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Quantifying the Water Flow through the Soil-Plant-Atmosphere System

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ABSTRACT
In order to quantify the flow of water in the soil plant atmosphere system by using and correlating various methods of measurements, an experimental study was undertaken. The study was carried out in the region of "The Field of Kosovo", in two climatic particular areas, Komoran and Vushtri, significantly different from each other. Meteorological stations were set up in each area and as a part of it, in each case, the evaporimeter Pan A and an atmometer were installed. Each meteorological station was equipped with the necessary devices to measure the sun radiation, relative humidity, wind speed and temperature. A particular computer program was prepared to convert automatically the data measured by the devices into potential evapotranspiration, expressed as mm evaporated water per day, calculated based on the Penman-Monteith formulae. The potential evapotranspiration calculated based on the Penman-Monteith method indicated, during the entire time of investigation, higher values comparing with the results taken from the atmometer and the Pan A evaporimeter methods. The differences were significant in both, Komoran and Vushtri.
Key words-water flow; potential evapotranspiration; Penman-Monteith formula; atmometer; Pan A evaporimeter

I. INTRODUCTION

Among various methods to calculate the potential evaporation, the Penman method [1] is considered to be more complex, physically well based [2]; [3]; [4] and as a result of this, a method widely applicable. Even more than this, the Penman method combined with the Monteith effort being summarized in the so called Penman-Monteith method [5], is already the method recommended by FAO to be used for the potential evapotranspiration computing.

To calculate the potential evapotranspiration by Penman-Monteith method, the information about sun radiation, wind speed, relative humidity and air temperature is necessary. The effort done in this study is focused on the establishing the relationships between both: the potential evapotranspiration calculated by the Penman-Monteith method and the potential evapotranspiration measured by the atmometer in an alfa alfa reference field in one hand; and the potential evapotranspiration calculated by the Penman-Monteith method and the rate of water evaporation from a free water surface of the evaporimeter Pan A [6] in the other hand. Theoretically, the relationship in each of the mentioned directions is supposed to be a causal one [7]; [8]; [9], [10] which means that the factors causing the potential evapotranspiration calculated by Penman-Monteith method are the same with those ones causing the water evaporation from either the canvas of the atmometer or from the free water surface of the Pan A evaporimeter. In this study we aim to quantify these relationships, find out the strength of the dependencies and of course, the differences among them. This effort would help us to better understand the nature and the magnitude of the water flow from soil to plant roots [11] through plant and finally, getting vaporized at the contact surface with the atmosphere.

II. MATERIALS AND METHODS

To fulfill the aim of this study, two locations were chosen in the Field of Kosovo: Vushtri and Komoran. The period of study includes about 110 days in summer time mainly, period in which it was supposed that the evapotransipration prevails to the rainfall. An experimental trial was established in each location. Each location was surrounded by a relatively large field of alfa alfa, which was kept under optimal irrigation conditions and the plants in a height of about 10 to 20 cm. The experimental trial was comprised of a digitalized meteorological system by which the sun radiation, the wind speed, the relative humidity and the air temperature were continuously measured producing the magnitude of ETp, calculated based on Penman-Monteith method and memorized automatically in the computer. An atmometer was also installed in each location having a canvas imitating the plant of alfa alfa. The atmometer was situated in the middle of the field planted with alfa alfa as it is described above. Before using, the atmometer was calibrated by the method of continuous measurement of soil water content on volume basis. The continuous measurement of soil water content became possible by using an electronic soil moisture measurement device. The data produced by this device were continuously memorized in the computer and the sum of differences between consecutive data produced the amount of soil moisture escaping from soil due to the evapotranspiration, which got compared with the measurements taken from the atmometers. The equations found served to calibrate the atmometers themselves. Measurements of potential evapotranspiration by atmometers were done every day of the period under study and three times per day: morning, noon and afternoon. The amount of water evaporated was replaced by pouring the same amount of water into the device by the end of each week, using distilled water, as it is required in the manual of the device. Close to the digitalized system, the Pan A evaporimeter was installed and the measurements of the amount of water evaporated were done at the same time as those ones done by using atmometers.

The data collected on ETp calculated (Penman-Monteith method), on ETp measured by atmometer and on evaporation from the Pan A evaporimeter, were compared to each other, plotting all of them in the same graph. In each graph, the x axis represents time and the y axis represents mm water evaporated. It was assumed that there is a relationship between $ETp-ETp_{atm}$; $ETp-E_{evap}$ and $ETp_{atm}-E_{evap}$. The strength of this relationship was determined by calculating the correlation among them, based on the principle that stronger the relationship, higher the coefficient of correlation. The confidence and the significance of the respective correlations were also presented.

III. RESULTS AND DISCUSSIONS

The results of three year research, for both locations: Komoran and Vushtri, are presented in the following tables (Table 1; Table 2). For each measurement, the mean of the three year data is considered. In order to have a visual dependency among the three ways of measuring the amount of water escaping as vapor from the field and from the free water surface, the data of both mentioned tables were put in a system of coordinates, in which the water evaporated is expressed over time, as in following graphs (Fig. 1; Fig.2). To find out the strength of the dependency, the correlation coefficients were determined and their respective significance as well. In each case, the blue color represents the calculated ETp by using the Penman-Monteith method; the purple color represents the potential evapotranspiration measured by the atmometer, ETp_{atm}; the yellow color represents the water evaporated from the evaporimeter Pan A, E_{evap}.

Table1 ET_p, ETp_{atm} E_{evap} expressed as mm, belonging to the Komoran location

Item calculated on daily basis measurements (mm)	June			July			August			September			October		
	ETp	ETp_{at}	E_{evap}	ETp	ETp_{at}	E_{evap}	ETp	ETp_{at}	E_{evap}	ETp	ETp_{at}	E_{evap}	ETp	ETp_{at}	E_{evap}
Sum	78.8	39	45.5	147.1	103	100.5	128.5	76	83.9	91.7	61.2	68.3	18.6	13	13.6
Mean	4.37	2.78	3.25	4.74	3.32	3.24	4.14	2.45	2.70	3.05	2.04	2.27	1.69	1.18	1.23
Stdeviation	1.34	0.98	1.123	1.054	1.136	0.99	0.78	0.81	0.943	0.79	0.782	0.85	0.53	0.76	0.50
min	1.4	2	1.5	1.8	1	1	1.5	1	1	1.2	0	0	0.8	0	0.5
max	6.4	5	5	6	5	4.7	5.7	4	5	5.6	4	3.9	2.2	2	2

Table2 ET_p, ET_{atm} E_{evap} expressed as mm, belonging to the Vushtri location

Item calculated on daily basis measurements (mm)	June			July			August			September			October		
	ETp	ETpa	E_{evap}	ETp	ETpa	E_{evap}	ETp	ETpa	E_{evap}	ETp	ETpa	E_{evap}	ETp	ETpat	E_{evap}
Sum	85.3	30	35.5	163.5	98	102	168	102	114	106.9	76	78.9	20.4	14	18.1
Mean	4.73	2.72	3.22	5.27	3.16	3.31	5.42	3.29	3.67	3.56	2.53	2.63	1.85	1.27	1.64
Stdev	1.07	1.42	1.18	1.13	0.93	1.34	0.97	0.93	0.77	1.09	0.93	0.91	0.63	0.87	0.52
min	3.2	1	1.5	2.7	1	1	3.2	2	2.5	1.2	1	1	0.7	0	1
max	6.6	5	5	7	5	5.4	7.6	5	5.5	5.3	4	4	2.5	2	2.5

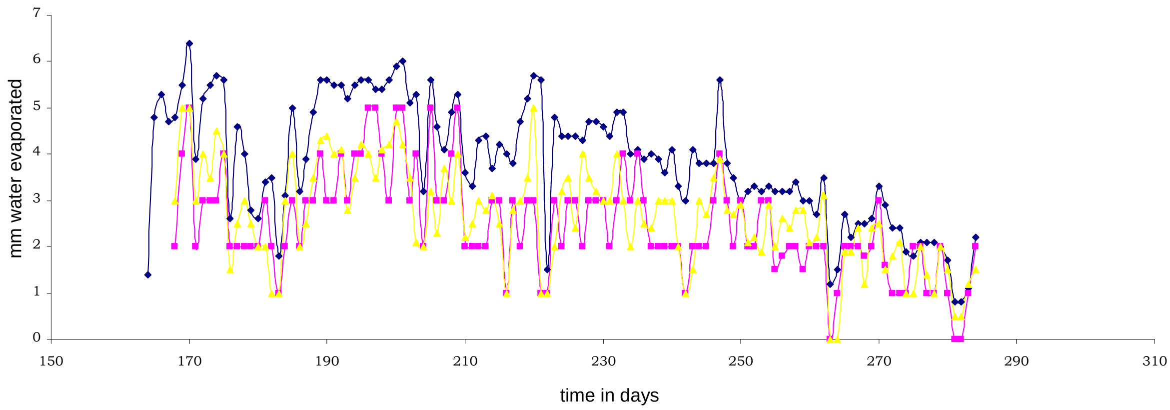

Fig.1 ETp and E calculated and measured over the entire period of measurements, Komoran

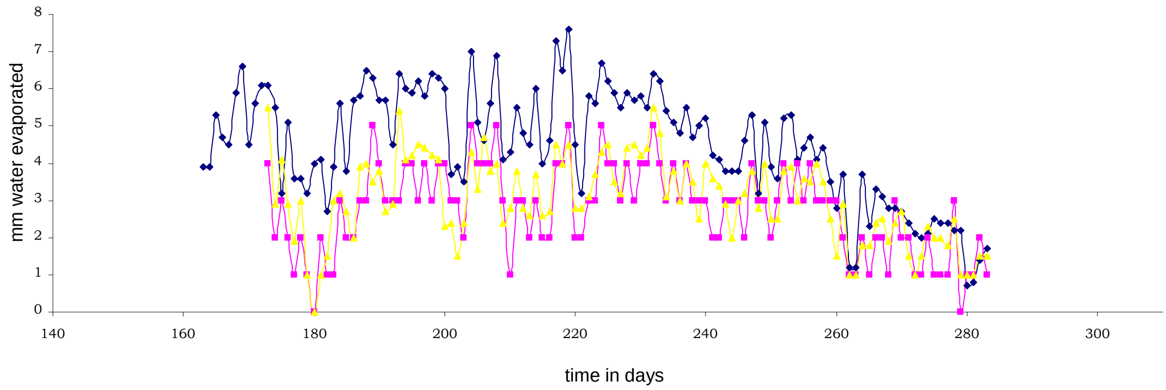

Fig.2 ETp and E calculated and measured over the entire period of measurements, Vushtri

Table3 Correlation coefficient, r, and coefficient of determination, r^2, for the entire period of measurements in Komoran and Vushtri locations

Location	Correlation coefficient r			Coefficient of determination r^2		
	$r_{ETp-atm}$	$r_{ETp-evap}$	$r_{atm-evap}$	$r^2_{ETp-atm}$	$r^2_{ETp-evap}$	$r^2_{atm-evap}$
Komoran	0.8**	0.83**	0.76**	0.64	0.69	0.58
Vushtri	0.77**	0.801**	0.78**	0.59	0.64	0.61

**Correlation is significant at the 0.01 level (2-tailed)

As it can be seen, there is a correlation between evapotranspiration calculated by the Penman-Monteith and that one measured by atmometer or the evaporation measured by the Pan A evaporimeter. The correlation is, in most cases, significant at the 0.01 level, which gives us the right to think that by using just one of the mentioned methods, it is possible to have an idea about the result that can be taken by each of the rest of them. However, there is a noticeable difference in the absolute values between the ETp calculated by the Penman-Monteith method and the evapotranspiration measured by using atmometer or evaporation by evaporimeter Pan A. Being as the measuring of the evapotranspiration by using atmometer, after a process in which its results are calibrated by an electronic soil moisture measurement device, could be considered as the most reliable measurement, the ETp calculated by the Penman-Monteith method might be necessary to get corrected in the conditions of experimentation.

IV. CONCLUSIONS

1. The potential evapotranspiration calculated based on the Penman-Monteith method indicates, during the entire time of investigation, higher values comparing with the results taken by the atmometer and the evaporimeter Pan A method.
2. There is a relationship among the results taken by using the three methods and each relationship (dependency) is significant in high levels of probability.
3. The strongest relationship appears between the ETp calculated by the Penman-Monteith method and the water evapotranspirated by the atmometer situated in the area planted with alfa-alfa and kept in optimal soil water conditions.
4. Clearly, the Penman-Monteith method of computing the potential evaporation based on the sun radiation, wind speed, relative humidity and air temperature, being that produces greater values than those measured by atmometer, should be corrected in the conditions of the Field of Kosovo, by using the data of atmometer.
5. In the conditions of lacking of either the alfa-alfa fields for measuring the potential evapotranspiration or the computerized meteorological system for computing it, the potential evaporation can be calculated by using the data taken from the evaporimeter Pan A. These data, based on the significance with the data collected by using atmometer, can be corrected in order to become more realistic.

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