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SOIL WATER CONTENT EVALUATION AND MODELLING IN SMALL CATCHMENT WITH AGRICULTURAL USE

OCENA I MODELOWANIE ZAWARTOŚCI WODY W GLEBIE W MAŁYCH ZLEWNIACH Z UŻYTKOWANIEM ROLNICZYM

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Abstract. Due to extreme consequences of drought and flood in soil and landscape is necessary to know hydrological balance and soil water content. We used historical data about discharge, weather and crops from years 1974–1994, as well as measurements of soil moisture in the forest and arable soil, in grassland and *Salix viminalis L*. According to this information, the baseflow (by ABSCAN), surface runoff (SCS method), water retention and soil water content were calculated and evaluated.

Streszczenie. Ze względu na ekstremalne skutki suszy i powodzi niezbędne jest poznanie bilansu hydrologicznego oraz zawartości wody w glebie. W niniejszym opracowaniu korzystaliśmy z danych historycznych dotyczących pogody i upraw z lat 1974–1994, a także pomiarów wilgotności gleby w lesie, gruncie ornym oraz, użytku zielonym porośniętym wierzbą *Salix viminalis* L. Na podstawie informacji, odpływu niskiego wody (przez ABSCAN), powierzchni odpływu (metoda SCS), były oceniane i obliczane zawartość wody w glebie.

Key words: baseflow, surface runoff, water retention, soil water content

Słowa kluczowe: przepływ niski, spływ powierzchniowy, retencja wody, zawartość wody w glebie

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INTRODUCTION

Soil water regime is a continuous temporal sentence of immediate spatial organization of water in a soil. It depends on water inflow and outflow from soil. Soil water regime is appreciated in term of hydrology – when is evaluate a direction and intensity of soil water movement in hydrological year; in term of ecology – when is evaluate a soil moisture and its location in soil profile, and in term of agronomy – when is evaluate a relation between actually and potentially available soil water for plants in active root layers [Štekauerova 2001]. According to Šutor [1991] water regime of a soil aeration zone express a progress of integral soil water content in the soil aeration zone during a monitoring period. Soil water content in that zone in natural conditions is moved in huge range, namely from completely dry soil in summer months to absolutely saturated soil [Antal 1985, 1999].

By the hydrological balance we understands relations between inputs, outputs, as well as difference in soil water storage in research environment and monitoring period. For example, for demands of agriculture is made hydrological balance of use in agricultural area as a unit (region), and particularly for active soil profile layer (root zone), too.

Soil takes water first of all through soil surface by infiltration of precipitation. In case of the groundwater level reaches the soil profile, water capillary rise. Very small part of water comes into soil by condensation of water vapour.

Total storage in rhizosphere soil depth 1 meter and soil moisture 25 volume per cent is circa 7 bilions m^3, what is 5.5 times more water than in all water reservoirs in Slovakia [Šutor 1991]. This water resource in agricultural landscape and in production process is without alternative, and sensitively responds to climate changes, impact of extraterrestrial powers and anthropogenic actions. Regulation of soil water regime and modification of water resources in agricultural landscape has its no fungible place [Demo, Bielek et al. 2000].

Balance equation is called an equation which quantitatively expresses the water content change in soil volume (V_w) in defined time interval (t_w) as difference between inputs and outputs, where soil water input is compared with outputs:

$$V_w = (V_i + P_d) - (I + E_e + E_t) \quad (1)$$

where:

- V_i – infiltration into soil,
- P_d – inflow from groundwater,
- I – outflow in down direction,
- E_e – evaporation,
- E_t – transpiration [Majercak 2002].

Because not all soil water is available for plants, and its movement is not the same, in a practical task of soil water balance are used characteristic soil moisture intervals defined as hydrolimits. As the most important characteristic is considered available water capacity, which is calculate as difference between field capacity and wilting point. We understands it as maximum of potential soil water storage in ahead define soil profile depth, which is available for plants. It is possible to express it in millimeters of water level or in $m^3 \cdot ha^{-1}$, and we call it available water capacity (W_{vvk}). We calculate it for layered soil profile as:

$$W_{vvk} = \sum_{i=1}^{n} (\Theta_{pk} - \Theta_{v})_i \cdot h_i \text{ , mm} \tag{2}$$

where:

$\Theta_{pk,i}$ – field capacity of soil layer, $cm^3 \cdot cm^{-3}$,
$\Theta_{v,i}$ – wilting point of soil layer, $cm^3 \cdot cm^{-3}$,
h_i – soil depth, mm.

Total soil water storage in soil profile can be calculate by measured soil moisture in particular soil layers from equation (3), and soil water storage in soil profile available for plants from equation (4).

$$W_c = \sum_{i=1}^{n} \Theta_i \cdot h_i \text{ , mm} \tag{3}$$

$$W_{c,r} = \sum_{i=1}^{n} (\Theta - \Theta_v)_i \cdot h_i \text{ , mm} \tag{4}$$

where:

Θ_i – actual soil moisture in soil layer, $cm^3 \cdot cm^{-3}$.

It is assumed that in recession of soil moisture to the wilting point are non-recurring changes on vegetation. In that case would it be better to use hydrolimit decrease of water availability point. Soil water storage calculate with this hydrolimit should (with regard to vegetation) be consider as critical, and in recession of soil water storage to this value, one should consider the regulation of soil water regime [Velebny et al. 2000].

MATERIAL AND METHODS

Soil water content was monitored from 23rd March 2010 to 24th May 2011 at a depth of 1 m. The average values of daily flows in hydrological years 1974–1994 from The Slovak Hydrometeorological Institute have been used. Meteorological data sets (precipitation) were from the weather station in Nitra.

Research area

The changes of soil water content we evaluated were in a subcatchment of the Bocegaj stream with an area of 9.75 km^2. The catchment is subject to intensive agricultural use. It is situated in Southeast Slovakia, approximately 10 kom northeast of Nitra. The research area is detailed present in work Kaletova [2010, 2011]. Soil moisture was measured at 7 points, where one point was situated at a forest edge, 2 locations were in a meadow, 3 points were in arable soil, and last one in *Salix viminalis* L. vegetation.

Bocegaj catchment is subcatchment of Zitava basin. The average annual flow is $Q_a = 43\ l \cdot s^{-1}$.

Recession of discharge in water stream start to be visible in July and the peak of recession is in August or September. During some years the recession continues to October. In October the runoff increase. The maximal discharges are in February and March. During those months, the runoff is creating by precipitation, melting water from accumulated snow in landscape and by water accumulated in soil during autumn and winter.

Methods

Baseflow was calculated by software ABSCAN. Automated Baseflow Separation for CANadian datasets is a Hydrograph Analysis tool that automatically filters streamflow data into runoff and baseflow components. It works with every year (or data sets) separately, therefore we calculated baseflow from calendar years, and then evaluated them for hydrological years. We calculated with Lyne and Hollick equation:

$$q_t = \alpha \cdot q_{t-1} + (Q_t - Q_{t-1}) \cdot \frac{1+\alpha}{2}, \quad [m^3 \cdot s^{-1}] \tag{5}$$

where:

α – the filter parameter associated with the catchment (in our case α = 0.99),

Q_t – the streamflow at timestep *t*,

q_t – the corresponding runoff component [Parker 2006].

SCS method was used to calculate the height of surface runoff from the landscape. We calculated by V.T. Chow methodology [1964], for Slovak conditions modified by Antal [1985, 1999]. The calculation were made for real precipitations measured in Nitra weather station, therefore we regarded antecedent moisture conditions separately for vegetation and non-vegetation season. Calculated height of direct water runoff was multiply by the area of particular estate, and sum of particular discharges gave the total direct surface runoff from research area. The retention of area was calculated as total runoff minus surface runoff and baseflow.

Volumetric soil moisture content was measured by the Profile Probe PR2/6 with connection to the Moisture Meter HH2. Soil water contents were calculated in depth 0–60 cm and 0–100 cm according the equation (3) from the measured soil moisture. In the grassland, the soil water content was calculated only for depth 0–40 cm. The measured values from depth 60 cm was used also in depth 50 cm and from depth 100 cm in depths 70, 80 and 90 cm.

RESULTS AND DISCUSSION

There is no exact information about vegetation cover of whole research area during the all years, therefore we had to apply simplification or use substitute values of CN, respectively. Also, the SCS method is not possible to use for winter season or for snow precipitation, respectively.

Starý [2005] has written that groundflow creates 30–50% of average runoff from landscape. Results from calculation by Lyne and Hollick equation gave us similar values (in comparison with other equations from ABSCAN – see Kaletova [2010]), therefore this equation and model was chosen.

Volume of surface runoff totally presented 3.06% (555,997.8 m^3) from total runoff, baseflow was 47.18% (8574,658.8 m^3), and total retention was 49.76% (9045,138.6 m^3). Range of surface runoff volume was from 2,335.4 m^3 (in 1978) to 59,996.5 m^3 (1977). Baseflow was in range from 197,786.5 m^3 (1990) to 1,098,082.5 m^3 (1987). The lowest volume of retention (122,144 m^3) was in 1990, reversal the highest (1,224,814 m^3) in 1977. From these values and values in table 1 one can see that the higher total precipitation in particular hydrological year not always was create higher total runoff from the landscape (catchment). Except the temporal distribution and amount of particular rainfall in hydrological year, also the tillage and vegetation cover that year had impact on the water distribution in landscape.

For example, in the year 1978, the total precipitation was the lowest one (364.1 mm) and approximately 83% of arable soil were covered by cereals and forage crops, which retard the surface runoff. The surface runoff was 0.49% of total runoff that year. In 1993, the total precipitation was 426.4 mm, surface runoff was 7.73% from total runoff and cereals and forage crops covered 80.64% of arable soil. In hydrological year 1978, the highest amount of precipitation was during the season from April to July, in 1993, it was in December, and from Jun to September. This different distribution of precipitation had impact on the difference in surface runoff. Hydrological year 1990 had the highest amount of precipitation (632.1 mm), the highest monthly amount of rainfall was in November (121 mm), lowest in April, Jun, July and October, so in months during which the vegetation cover either even is not or already is not covered the surface. From this year we did not have exact information about the vegetation cover, therefore we cannot exactly explain the difference in particular parts of total runoff.

Following graphs shows the progress of precipitation and soil water content in forest and arable soil, as well as in the soil covered by *Salix viminalis* L. in depth 0–60 cm (fig. 1) and 0–100 cm (fig. 2). In arable soil 2 was measured lower values, but they copy the progress of values in arable soil 3. The lowest values were in the forest soil. Soil water content in this soil slowly copies the progress of soil water content in arable soils. Also, the respond from the rainfall event was slower. The main reason for it has higher concretion of forest soil and higher ratio of leaf area over the surface in the forest. Forest soil is during the non-vegetation season covered by tree and bush branches, also.

Similar situation was in depth 0–100 cm. In this case, the soil water content in arable soil 1 was lower than in forest soil. Measured volumetric soil moisture in depth 100 cm was higher than in arable soil 1, therefore total soil water content in forest soil was higher. Analogically one can explain depression of differences in soil water content between arable soil 2 and arable soil 3.

From the shown soil water contents in depth 0–100 cm is visible that the respond to the rainfall event is not as evident as it was in depth 0–60 cm. As Dub [1963] had written, by the influence of evapotranspiration is the arable soil during the dry season dried only in layer up to 15 cm, lower in layer up to 15 or 25 cm. Lower layers are dried very slowly. Benetin [1970] also wrote that during the vegetation season water from rainfall event in middle heavy and heavy soils usually not infiltrate lower than into 30 or 50 cm under the soil surface. During the drilling of pits up to 200 cm under the soil surface around the point in arable soil 1 and arable soil 2 was not covered the groundwater level. Therefore, there is not creating an assumption of influence the soil moisture by the rising groundwater in the lowest layers of research soil profile. Different situation is in the soil covered by

Table 1. Percentage of yearly baseflow, yearly surface runoff and yearly retention from total runoff in research area

Tabela 1. Procentowy udział odpływu niskiego, rocznego spływu powierzchniowego i rocznej retencji na obszarze badań

Year Rok	Baseflow Odpływ niski %	Surface runoff Spływ powierzchniowy %	Retention Retencja %	Year Rok	Baseflow Odpływ niski %	Surface runoff Spływ powierzchniowy %	Retention Retencja %
1975	50.28	1.57	48.14	1985	49.38	2.10	48.51
1976	55.77	2.51	41.72	1986	49.42	2.14	48.44
1977	38.86	2.85	58.28	1987	53.25	0.35	46.41
1978	63.10	0.49	36.41	1988	38.18	6.75	55.07
1979	50.70	7.32	41.98	1989	54.98	6.20	38.82
1980	55.55	3.97	40.47	1990	58.29	5.71	36.00
1981	38.40	2.94	58.66	1991	54.34	1.62	44.04
1982	49.35	3.82	46.83	1992	51.89	4.81	43.30
1983	41.10	2.57	56.33	1993	53.41	7.73	38.86
1984	33.93	2.57	63.50	1994	41.43	2.97	55.60

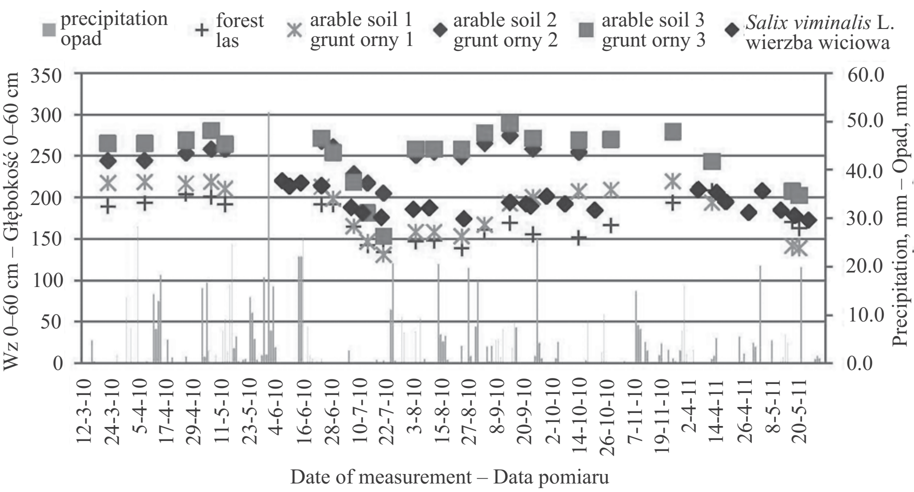

Fig. 1. Rainfall and soil water content in forest and arable soil and under the *Salix viminalis* L. in mm in depth 0–60 cm

Rys. 1. Opady i wilgotności gleby w lesie na glebach ornych i pod wierzbą *Salix viminalis* L. w mm na głębokości 0–60 cm

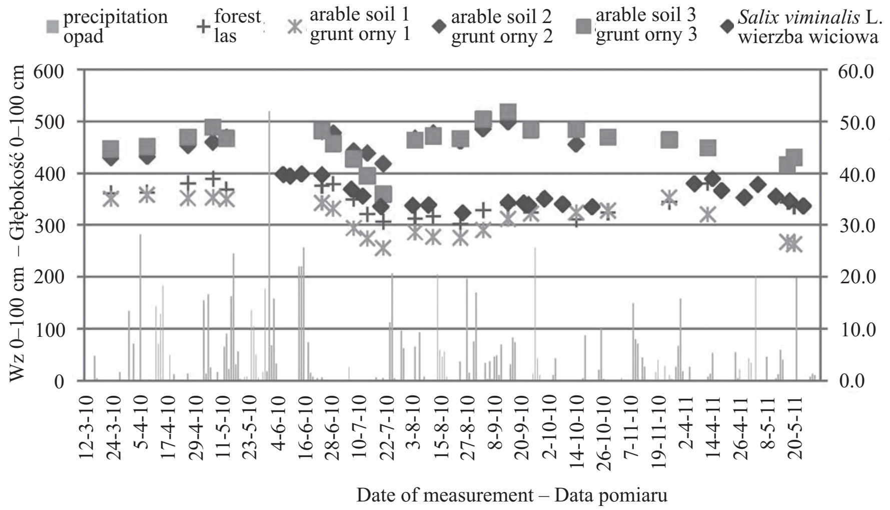

Fig. 2. Rainfall and soil water content in forest and arable soil and under the *Salix viminalis* L. in mm in depth 0–100 cm

Rys. 2. Opady i wilgotności gleby w lesie na glebach ornych i pod wierzbą *Salix viminalis L.* w mm na głębokości 0–100 cm

Salix viminalis L., where the groundwater level was between 120 and 147 cm during the evaluated part of the year 2011.

Except the soil type, soil water content is influenced also by vegetation cover, its roots and water requirements. Different plant water requirements are expressed by transpiration coefficients which are different not only for particular plants, but also for vegetation phases of plants, as are listed by FAO [Allen et al. 1998]. Also, the vegetation season, term of sowing and yield has a role on the amount of water taken by plant roots from the soil.

Soil water content in the forest soil in depth 0–60 cm during the evaluated soil profile up to 100 cm had percentage contribution from 43.94% to 56.24%, in arable soil 1from 51.27% to 64.15%, in arable soil 2 in range 49.09–56.81%, in arable soil 3 between 42.67% and 60.31%, and in the soil with *Salix viminalis* L. 51.05–57.53%. Percentage contribution of soil water content in depth 0–60 cm on the soil profile up to 100 cm in particular weather seasons in 2010, as well as whole year 2010 is shown on fig. 3. In all cases, the lowest contribution was in forest soil, and the highest in the arable soil 1.

From comparison of minimal, average and maximal percentage contribution of soil water content in particular layers of soil profile results that in all evaluated profiles are these values different. One cannot exactly say in which layer of soil profile is the highest amount of accumulated water. In the forest soil, the values gradually grow, in arable soil 1 is the highest contribution in depth 60 cm (average values in depths 40 and 100 cm are almost equal – 10.18%, 10.26% respectively). Arable soil 2 had steady progress, equal contribution of soil water content in depths 60 and 100 cm, respectively; arable soil 3 had in depth 30 cm the higher contribution of soil water content than in depth 40 cm, but

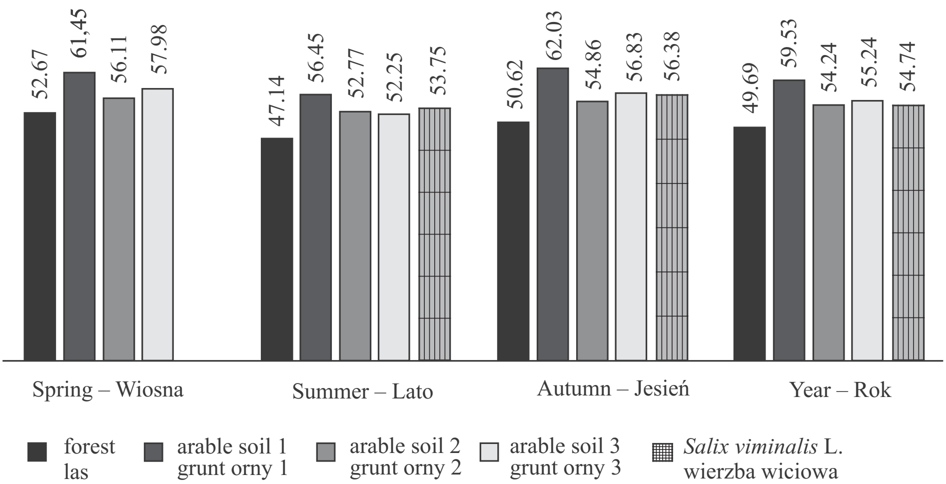

Fig. 3. Average percentage contribution of soil water content in depth 0–60 cm in soil profile up to 100 cm in particular seasons in year 2010 and whole year 2010

Rys. 3. Średni udział procentowy zawartości wody w glebie na głębokości 0–60 cm w profilu glebowym do 100 cm w poszczególnych porach w roku 2010 i za cały rok 2010

in depths 60 and 100 cm the contribution increase again. In the soil covered with *Salix viminalis* L. in depth 20 cm, the contribution of soil water content increase compare to depth 10 cm, and in depth 30 cm decrease. In lower layers, the contribution increase.

Soil water content in the grassland in depth 0–40 cm was compared between two locations in the same soil type; however, soil water content was different (fig. 4). Except the

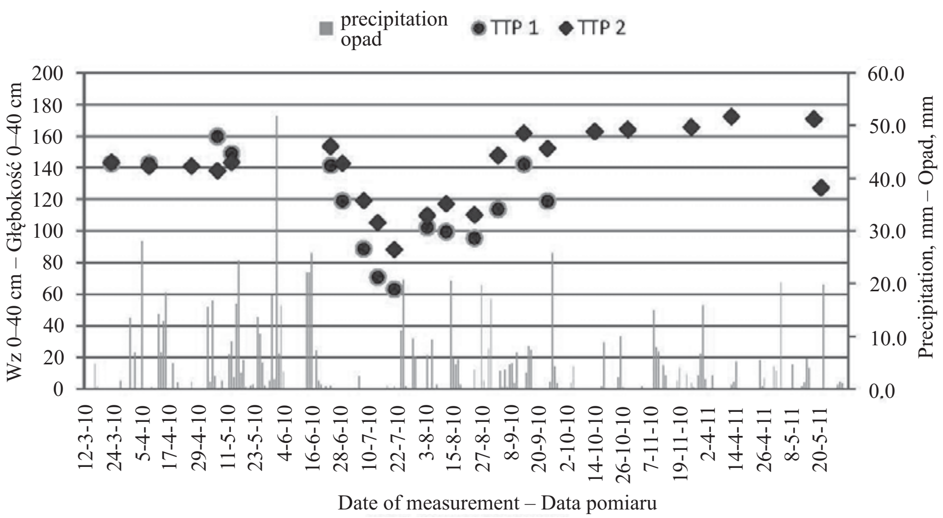

Fig. 4. Rainfall and soil water content in grassland in mm in depth 0–40 cm

Rys. 4. Opady i wilgotności gleby na użytkach zielonych w mm na głębokości 0–40 cm beginning of evaluated period 2010, the values had the same trend, though the soil water content was different. Higher measured soil water content values in the location TTP 2 evidenced water on the soil surface around the measured point, until all water around the location TTP 1 was infiltrated.

CONCLUSION

Evaluations of soil water content in the form which we presented in this article are important especially for water managers and landscape engineers. They can more precisely design a flood protection and soil erosion arrangements according to knowing the possibility of water retention in the soil. For ecologist, but mainly for farmers, the soil water content itself is not so important information. For them is more important to know the available amount of soil water for plants. Information about development of particular parts of total runoff from the landscape in previous years, and soil water content, too, can help farmers and other landscape managers to predict the situation according to development of weather during the year, as well as to choose the appropriate vegetation cover for that year.

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