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TDR DETECTED AND SIMULATED SOIL WATER CONTENT DYNAMICS OF MANAGED FOREST STANDS*

Zsolt Gácsi[1], *Kálmán Rajkai*[2], *Andrea Hagyó*[2]

[1]Kiskunság Forest Manager Ltd., H-6000 Külső Szegedi u.135, Kecskemét, Hungary
[2]Research Institute for Soil Science and Agricultural Chemistry, H-1525 P.O.B. 35, Budapest, Hungary
e-mail: krajkai@rissac.hu

A b s t r a c t. The water content of the root zone of two different forest soils was monitored in order to establish the characteristic water balance of forest stands. To validate the water content readings, the moisture probes were calibrated and reference samplings and measurements were applied. The measured soil water content dynamics was simulated using a soil water and heat model. The water balance of the forest stand and its forest management aspects are discussed.
K e y w o r d s: soil water content dynamics, moisture probe, soil water content modelling

INTRODUCTION

Afforestation has increased the forest area from 4.5% to 12% in the Great Hungarian Plain and it is not yet finished. The Great Plain area has a negative water balance in general. In spite of that, afforestation is not problematic where the ground water table is close to the soil surface. However, in the last 30 years a continuous sinking of the ground water table depth has occurred. So the water management of different forest stands has become in focus of the lowland forestry. Besides the ground water use of a lowland forest, even its role in the regional water management is becoming more and more interesting.

Another problem in forestry is the management system. The clear-cut regime with the use of heavy machinery has been the commonly used silvicultural practice for managing beech stands in Hungary since the late 1960's. It has negative effects on forest ecosystems and may cause erosion. The smaller-scale cutting systems mimic the natural gap dynamics. A higher biodiversity and heterogeneity of stand structure and composition can be created by applying such systems. Research of the nature-based forestry regimes is important to formulate a sustainable forest management.

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For studying the water flow of the lowland forest, a water and heat flow model named the SOIL-model was used [7]. Meteorological data are the driving variables of the water flow model by which the elements of the soil-forest-atmosphere hydrological cycle can be analyzed. As reference of the hydrology model, the time dynamics of the measured soil water content was used. The good agreement of the simulated and measured soil water content time dynamics in the different soil layers indicates the correctness and accuracy of the soil and plant parameter values used in the model. Consequently, the non-measured elements of the forest hydrology can be studied as well, e.g. the evapo-transpiration rate of the forest stands.

In a managed sub-mountainous beech forest, soil water content monitoring was performed, using CS615 Water Content Reflectometers, for 2.5 years. The effects of gap creation in the E-NE-facing even-aged beech stand on the soil water content and the forest regeneration was in the focus of the study.

Modeling of the beech stand hydrology has not been done yet because of the lack of meteorological data, so the recorded water content dynamics and its plant availability is evaluated and presented.

MATERIALS AND METHODS

The lowland forest study site is about in the middle of the Great Hungarian Plain, in the region of Kecskemét. The soil of the study site is Cambisol. The forest is a 40 year old Scotch pine stand where a meteorological station was built to record the insolation above and below the tree canopy, rainfall above and below the canopy and water flowing down the tree trunks, wind speed and air temperature above the tree canopy.

Hydrophysical functions of the soil were determined on core samples taken from a soil profile dug near the measured site using the standard Hungarian methods [3].

Soil water content of the lowland forest was recorded by four CS615 probes [4,6] installed vertically in the soil profile from 10 cm to 130 cm consecutively. Probe data were collected from 1st January to 31st December 1999 every hour, but only their daily average values are presented. For reference, capacitive probe measurement using the BR-150 probe [1] and the conventional oven drying method were applied on drilled soil samples. Calibration of the Campbell probes was made on the soil of the study site [5].

In between the rain events, we assumed that the change of the soil water storage is practically equal with the evapo-transpiration water loss, since in the coarse texture sandy soil there is no ground water table and deep percolation during the rainless periods. For the rainless periods, water storage changes were calculated by summing the TDR water contents at 10 cm depth increments for the 10-130 cm soil profile.

The beech forest study site is about 50 km north of Budapest at about 560 m elevation in the Börzsöny Mountains. The forest is about 80 year old. The soil is a medium or strongly eroded Haplic Luvisoil formed on andesite rock parent material with an average depth of 20-30 cm. Field capacity and wilting point water content was established using the soil water retention data for the site.

The temporal dynamics of the soil water content and plant available soil water content were studied below the closed beech canopy. Three CS615 type moisture probes were buried in the soil. Two of them were installed parallel to the soil surface, at 15 cm and 30 cm depth, the third one vertically at 10-40 cm. Hourly data recording was carried between June 2001 and October 2003. Calibration of the instrument was made in laboratory with the soil of the study site according to [5].

RESULTS AND DISCUSSION

Modeling of the water flow of the lowland Scotch pine forest soil with the SOIL model required the water retention and water conductivity data and fitting the van Genuchten function to them. The measured hydrophysical data and fitted functions are shown on Figure 1. The soil physical parameterization of the SOIL model was made using these data. The hydrophysical properties of the litter layer were also involved in the modeling [6].

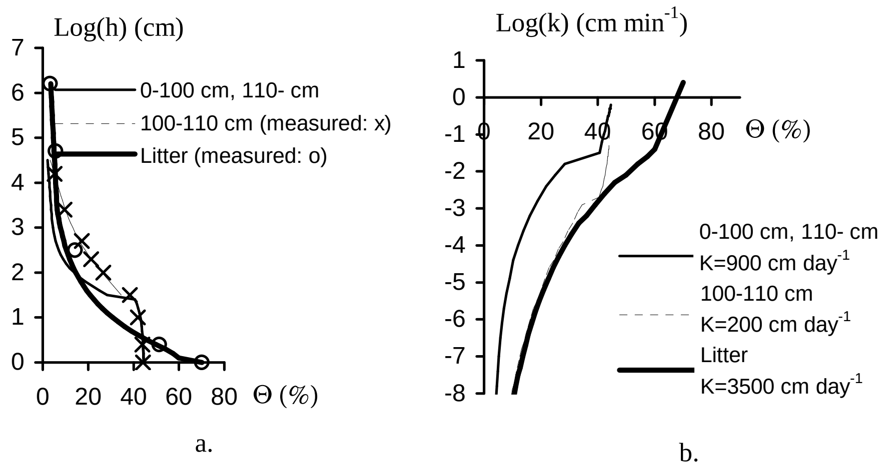

Fig. 1. The water retention (a) and water conductivity (b) data and functions of the lowland sandy soil and litter. The 100-110 cm depth is a buried humus layer in the soil profile

The recorded soil water content dynamics is shown together with the oven dried and capacitance probe water content data in Figure 2.

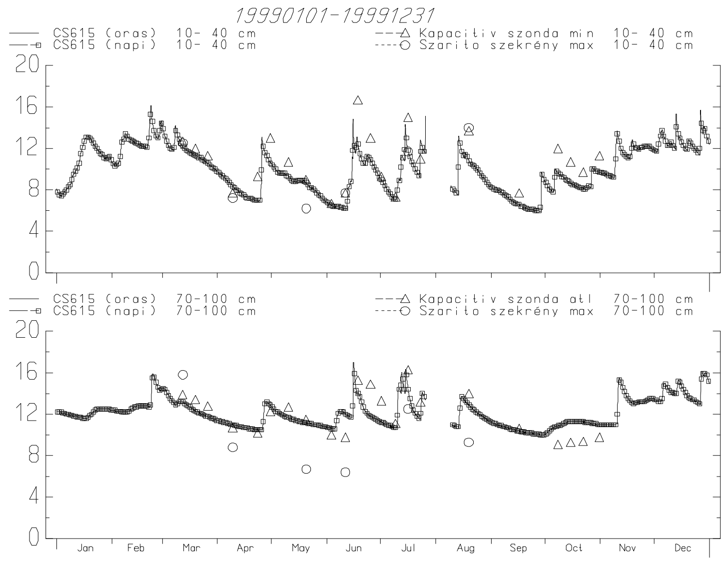

Fig. 2. CS615 (—), BR-150 (Δ) and oven dried (o) soil water content data of the Scotch pine stand

The break in the CS615 probe records was caused by an electric supply problem. The capacitance probe readings show generally good agreement with the CS615 moisture probe records, while oven dried water content data are usually lower than the electric probe readings. The reason for this can come from the difference of bulk density of the soil layers and the water content of the plant roots sensed by the electric water content measuring methods and not involved in the oven dried method that regards only for the soil. To the latter cause a higher probability is given because the difference is the highest in spring when the herb vegetation is the densest.

The water storage changes of the non-rainy periods and their daily values are given in Table 1 and shown in Figure 3. The slope of the water storage change indicates the intensity of differences of actual evapo-transpiration (ET). The average ET intensity is given as 1.1 mm day^{-1}. The ET intensity reaches the energetically possible maximum at the end of July. The weighted average of the whole period (210 days) is 1.55 mm day^{-1}, which gives a total ET as 300±20 mm. The end of the vegetation period is well indicated by the 0.2 mm day^{-1} ET intensity. Accepting this ET intensity to be valid out of the vegetation period gives about 30 mm for ET per 150 days.

The SOIL model was used to simulate the soil water content time dynamics of the 10-40 cm soil layer in order to check the validity of the soil and plant parameters used and to estimate the non measured parameters of the Scotch pine forest which influence the water cycle of the study period as e.g. the LAI, the interception, herb layer ET, etc. The quality of the SOIL model parameterization can be checked with the comparison of measured and simulated soil water content values as it is shown in Figure 4.

Table 1. Rainless periods and actual evapo-transpiration calculated from the soil water storage changes

Rainless time-periods			Length of the rainless period (day)	Change of soil water storage (in 10-130 cm)	Actual evapotranspiration	
					(mm)	(mm day^{-1})
03.09.	–	04.12.1999.	35	–42.9	42.9	1.2
05.06.	–	05.11.1999.	6	–5.1	5.1	0.9
05.24.	–	05.31.1999.	8	–8.4	8.4	1.1
06.25.	–	06.29.1999.	5	–9.9	9.9	2.0
07.02.	–	07.06.1999.	5	–8.4	8.4	1.7
07.16.	–	07.22.1999.	7	–35.4	35.4	5.1
08.24.	–	08.29.1999.	6	–9.0	9.0	1.5
09.05.	–	09.17.1999.	13	–12.9	12.9	1.0
10.08.	–	10.23.1999.	16	–3.3	3.3	0.2
10.28.	–	11.08.1999.	12	–2.7	2.7	0.2

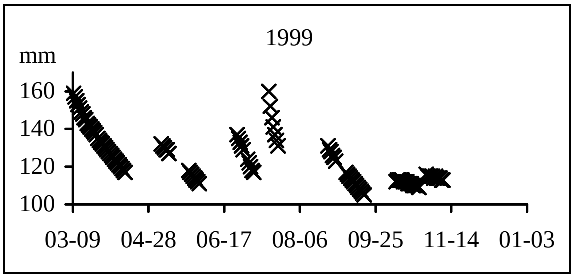

Fig. 3. The actual evapo-transpiration rates in between rain events of the Scotch pine stand

In Figure 4 (a) and (b) it is seen that measured soil water contents are generally lower than the simulated ones. The only exception is the first two months of the year when winter snow melting caused the higher measured water content. It was not considered in the simulation that the amount of snow that fell in the simulation period was less then the melted snow that fell in the previous year [6]. The agreement of the measured and simulated soil water contents of both soil layers was within the acceptable measurement error of < 2%. The difference of measured and simulated water contents was higher than 2% in August when high amount of rain fell. The difference can be attributed to the macropore flow rate, the lower water holding capacity of the soil, and its higher water conductivity that may result in smaller water content. To verify this assumption further specific measurements are required.

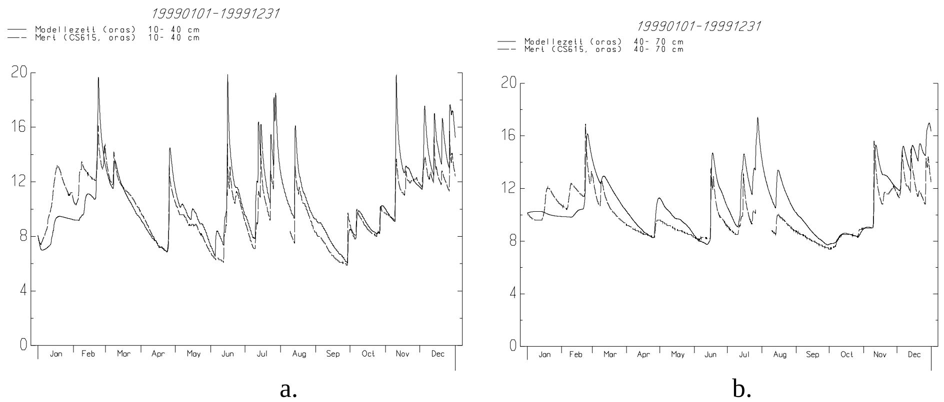

Fig. 4. The measured TDR and simulated soil water content time dynamics of the 10-40 cm (a) and 40-70 (b) cm soil layers

In the beech forest study site, the CS615 probes also detected the period time. The soil specific calibration is important because it can differ considerably from the calibration given by the producer as it is shown in figure 5 for the beech forest study site.

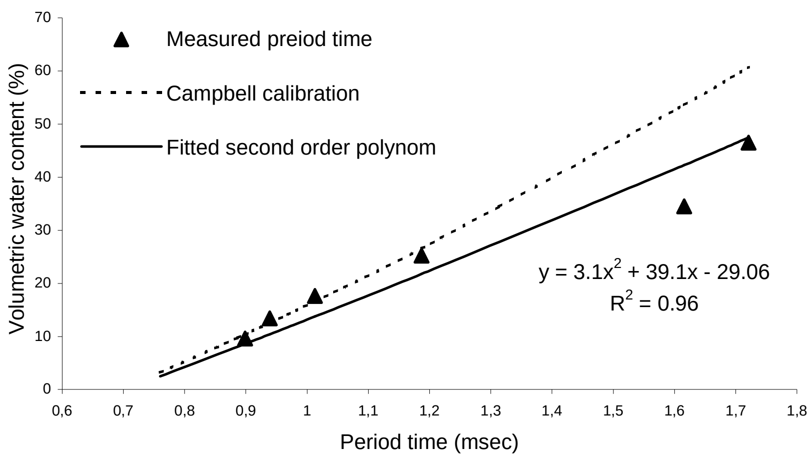

Fig. 5. The CS615 sensor calibration curve for the soil of the beech forest study site

The measured soil water content time dynamics is shown in Figure 6. From the figure one can see that the vertical probe record is almost identical with that of the horizontal probe at 30 cm depth. However the soil moisture content records at 15 cm depth are higher showing the increasing water saturation toward the soil surface.

From the measured soil water contents the usable or plant available soil water storage of the 10-40 cm soil layer was calculated (Fig. 7). When the soil water storage approximates the wilting point water storage, the water availability for plants is strongly limited or not possible at all. When the plant available water storage decreases below 10 % plants suffer from water shortage [2].

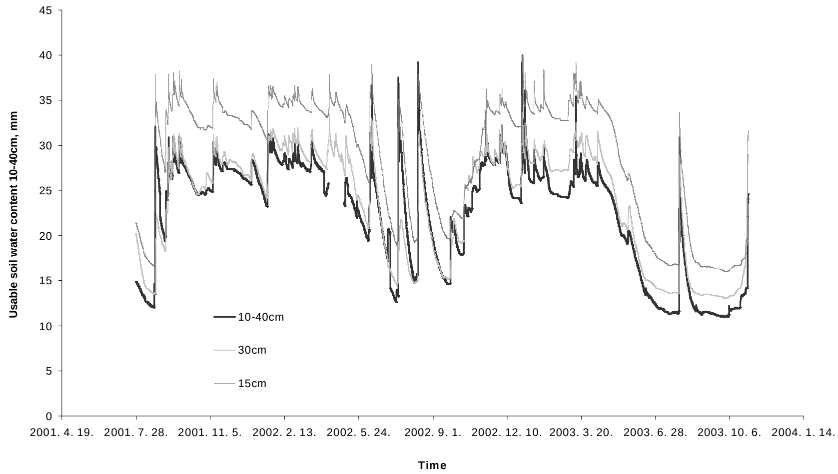

Fig. 6. The CS615 recorded soil water content dynamics in the soil of the beech forest study site

From Figure 7 it can be seen that the amount of plant available soil water is sufficient in most of the growing periods. It decreases during spring and summer periods. In summer there were periods when its amount decreased below 10 mm.

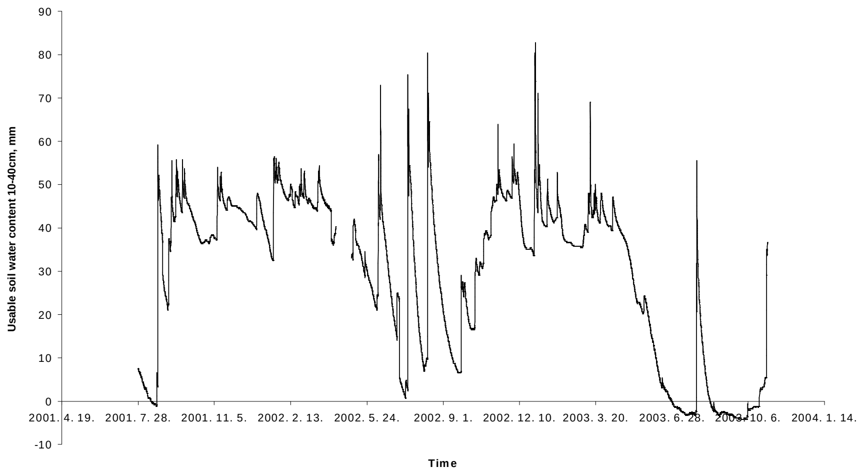

Fig. 7. The plant available soil water storage of the beech forest

CONCLUSION

Electric methods for measuring the soil water content time dynamics in different natural systems, such as managed forests, are suitable. The CS615 TDR moisture probe applied gave realistic water content data about the soils of forest stands of Scotch pine and beech in two very different environments – lowland sandy soil and shallow Luvisoil formed on andezite rock on a hill slope. The measured soil water content dynamics itself is useful to derive information on the amount of plant available water storage of the soil and the water use intensity of the forest stand.

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DYNAMIKA ZAWARTOŚCI WODY GLEBOWEJ STANOWISK LEŚNYCH W BADANIACH METODĄ TDR ORAZ MODELOWANA MATEMATYCZNIE

Zsolt Gácsi[1], Kálmán Rajkai[2], Andrea Hagyó[2]

[1]Kiskunság Forest Manager Ltd., H-6000 Külső Szegedi u.135, Kecskemét, Wegry
[2]Instytut Gleboznawstwa i Chemii Rolnej, H-1525 P.O.B. 35, Budapest, Wegry
e-mail: krajkai@rissac.hu

Streszczenie. Prowadzono monitoring zawartości wody glebowej w strefie korzeniowej dwóch różnych gleb leśnych w celu określenia charakterystyki bilansu wodnego stanowisk leśnych. W celu weryfikacji zmierzonych wartości zawartości wody, stosowano kalibrację mierników wilgotności oraz dokonywano pomiarów na próbkach kontrolnych. Zmierzoną dynamikę zawartości wody glebowej symulowano przy użyciu modelu wody glebowej i ciepła. Przeprowadzono analizę bilansu wodnego stanowisk leśnych oraz jego aspektu zarządzania obszarami leśnymi.

Słowa kluczowe: dynamika zawartości wody glebowej, miernik wilgotności, modelowanie zawartości wody glebowej