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COMPARISON OF WATERMARK SOIL MOISTURE CONTENT WITH SELYANINOV HYDROTHERMAL COEFFICIENT

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ABSTRACT

Agricultural producers to determine irrigation scheduling practices for crop‘s water requirement better when the soil water content of their fields is known. Selyaninov Hydrothermal Coefficient (*HTC)* coefficient is used for identifying droughts during the active vegetation period, based on the water balance equation. For farmers to make measurements of soil moisture is simply with humidity sensors, for example *Watermark* type. Soil humidity values established using *Watermark* type humidity sensors, value interpretations are based on manufacture indications, however they have not been adapted to Lithuanian conditions. Soil moisture was measured with *Watermark* soil moisture sensors placed at 20 and 50 cm depths. After analysing the values taken throughout the whole period and summarizing the results it has been identified that plant growth condition period evaluation according to *HTC* and factual soil humidity reserves (*W*) differs by 20%. *HTC* meaning dependencies during vegetation period using *Watermark* measured humidity, strong or averagely strong interrelation is determinate, in most cases – statistically significant. When evaluating soil humidity reserves based on soil texture, it is recommended to keep the critical *Watermark* level in light texture soil (sands) at 80 cbar, and in all other types of soil - at 150 cbar. The results clearly indicate that soil composition could be factors limiting the success of identifying droughts in agriculture carried by *Watermark* type humidity sensors.

Keywords: *agriculture droughts, humidity, soil moisture, Lithuania.*

INTRODUCTION

Drought or water deficit stress is the major environmental factor that negatively impacts agricultural yield throughout the world (Selote, Khana-Chopra, 2004). Droughts and their consequences cause substantial damages and losses to the sectors of agriculture, energy, nature, they have significant social and other impacts (Wilhite et al., 2000). Climate change affects water availability not only by changing regional precipitation levels and temporal variability, but also by affecting water flows and soil moisture dynamics (Holsten et al., 2009). An efficient irrigation system should meet crop demands for water. A limited water supply may result in reductions in yield, while excess irrigation is a waste of resources. To investigate water availability throughout the growing season, on-the-go sensing technologies (field elevation and apparent electrical conductivity) were used to analyse the spatial variability of soil relevant to its water-holding capacity (Pan et al., 2013). Soil moisture sensing network is used to monitor the moisture contained in soil and help irrigation decisions in drip irrigation systems. Evapotranspiration is directly linked to soil moisture from one part and to crop yield from the other part (Eagleson, 1994). Irrigation scheduling is crucial to effectively manage water resources and optimize profitability of an irrigated operation. Tools that can be customized to a field's characteristics can greatly facilitate irrigation scheduling decisions (Aguilar et al., 2015). Drought indices have been developed by several generations of researchers during the XX century in the domains of meteorology, hydrology, agricultural research and application, remote sensing, and water resources management. More than 80 drought indices have been easily identified, and probably the total number of drought indices is close to double (Niemeyer 2008). The wireless sensors networks are actually used in the agriculture field to monitor the climate, the crops, the control of the crop inputs and the irrigation supply. A good control of these parameters would make it possible to the farmers to carry out proactive actions in order to better improve the crop yield (Diaz et al. 2011, Garcia-Sanchez et al. 2011, Lopez et al. 2009, Wark et al. 2007). The use of soil moisture sensors, like the granular matrix and those based on the time and frequency domain reXectometry, has increased in the last decades since advances in electronics and computers applied to agriculture enable better soil water monitoring (Hilhorst and Dirksen 1994; Girona et al. 2002). Errors in soil moisture measurements (or other methods of soil moisture determination) require that irrigation commences at a higher threshold of the measured soil moisture content, so that with a given statistical probability (coincidence level), the true value of soil moisture content is not lower than the threshold. A 'true value' of soil moisture content needs to be defends. Here, the total amount of water that is in the soil volume within reach of the roots of one plant, divided by that volume, is intended. Scheduling irrigation by soil moisture sensors should not be done without carefully considering the measurement uncertainty (Schmitz, Sourell, 2000). Rapid progress is being made in transmitting sensor data, obtained from different depths down the soil profile across irrigated areas, to a PC that processes the data and on this basis automatically commands irrigation equipment to deliver amounts of water, according to need, across the field (Greenwood et al., 2009). *Watermark* sensors allow for multiplexed, automated, in situ measurements for determining changes in soil water content and the onset of wetting fronts when such occur abruptly in the field. The system described here proved reliable, effective, and cost efficient, exhibiting only minor problems (Light, 1990). The *Watermark* sensor has proven to work quite well in both the clay and sandy soils, however because it does not have an indicator light on the sensor control next to the controller, it took most of the summer to tweak it to operate at acceptable levels (Mecham, 2006). McCann et al. (1992) noted that three to six *Watermark* granular matrix sensors placed at a given location should yield matric potential within 10% of the actual value with a 90% confidence interval. The dynamic response of the sensors can vary with changing soil moisture. Agricultural producers to determine irrigation scheduling practices for crop‘s water requirement better when the soil water content of their fields is known. G.T. Selyaninov suggested using the hydrothermal index for agrometeorological problems. This index has been widely used in practice till now. It has many different modifications for specific territories. The index considers the water budget input and moisture evaporation from the surface of a territory under study. It is easily calculated. However, it characterizes only wetness, without considering stored soil moisture (Utkuzova et al., 2015). The Selyaninov hydrothermal coefficient (HTC) is used as the primary climate variable, which includes not only precipitation, but also temperature during the vegetative period (Melkonyan, Asadoorian, 2013). In Lithuania HTC is used to identify the droughts. This index also was used in all former USSR territory in previous decades by forestry, agricultural and hydrology specialists for long time (Meshcherskaya and Blazhevich, 1996). *HTC* is used Lithuania for identifying droughts during the active vegetation period, based on the water balance equation. For farmers to make measurements of soil moisture is simply with humidity sensors, for example *Watermark* type. Soil humidity values established using *Watermark* type humidity sensors, value interpretations are based on manufacture indications, however they have not been adapted to Lithuanian conditions. The main goal of this study is to evaluate the *HTC* links with soil humidity measurements carried by *Watermark* type humidity sensors and the possibility of applying it for identifying droughts in agriculture.

MATERIAL AND METHODS

The experimental plots are located across the Lithuania (Figure 1).

Figure 1. Objects area location

Meteorological conditions have been explored in hydro-meteorological stations of the Lithuania Hydro meteorological Institute located in the catchment surroundings. Sampling was done each day May to September during 2013. The object basic characteristics are given in Table 1.

Table 1. Characteristics of objects

Object No.	Soil	Precipitation during the year (mm)	Thermal conditions of summer ($\Sigma T > 10°C$)	Wilting moisture, %
1.	Dusty, heavy loam	500 - 600	2100 - 2200	9,1-10,2
2.	Averagely heavy gravel loam	500 - 600	2100 - 2200	5,6-6,9
3.	Heavy loam	500 - 700	2000 - 2200	9,1-10,2
4.	Averagely heavy clay	650 - 750	2200 - 2300	9,5-10,2
5.	Sand	700 - 800	2000 - 2200	4,4-6,4
6.	Alluvial clay	700 - 900	1900 - 2000	7,9-9,1
7.	Averagely coarse sand	600 - 700	2100 - 2300	6,4-6,6

Soil humidity measurements have been carried out using *Watermark* (*W*, *cbar*) humidity sensors. Soil moisture was measured with *Watermark* 200 SS soil moisture sensors (USA) placed at 20 (*W*20) and 50 (*W*50) cm depths.
The Watermark soil moisture block is sold as a qualitative indicator of soil moisture for applications such as irrigation scheduling. It consists of two concentric electrodes embedded in a porous matrix containing a soluble salt (CaSO4), so that the water in the porous matrix is always gypsumsaturated. Lead wires are connected to the electrodes so that the electrical resistance of the porous medium can be measured. The device is encased in a synthetic membrane supported by PVC plastic. This presumably confers a life expectancy longer than that of gypsum blocks, which dissolve over time (Egbert, 1992).
Complex indicators give more comprehensive characteristics. In order to get a more complete analysis of thermal and rainfall conditions, the relative (non-dimensional) indicator known as G. T. Selyaninov's hydrothermal coefficient (HTC) (Gathara at al., 2006):

$$HTC = R / 0.1 \Sigma T,$$

where R is the total precipitation for the period having an average air temperature of greater than 10° C;
ΣT is the sum of average daily air temperatures for the same period, which is divided by 10, giving a figure that characterizes evaporation quite well.

HTC meaning scale is divided into 3 groups which are most relevant to drought, optimal and rainy period soil according to recommended interpretations by *Watermark*. Aiming at identifying interlinked connections the *HTC* meanings have been compared to *Watermark* type sensor results. *HTC* and *Watermark* meaning comparison is presented in Table 2. Correlative analysis is used for statistical evaluation of the study data (5% significance level).

Table 2. *HTC* and soil humidity (based on *Watermark* sensors) value interpretation

Group	*HTC*	*Watermark*
Wet	>1,5 (Wet)	<11 cb (Wet)
	1,0 - 1,5 (Sufficiently humid)	11 – 29 cb (Humid/ averagely wet)
Optimal	0,8 - 1,0 (Insufficiently humid)	30 – 60 cb (Optimal)
Dry	0,6 - 0,7 (Arid)	60 – 100 cb (Arid)
	0,0 - 0,5 (Dry)	100 – 200 cb (Dry)

Differences were considered significant if $P< 0.05$. Correlation analysis (r) was used to determine the relationship between the humidity sensors *Watermark* in 20 cm or 50 cm depth and *HTC*.

RESULTS AND DISCUSSION

When analysing the *HTC* meaning dependency during vegetation period using humidity measurements *W, cbar* quantity at 20cm depth taken using *Watermark*, the average strength interrelationship has been achieved No. 2 (r = 0.54), No. 3 (r = 0.51), No. 6 (r = 0.46) at 20 cm depth, and the average strength interrelationship has been achieved No. 1 (r = 0.61), No. 4 (r = 0.63), No. 5 (r = 0.74), No. 6 (r = 0.74), No. 7 (r = 0.55), a strong relationship is present at No.3 (r = 0.78). The standard variance in all stations contains more than 20% of the arithmetical average, so, the spread of the results is very wide, but the results are statistically important at objects No. 2, No. 3 and No. 6 at 20 cm depth and at all objects - at 50 cm depth (Table 3).

After analyzing the values taken throughout the whole period and summarizing the results it has been identified that plant growth condition period evaluation according to *HTC* and factual soil humidity reserves (*W*) differs by 20% (Fig. 2). McCann et al. (1992) noted that the dynamic response of *Watermark* granular matrix sensors was good during typical soil water drying cycles after complete rewetting, but was poor during rapid drying or partial rewetting of the soil. By Thompson et al. (2006), the general performance of the Watermark sensor under the given environmental and soil water conditions. The best performance of the Watermark sensor was obtained under conditions of moderate evaporative demand in moist soil.

Table 3. The results of regression analysis between *HTC* and *Watermark*

Object No.	Method	Stdev	Average	c_v	*r*		*P*	
1.	W (20)	29.18	76.14	0.38				
	HTC	0.34	0.95	0.36	-0.10		0.26	
	W (50)	13.89	107.94	0.13		-0.61		0.00
2.	W (20)	51.36	56.21	0.91			0.00	
	HTC	0.33	1.32	0.25	-0.54	-0.41		0.00
	W (50)	33.89	107.77	0.31				
3.	W (20)	58.90	93.33	0.63				
	HTC	0.40	1.20	0.33	-0.51	-0.78	0.00	0.00
	W (50)	68.10	86.19	0.79				
4.	W (20)	62.49	126.18	0.50				
	HTC	0.53	1.66	0.32	-0.07	-0.63	0.43	0.00
	W (50)	40.69	167.57	0.24				
5.	W (20)	66.11	117.50	0.56				
	HTC	0.49	1.25	0.39	-0.10	-0.74	0.26	0.00
	W (50)	25.33	69.82	0.36				
6.	W (20)	57.39	49.18	1.17				
	HTC	0.81	1.45	0.56	-0.46	-0.52	0.00	0.00
	W (50)	24.99	15.28	1.64				
7.	W (20)	32.52	38.85	0.84				
	HTC	0.27	1.29	0.21	-0.16	-0.55	0.08	0.00
	W (50)	16.14	48.12	0.34				

The Watermark may be used in soil water monitoring systems, under drier conditions than the ones measured by the tensiometer, contributing to a better understanding of the different hydrological and erosional processes acting on the hillslopes (Bertolino, 2002). Drought occurs when moisture around the roots is so drought but depending on the severity and time of reduced that a plant is not able to absorb enough water, occurrence of the drought, yield reduction could reach or in other words with transpiration of water absorption 80% (Tarighaleslami et al., 2012).

Using an experiment it has been identified that dependently on soil, wilting humidity is reachable when humidity reserved in soil range from 4.4 to 10.2 % based on weight of dry soil, which according to *Watermark* device's calibration curve meets 80 to 160 *cbar* or higher value (Table 4).

After implementing the correlation, taking into consideration the values presented above it becomes evident that plant vegetation period humidity evaluation according to *HTC* and soil humidity values (*Watermark*), the values indicating the beginning of drought are matching in 50 cm depth (Fig. 2).

Table 4. Interpretation for moisture meters estimates of beginning the drought

Object No.	Moisture reserves in the soil from the dry weight of the soil, %	*W, cbar*
1.	4.4- 6.4	≥80
2.	9.1- 10.2	≥100
3.	5.6- 6.9	≥ 120
4.	7.9- 9.1	≥ 100
5.	9.5- 10.2	≥ 160
6.	6.4- 6.6	≥80
7.	9.1-10.2	≥80

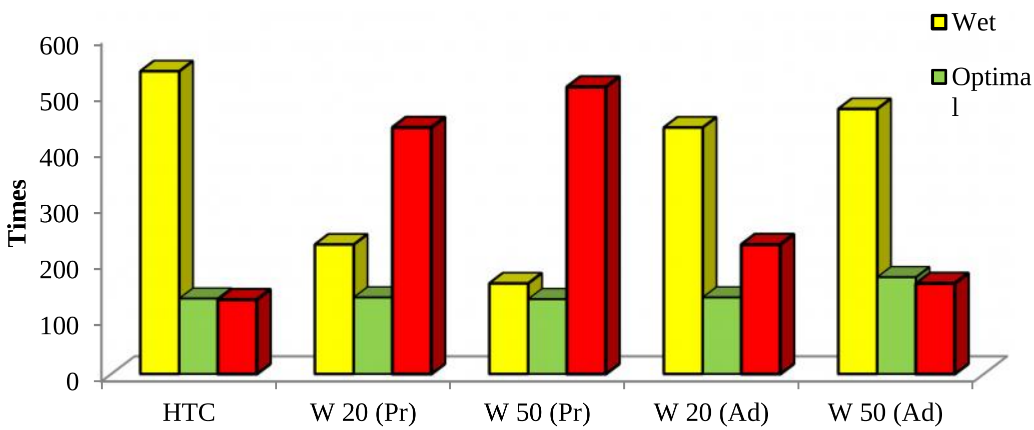

Figure 2. Matching of *Watermark* and *HTC* after a correction is made based on granulomeres texture (*Pr-producer recommendation, Ad- adjusted by soil)*

These trigger points cannot easily be related to different soils, different sensors, and other sources of information such as extension fact sheets and research publications, however, because the actual water content measurements may not be correct (Leib et al., 2003). The Watermark sensors utilized a local soil water retention relationship in order to convert soil water potential into volumetric water content. The results suggests that irrigators can still use uncalibrated sensors to improve their watering schedules by setting irrigation trigger points that may relate only to specific sensor in a specific soil.

CONCLUSIONS

When researching *HTC* meaning dependencies during vegetation period using *Watermark* measured humidity, strong or averagely strong interrelation is determinate, in most cases – statistically significant: statistically important at objects No. 2, No. 3 and No. 6 at 20 cm depth and at all objects - at 50 cm depth. Evaluating soil humidity reserves based on soil texture, and it is recommended to keep the critical *Watermark* level in light texture soil (sands) at 80 cbar, and in all other types of soil - at 150 cbar. Plant growth condition period evaluation according to *HTC* and factual soil humidity reserves (*W*) differs by 20%. Correlative analysis of the study data (5% significance level) shows that differences were considered significant. The results clearly indicate that soil composition could be factors limiting the success of identifying droughts in agriculture carried by *Watermark* type humidity sensors.

REFERENCES

Aguilar J., Rogers D., Kisekka I. (2015). Irrigation scheduling based on soil moisture sensors and evapotranspiration. Southwest research-extension center reports, vol. 1(5), pp. 1-6.

Bertolino A.V.F.A., Souza A.P., Fernandes N.F., Rangel A.M., de Campos T.M.P., Shock C.C. (2002). Comparison of the soil matrix potential using tensiometers and Watermark sensors. Available at http://www.irrometer.com/pdf/research/Comparison_soil_matrix_potential_using_tensiometers_and_WATERMARK_sensors-Brazil_soil_erosion_paper.pdf

Diaz S.E., Perez J.C., Mateos A.C., Marinescu M.C., Guerra B.B. (2011). A novel methodology for the monitoring of the agricultural production process based on wireless sensor networks. Computers and Electronics in Agriculture, vol. 76 (2), pp. 252–265.

Eagleson, P.S. (1994). The evolution of modern hydrology (from watershed to continent in 30 years), Advances in Water Resources, vol. 17, pp. 3-18.

Egbert J.A.S., John M.B. (1992). Calibration of Watermark soil moisture sensors for soil matric potential and temperature. Plant and Soil, vol. 143, pp. 213-217.

Garcia-Sanchez A.J., Garcia-Sanchez F., Garcia-Haro J. (2011). Wireless sensor network deployment for integrating video surveillance and Data-Monitoring in precision agriculture over distributed crops. Computers and Electronics in Agriculture, vol. 75 (2), pp. 288 – 303.

Gathara S.T., Gringof L.G., Mersha E., Sinha Ray K.C., Spasov P. (2006). Impacts of desertification and drought and other extreme meterological events. Word meteorological organization commission for agricultural meteorology. Report No. 101, Geneva, Switzerland, December 2006, p. 88.

Girona J., Mata M., Federes E., Goldhamer D.A., Cohen M. (2002). Evapotranspiration and soil water dynamics of peach trees under water deWcits. Agricultural Water Management, vol. 54, pp. 107–122.

Greenwood D.J., Zhang K., Hilton H.W., Thompson A. (2009). Opportunities for improving irrigation efficiency with quantitative models, soil water sensors and wireless technology. Journal of Agricultural Science, Vol.148, No.1 p. 1-16.

Hilhorst M.A., Dirksen C. (1994). Dielectric water content sensors: time domain versus frequency domain. In: Proceedings of the Symposium on TDR in environmental infrastructure and mining applications, Evanston Illinois, USA, pp. 23–33.

Holsten A., Vetter T., Vohland K., Krysanova V. (2009). Impact of climate changes on soil moisture dynamics in Brandenburg with a focus on nature conservation areas. Ecological Modelling, vol. 220, pp. 2076–2087.

Leib G.B., Jabro J., Matthews G.R. (2003). Field evaluation and performance comparison of soil moisture sensors. Soil Science, vol. 168 (6), pp. 396-408.

Light J.E., Mitchell A.R., Barnum J.M., Shock C.C., Madras O.R., Ontario O.R. (1990). Granular matrix sensors for irrigation management. Central Oregon Agricultural Research Center, and Malheur Experiment Station, pp.37-42.

Lopez R.J.A., Soto F., Suardiaz J., Sanchez P., Iborra A., Vera J.A. (2009). Wireless sensor networks for precision horticulture in Southern Spain. Computers and Electronics in Agriculture, vol. 68 (1), pp. 25 – 35.

McCann I.R., Kincaid D.C., Wang D. (1992). Operational characteristics of the Watermark Model 200 soil water potential sensor for irrigation management. Applied Engineering in Agriculture, vol. 8, pp. 603–609.

Mecham B.Q. (2006). A practical guide to using soil moisture sensors to control landscape irrigation. Available at https://watergreat.com/reference/Practical_overview_2010.pdf

Melkonyan M., Asadoorian O. (2013). Climate impact on agroeconomy in semiarid region of Armenia. Environment Development Sustainable. Available at https://www.uni-due.de/imperia/md/content/geographie/klimatologie/environment_______sustainable_development.pdf

Meshcherskaya A.V., Blazhevich V.G. (1996). The drought and excessive moisture indices in a historical perspective in the principal grain-producing regions of the former Soviet Union. Journal of Climate, vol. 10, pp. 2670–2682.

Niemeyer S. (2008). New drought indices. Options Mediterraneennes, Series A, vol. 80, pp. 267-274.

Pan L., Adamchuk V. I., Martin D. L., Schroeder M. A., Ferguson R. B. (2013). Analysis of soil water availability by integrating spatial and temporal sensor-based data.Precision Agriculture, vol. 14(4), pp. 414-433.

Schmitz M., Sourell H. (2000). Variability in soil moisture measurements. Irrigation Science, vol. 19, pp. 147-151.

Selote D.S., Khana-Chopra R. (2004). Drought-induced Spikelet Sterility is Associated with an Inefficient Antioxidant Defence in Rice Plants. Physiologia Plantarum, vol. 121, pp. 462-467.

Tarighaleslami M., Zarghami R., Boojar M.M.A., Oveysi M. (2012). Effects of drought stress and different nitrogen levels on morphological traits of proline in leaf and protein of corn seed (Zea mays L.). American-Eurasian Journal of Agricultural and Environmental Sciences, vol. 12, pp. 49-56.

Thompson R.B., Gallardo M., Aguera T., Valdez L.C., Fernandez M.D. (2006). Evaluation of the Watermark sensor for use with drip irrigated vegetable crops. Irrigation Science, vol. 24 (3), pp. 185-202.

Thomson S.J., Armstrong C.F. (1987). Calibration of the Watermark 200 soil moisture sensor. Applied Engineering in Agriculture, vol. 3(2), pp. 186-189.

Utkuzova D.N., Han V.M., Vilfand R.M. (2015). Statistical Analysis of Extreme Drought and Wet Events in Russia. Atmospheric and Oceanic Optics, vol. 28 (4), pp. 336–346.

Wark T., Corke P., Sikka P., Klingbeil L., Ying Guo C., Crossman P. V., Swain D., Bishop-Hurley G. (2007). Transforming Agriculture through Pervasive Wireless Sensor Networks. Pervasive Computing, IEEE, vol. 6 (2), pp. 50–57.

Wilhite D. A., Hayes M. J. C., Knutson K. H. (2000). Planning for drought: Moving from Crisis to risk management. Journal of American Water Resources Association, vol. 36(4), pp. 697–710.