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CHANGES OF SOIL MOISTURE IN THE UNSATURATED ZONE DURING RAINLESS PERIODS IN THE MARTEW FOREST AREA

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Abstract

The paper presents changes of volumetric soil moisture during rainless periods in the area covered by the sixty year-old pine stand. The analysed area is located in the Tuczno Forest District, the Martew Forest Area in the north-western part of Poland. The calculations were based on the measurements of volumetric soil moisture at seven different depths below the ground level (to the depth of about 7 m). A set of probes was installed in the unsaturated zone for moisture measuring, using TDR method (Decagon Devices Em5b-ECH2O), in order to calculate volumetric soil moisture changes in the unsaturated zone. Volumetric soil moisture measurements used in this work were calculated at daily intervals during rainless periods in the years 2013-2016. The variability of volumetric soil moisture during the rainless periods was registered only at the shallowest level (0.85 m below the ground level). On deeper levels over relatively long (more than 20 days) rainless periods these changes are negligible. The Authors suggested the Weibull equation to describe the changes of volumetric soil moisture at shallow levels during the rainless periods.

Keywords: forest volumetric soil moisture, rainless period, the Martew Forest Area

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INTRODUCTION

Soil retention results from water holding in the saturation and the unsaturated zone of the soil profile. The amount of water reserve in soil reveals both short term and long term variability. Short term changes are the response to the weather conditions: increases follow precipitations, whereas losses are mainly connected with water use by the tree stands for transpiration and evaporation from soils. Long term changes are connected with biometric stand properties, which are changing during its subsequent development phases. A change of retention in the saturated zone is connected with a change of the state of groundwater which is measured regularly. Retention changes in the unsaturated zone are usually measured to the depth of 1m, in so called rhizosphere. Moisture measurements in deep profiles are conducted rarely, whereas on-going measurements in deep profiles are extremely rare (e.g. Ray *et al*. 2010, Guderle and Hildebrand 2015). Changes of soil moisture, like changes of the state of groundwater are inversely proportional to the depth (Chang 2012). Some premises in the literature of the subject indicate, that trends concerning soil moisture for the analysed data over the last year reveal decreasing tendencies (Chiew, McMahon 1993, Khambhammettu 2005, Robock *et al*. 2005, Keshavarz *et al*. 2011, Dorigo *et al*. 2012).

The paper aims to analyse changes of volumetric soil moisture at various depths of the forested area during the rainless periods.

Generally, on a global scale no measurements of soil moisture are conducted in situ, usually the values simulated from climatic models are used (mainly for a one meter layer) (Somorowska 2008). Selected information about the global data base is to be found among others in the paper by Li, Robek and Wild 2007.

The researched object presented in this paper was organized for realization of the project : Estimating net flows of carbon dioxide exchanged between forest ecosystem on former farmlands and the atmosphere using spectroscopic and digital measurement methods (OR-2717/27/11 Dyrekcja Generalna Lasów Państwowych). The project comprises several specific tasks, including among others hydrological processes in the balance vertical profile. Literature of the subject comprises many papers, which are overviews containing comparisons of various moisture measurement techniques (e.g. Walker *et al*. 2004, Leciejewski 2009, Skierucha *et al*. 2012). Vast majority of authors point to TDR methods as the optimal. However, presented results of this method application refer mainly to moisture measurements in shallow soil profiles (e.g. Skierucha *et al*. 2012 – measurements to the depth of 0.5m).

The paper aims to analyse soil moisture changes of volumetric at various depths of the forested area during the rainless periods. The analysed soil profile is unique because of its particle size homogeneity. The whole 8-meter-thick top layer (to the floor of permeable layer) was composed of loose sand, except the several centimetre thick underbrush.

DESCRIPTION OF RESEARCHED OBJECT

The researched area is located in the north-western part of Poland in the Tuczno Forest District, Martew Forest Area. Concerning the administrative division, the area is situated in the Wielkopolskie and Zachodniopomorskie provinces in the Drawinski National Park protection zone. The area is not much urbanized and the forest complexes are dense (http://www.tuczno.pila.lasy.gov.pl). Formerly, this area was used as farmlands, currently after the afforestation it is covered by the sixty-year-old pine stand growing on a fresh forest site. Pine (*Pinus sylvestris* L.) constitutes 99% of the stand species composition. The other 1% is composed of an admixture of silver birch (*Betula pendula* Roth.). The underbrush is composed of beech trees (*Fagus sylvatica* L.) and the hornbeam (*Carpinus betulus* L.) (Chojnicki *et al*. 2009). The soils were identified as proper rusty soil, and rusty gley soil in some places, deposited on loamy sand (Urbaniak *et al*. 2014). Physical, chemical and water properties of soils were described in detail in the paper by Krysztofiak-Kaniewska *et al*. (2016). Climatic description of the mezoregion where the studied object is situated is presented in the paper by Krysztofiak-Kaniewska and Miler (2013)

METHODS

A 34m high measurement tower was erected in the center of the studied object (53°11’33.65”N;16°5’50.15”E). Eddy covariance measurement system (CSAT3 anemometer Campbell Sci and LI-7500 –Licor gas analyser) were installed on its top (Handbook …2004), which among others measured evaporation, as well as two pluviometers (A-ASTER and Vaisala). On a standard height of 1m, 13 A-ASTER pluviometers were installed. A well of concrete rings with diameters of 1m was dug to the depth of 8 m below ground level (b.g.l), in which 7 reflectometers CS616 (sensors) were installed for on-going measurements of volumetric soil moisture using TDR method (Evertt 2003, Jones *et al*. 2002) on the levels of 0.85, 2.00, 3.15, 4.30, 5.50, 6.55 and 7.25 m b.g.l. Additionally, continuous measurements of soil volumetric moisture are conducted in the soil pit on the levels of: 0.11, 0.31, 0.51, 0.81 and 1.31 m b.g.l., using the same TDR method. Due to different conditions of measurements in the well (isolated sensor system) and in the soil pit, present paper analysed only the results for the sensors placed in the well. In order to analyse potential runoff by saturated zone, 3 drilled wells were made in the runoff transect, in which Mini-Diver sensors were installed. Continuous measurements of the air temperature and humidity (Vaisala

WXT520), radiation balance (Hukseflux NR01) and soil heat flux (Hukseflux HFP01) are conducted. All data are recorded on Campbell Sci. CR5000 and CR 1000recorders as average values in 30-minute time intervals. A detailed description of the conception, the scope and place of the measurement were presented in the papers by: Chojnicki (2009), Krysztofiak-Kaniewska and Miler (2013) and Urbaniak *et al*. (2014).

Measurements of volumetric soil moisture are conducted using time domain reflectometry (TDR) by means of specialist equipment (Decagon Devices Em5b-ECH2O set, Campbell SCi. CS16 probe) factory calibrated for forest conditions on respective objects. The methods assumes measurement of the speed of electromagnetic wave propagation along the probe rods placed in the soil. The speed depends of the dielectric constant of the medium. Relative (to the vacuum) dielectric constant of water is c.a. 80 (changes with the temperature), whereas a dielectric constant of soil solid phase is between 3 and 6. Therefore, the value of soil dielectric permittivity determined water content.

For the 60-year-old tree stand growing on the studied object, the interception value was computed on the basis of measured rainfall values above and under the canopy for several dozen rainfall episodes. The value is 3.26mm (Urbaniak *et al*. 2015.) So, it may be assumed that single rainfall episodes with a summary value of below 3mm do not feed the soils, therefore do not break the rainless period understood in this way.

Assessment of the meteorological conditions in the years 2013-2016 was presented on the basis of precipitations and air temperatures noted in Wałcz over the last thirty years. The researched object is situated about 30 km from Wałcz. It was assumed after Kaczorowska (1962), that the yearly precipitation total is standard, if ranges from 90 to 110% of mean precipitation total for the reference period. Similar assumption was adopted for average annual air temperatures. Additionally the studied period was assessed using Sieljaninov's *HTC* hydrothermal index, which according to Kuchar *et al*. (2017) is a very simple and at the same time good drought indicator. The index was computed for the June-September months according to the equation:

$$HTC = \frac{10 \cdot P}{\sum T_i} \tag{1}$$

where: P – total precipitation [mm],
T_i – mean daily air temperature [^{0}C].

When *HTC* values remains between 1.3 and 1.6, a given period is optimal, whereas the values from the range of 1.0 to 1.3 indicate a dry period (Kuchar *et al*. 2017).

The analysed rainless periods were characterised by mean air temperature and rain deficit (*D*) which is a modification of a climatic balance (*P-EP*) defined as a difference between precipitation totals (*P*) and potential evapotranspiration. The change relied on replacing potential evapotranspiration (*PE*) by real evapotranspiration (*RE*) measured directly on the experimental object.

Analyses presented in the paper used mean daily values of volumetric soil moisture computed for six selected rainless episodes from the years 2013-2016. The following were assumed: the episode must be longer than 20 days and the single rainfall during that period cannot be higher than 3 mm. The second limitation results from the fact of estimated interception for the analysed object.

The Authors suggested the Weibull equation to describe the changes of volumetric soil moisture during the rainless periods. Weibull equation is a generalised Maillet equation, usually suggested for the description of ground water recession state. Weibull equation assumes the following form:

$$\theta = a - b \cdot exp(-c \cdot t^{d}) \tag{2}$$

where: θ – volumetric soil moisture [-],
t – day,
a, b, c, d – parameters.

RESULTS

Considering the investigated period, the year 2015 was a dry year, whereas the other 3 years should be regarded as average as to precipitations. The years 2014 and 2015 belong to warm, whereas the years 2013 and 2016 to average in terms of the air temperatures. Hytrothermal index of Sieljaninov *HTC* indicates that the three first years should be treated as dry, whereas the year 2016 as optimal (Table 1).

Table 1. Meteorological characteristic of investigated year

Year	Total precipitation	Mean air temperature	Hydrothermal index of Sieljaninov *HTC*
	P [mm] (Percentage of average)	*T* [^{0}C] (Percentage of average)	
2013	630 (104%)	9.0 (101%)	1.23
2014	599 (99%)	10.5 (118%)	1.17
2015	535 (88%)	10.2 (115%)	1.25
2016	608 (100%)	8.7 (97%)	1.50

The highest daily volumetric soil moisture variability was registered for the measurements conducted on the researched object in the years 2013-2016, on the levels of 0.85 and 2.00 m below the ground level (b.g.l.) – respectively 0.060 and 0.033 [-] ([cm^3/cm^3]). On the other hand the variability on the deepest levels 6.55 and 7.25 m b.g.l. was only 0.005 [-] (Krysztofiak-Kaniewska *et al*. 2016).

Characteristics of the analysed rainless episodes was presented in Table 2.

Table 2. Characteristic of rainless episodes

Rainless Episode	Period	Number of days	Mean of air temperature	Deficit of precipitation
			T [^{0}C]	D [mm]
1	09.09-13.10.2014	35	14.0	25.4
2	02.04-08.05.2015	37	11.4	47.7
3	18.05-19.06.2015	33	15.9	61.3
4	26.07-31.08.2015	37	20.8	46.9
5	21.09-14.10.2015	24	11.0	23.1
6	05.09-30.09.2016	26	17.0	36.7

Table 3. Value of Weibull equation parameters for analysed rainless episodes

Rainless episode	Parameter				Standard error S	Correlation coefficient R
	a	b	c	d		
1	0.08309	0.07276	3.127	-0.3619	0.0013	0.9864
2	0.09751	0.08859	2.813	-0.2562	0.0007	0.9935
3	0.07177	0.1666	6.762	-0.3522	0.0004	0.9989
4	0.06906	0.06182	4.954	-0.5281	0.0004	0.9989
5	0.05724	0.05347	2.886	-0.2766	0.0006	0.9898
6	0.08333	0.1392	4.144	-0.3051	0.0006	0.9975

Figures 1-6 present average measured daily values of the relative volumetric soil moisture on the seven depths 0.85, 2.00, 3.15, 4.30, 5.50, 6.55 and 7.25 m b.g.l., respectively for the six selected rainless periods – episodes. It is easily perceivable that the moisture variability occurs practically only on the 0.85 m level, in the rhizosphere actively participating in the transpiration.

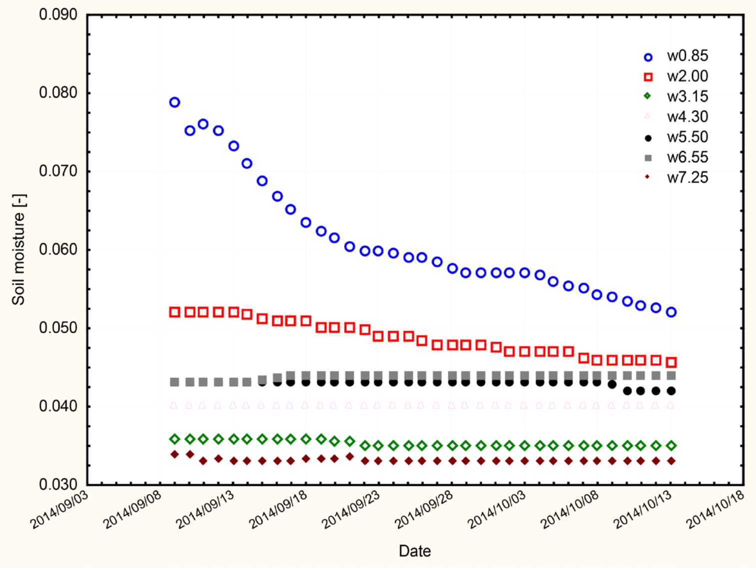

Figure 1. Changes of average daily volumetric soil moisture at episode 1– 35-day rainless period Designations: w.085, w2.00, w3.15, w4.30, w5.50, w6.55 and w7.25 – soil moisture at the depths: 0.85, 2.00, 3.15, 4.30, 5.50, 6.55 and 7.25 m.

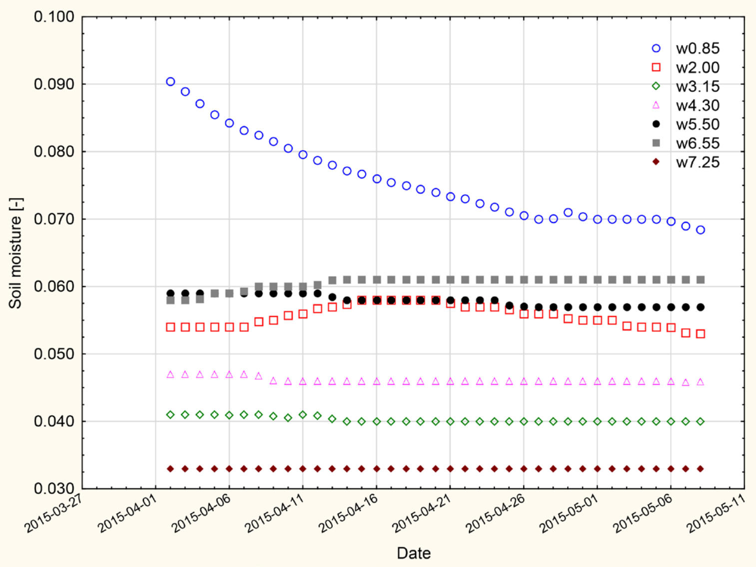

Figure 2. Changes of average daily volumetric soil moisture at episode 2– 37 – day rainless period; Designations as on Fig.1.

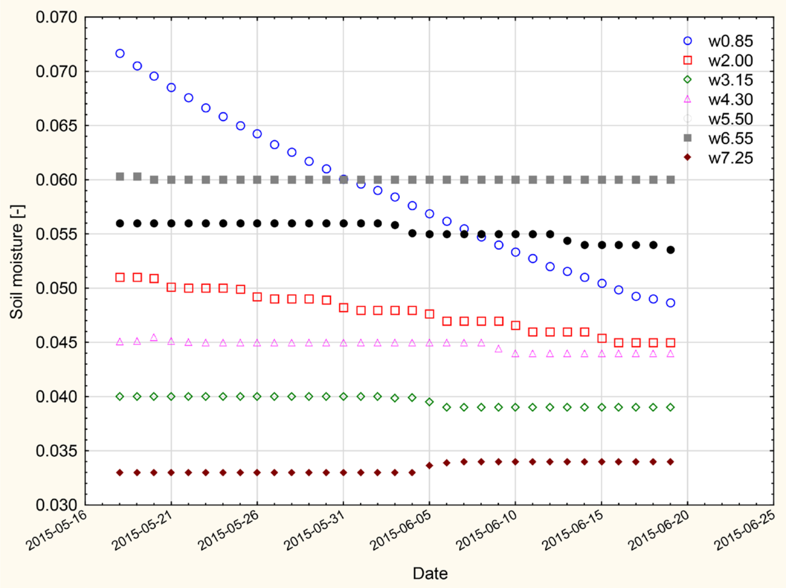

Figure 3. Changes of average daily volumetric soil moisture at episode 3 – 33-day rainless period; Designations as on Fig.1.

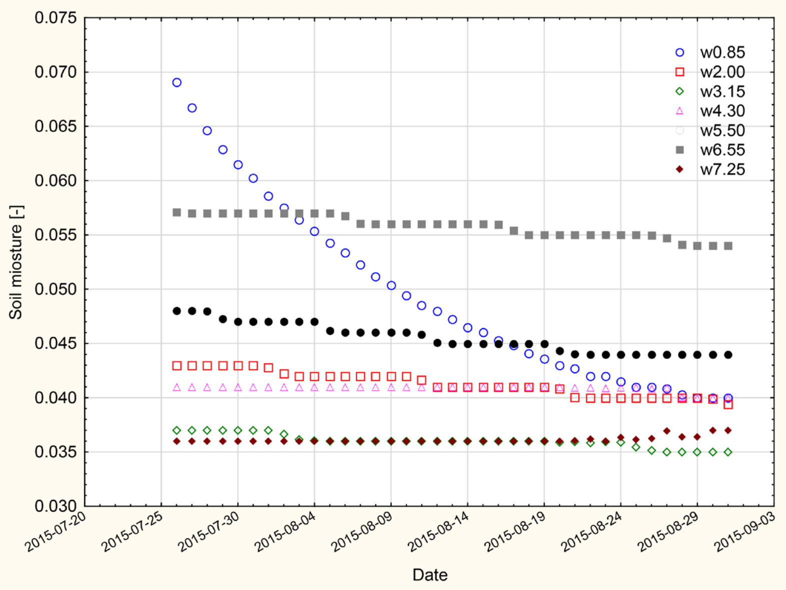

Figure 4. Changes of average daily volumetric soil moisture at episode 4– 37-day rainless period; Designations as on Fig.1.

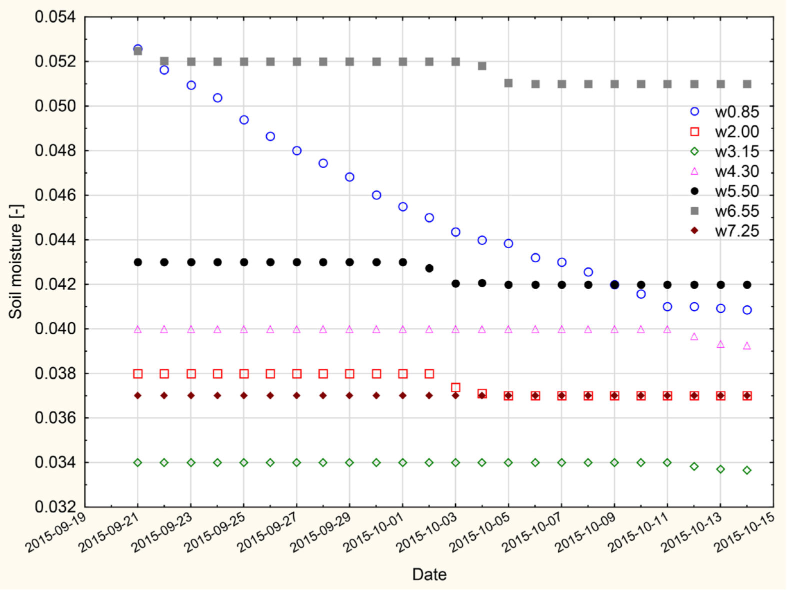

Figure 5. Changes of average daily volumetric soil moisture at episode 5– 24 day rainless period; Designations as on Fig.1.

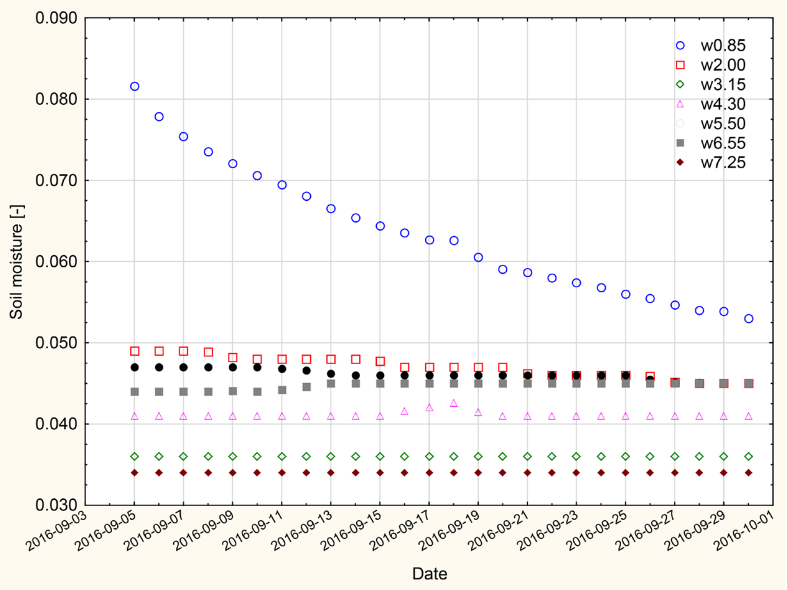

Figure 6. Changes of average daily volumetric soil moisture at episode 6– 26-day rainless period; Designations as on Fig.1.

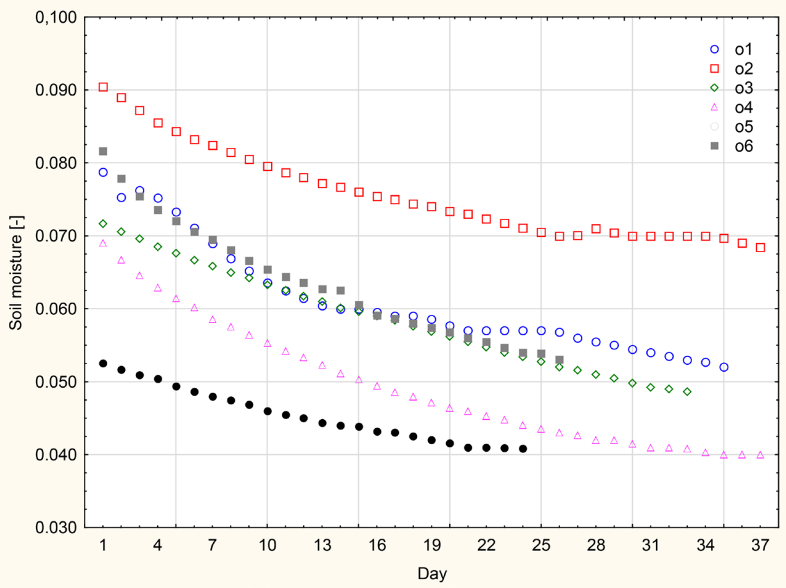

Figure 7. Changes of average daily volumetric soil moisture in six analysed rainless episodes at the depth 0.85 m below ground level

Figure 7 shows collectively the variability of moisture on the shallowest level for the six above mentioned episodes. Recession curves for the volumetric soil moisture on the level of 0.85 m may be described by Weibull equation. Numerical values of parameters *a, b, c, d*, standard error *S* and correlation coefficient r computed using CurveExpert ver. 1.4 programme were compiled in Table 3.

SUMMARY AND CONCLUSION

Variability of volumetric soil moisture during the rainless periods was observed practically only on the shallowest level (0.85 m b.g.l.). On the deeper levels and over relatively long rainless periods (more than 20 days) the changes are negligible (Table 4). Considering the fact that the whole analysed soil profile to the floor of the permeable layer (8 m b.g.l.) is genetically quasi-homogenous (loose sand), the result may be generalized, since there are no disturbances in water movement connected with possible interbeddings in the soil profile.

Table 4. Mean relative change of soil moisture during rainless episodes

Depth	Mean relative change of soil moisture
[m] b.g.l.	[%]
0.85	40.3
2.00	7.9
3.15	2.9
4.30	2.3
5.50	4.3
6.55	3.0
7.25	2.7

Weibul equation suggested for the description of volumetric soil moisture variability during the rainless periods on shallow levels seems justified, which has been indicated by low value of standard errors and high correlation coefficients (Table 3).

The fact of decreasing soil moisture variability with depth is generally known in respect of quality. The land use is not without importance, either (Biniak 2004). Present paper indicated a relative quantitative variability of volumetric soil moisture during rainless periods on various levels in a deep soil profile. It is impossible to compare the results with those obtained by other researchers because the Authors do not know the results of on-going measurements of soil moisture on the levels deeper than 2.20m b.g.l (Guderle and Hildebrand 20150.

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