level keeps a more uniform taxons and subtaxons of soil water regime due to the crop variation than the profile with a deep ground water level.

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