Tarım Makinaları Bilimi Dergisi (Journal of Agricultural Machinery Science)
2008, 4 (2), 151 - 156

Precise Estimation of the Evapotranspiration Losses in Bulgaria – a Precondition for Water and Energy Conservation for the Economy

Milena MOTEVA
Research Institute of Land Reclamation and Agricultural Mechanization, 1331 Sofia, Bulgaria
milena_moteva@yahoo.com

Abstract: Precise planning of irrigation scheduling contributes for plant providing with the necessary water amounts on one hand, and for avoiding extra water consumption on the other. In this way planned yields are obtained as well as water amounts and energy are saved. In order to optimize the water consumption by the irrigated fields, either in water sufficiency or water deficit conditions, the evapotranspiration losses should be accurately estimated. Since 1998, FAO recommended FAO Penman-Monteith calculation method for all over the world as most accurate one. Supplemented and adjusted version of Penman-Monteith equation was proposed together with a number of associated calculating procedures and calibrated crop coefficients. One of the most weighing components is the net radiation at the crop surface. It has been established in Bulgaria that more precise shortwave radiation daily estimates (compared to the measured values) are obtained by the local Slavov-Georgiev equation than those by FAO formula, especially for the growing season. The paper presents the results from an investigation of the reference evapotranspiration and the irrigation scheduling of maize in cases of calculating net radiation by both - FAO calculation procedure and Slavov-Georgiev equation. A comparison between the two kinds of ET_o values obtained is made. Thus-estimated potential water losses are assessed. Irrigation scheduling of maize in both cases is performed. The potential possibility for saving water and for energy conservation from irrigation network exploitation is discussed.

Key words: net solar radiation, reference evapotranspiration, irrigation scheduling, Bulgaria

INTRODUCTION

Precise planning of the irrigation scheduling contributes for plant providing with the necessary water amounts on one hand, and for avoiding extra water consumption on the other. In this way yields can be planned as well as water amounts and energy saved. In order to optimize the water consumption by the irrigated fields, either in water sufficiency or water deficit conditions, the evapotranspiration losses should be accurately estimated. Since 1998, FAO recommended FAO Penman-Monteith calculation method for all over the world as most accurate. Supplemented and adjusted version of Penman-Monteith equation was proposed together with a number of associated calculating procedures and calibrated crop coefficients. One of the most weighing components is the net radiation at the crop surface. It has been established in Bulgaria that more precise shortwave (summed up) radiation daily estimates (compared to the measured ones) are obtained by the local Slavov-Georgiev equation *(Slavov and Georgiev, 1985)* than those by FAO formula, especially for the growing season *(Slavov and Moteva, 2005)*.

The goal of the paper is to explore and compare the effect of the summed up solar irrigation as calculated by FAO procedure and by Slavov-Georgiev equation on the reference evapotranspiration (ET_o-*PM*); to check the accuracy of both formulas through the related maize (grain) irrigation scheduling alternatives, elaborated on the basis of the two kinds of ET_o-*PM* estimates and proceeding from field experiment results; to assess the water losses by irrigation in both cases and to make conclusion about the applicability of the Bulgarian formula to FAO evapotranspiration calculation method and the potential possibility for saving water and energy conservation from irrigation when practicing either of the two calculation procedures.

MATERIAL AND METHODS

FAO Penman-Monteith method is fully described in *Allen et al. (1998).* One of the parameters, by which reference evapotranspiration estimates are obtained is the net radiation. It is calculated by the following procedure (Eq.1-4):

$$R_n = R_{ns} - R_{nl} \tag{1}$$

$$R_{ns} = (1-\alpha)R_s \tag{2}$$

$$R_{nl} = \sigma\left[\frac{T^4_{\max,K} + T^4_{\min,K}}{2}\right]\left(0.34 - 0.14\sqrt{e_a}\right)\left(1.35\frac{R_s}{R_{so}} - 0.35\right) \tag{3}$$

$$R_{so} = (0.75 + 2x10^{-5}z)R_a \tag{4}$$

$$R_s = \left(a_s + b_s\frac{n}{N}\right)R_a \tag{5}$$

where: R_n - net radiation [MJ m^{-2} d^{-1}]; R_{ns} - net solar or shortwave radiation [MJ m^{-2} d^{-1}]; R_{nl} - net outgoing longwave radiation [MJ m^{-2} d^{-1}]; R_s - incoming solar radiation [MJ m^{-2} d^{-1}]; a_s - regression constant, expressing the fraction of extraterrestrial radiation reaching the earth on overcast days ≈ 0.25; $a_s + b_s$ - fraction of extraterrestrial radiation reaching the earth on clear days ≈ 0.75; b_s ≈ 0.50; n/N - relative sunshine duration [hr]; R_a -extraterrestrial radiation [MJ m^{-2} d^{-1}]; α - albedo, R_{so} - clear sky radiation [MJ m^{-2} d^{-1}]; z - station elevetion above sea level [m]; $T_{max,K}$, $T_{min,K}$, and e_a – other parameters.

The equvalent of the incomming radiation in Bulgarian notion is the summed up radiation. As to *Slavov and Georgiev (1985)*, it is calculated by the equation:

$$Q_j = 30{,}3SS_j^{0{,}873} + 303.2(\sinh_0)^{2.19} \tag{6}$$

$$\sinh_0 = \sin f \sin d + \cos f \cos d \tag{7}$$

$$d_j = 23{,}257\cos\left(\frac{(m - 94{,}049)3{,}0928}{180{,}018}\right) + 0{,}3734 \tag{8}$$

where: Q_j – summed up radiation [MJ m^{-2} d^{-1}]; SS_j – sunshine duration (hr); $\sinh_o$ – sun height; f – geographical latitude; d – sun's declination

Data about the sunshine duration, T_{max} and T_{min} at Sofia for the 30-year period 1971-2000 is taken from NIMH database.

A field experiment with irrigation of maize (grain) has been conducted in the periods 1987-1989 and 1996-1998 in Chelopechene Field near Sofia. There are results about optimal irrigation scheduling, proceeded on the base of soil moisture and meteorological measurements.

First we have calculated the reference evapotranspiration by FAO Penman-Monteith method. Then we substituted R_s for Q_j in Eq. (2) and Eq. (3) and obtained new values for the reference evapotranspiration. Basing on the field experiment, K_c factors have been calculated by the following fomula:

$$K_c^i = \frac{\sum ET_a^i}{\sum ET_o^i} \tag{9}$$

where: K_c^i – crop coefficient for the *i*-perod (decade); ΣET_a – sum of ET_{maize} from the experiment for *i*-period; ΣET_{oi} – sum of ET_o-*PM* for *i*-period.

The terms of the applications in each irrigation scheduling, estimated on the base of K_c were fixed by the soil water-balance equation.

Three of the experimental years are dry and warm (1987, 1988 и 1997), one is moderate (1998) and two are humid and cool (1989 и 1996).

RESEARCH RESULTS

The 30-year standardized daily summed up solar radiation as calculated by Eq. (5) is with 3-4 MJ m^{-2} d^{-1} higher than that calculated by Slavov-Georgiev equation (Eq. 6), especially in summer months (Fig. 1). The *Q*-values are closer to the measured ones. Unlike R_s values, *Q*-values are almost identical with the measured ones during all the year.

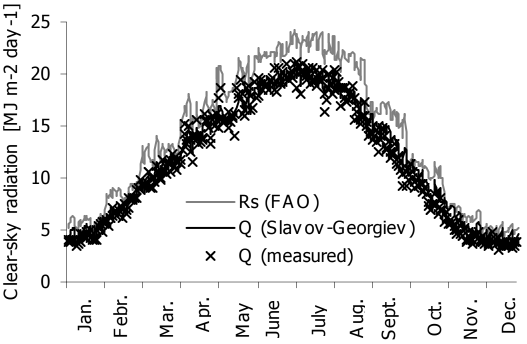

Figure 1. Measured and calculated summed up solar radiation

The ratio between *Q* (by Slavov-Georgiev) and *Q* (measured) fluctuates around 1 during the potential vegetation period March-August, while the ratio R_s (FAO)/*Q* (measured) is 1,15-1,20 considering higher solar radiation estimates (Fig. 2).

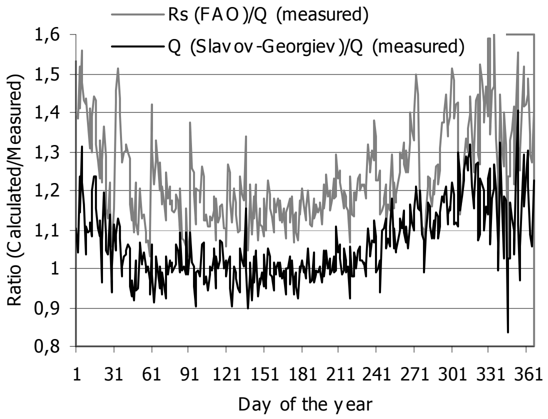

Figure 2. Ratio between the calculated and measured summed up solar radiation at Sofia station for the period 1971-2000

Though the summed up solar radiation, calculated by Eq.5 and 6 differs a lot, the estimates for FAO Penman-Monteith reference evapotranspiration (ET_o-*PM*), calculated by using R_s and Q are close (Fig. 3). The approximations of 3rd power show that in summer months ET_o-*PM*, calculated by R_s is with about 0,1 mm higher than that, calculated by Q.

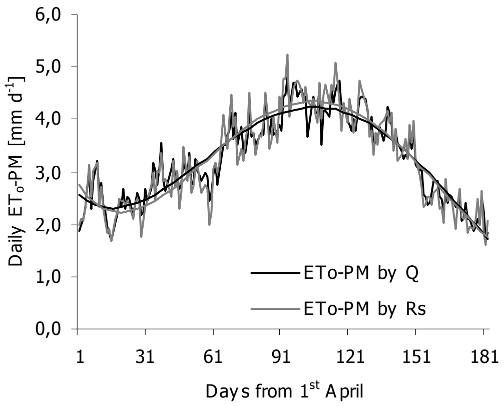

Figure 3. Calculated ET_o-*PM* by FAO R_s and Slavov-Georgiev Q input daily data

The determination of the output ET_o-*PM* by the relevant input solar radiation values is a bit higher in the case of the original FAO procedure (R^2=0,81) than, when using Slavov-Georgiev equation (R^2=0,79) (Figs 4 and 5)

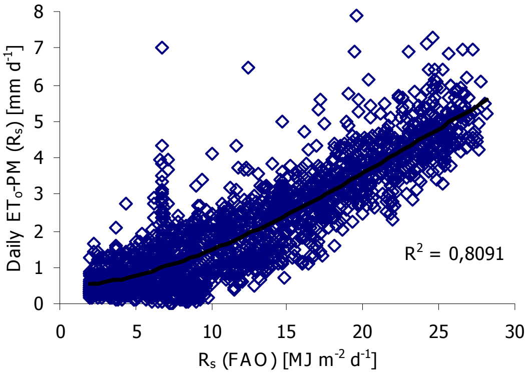

Figure 4. Relation between daily ET_o-*PM* (by R_s) and R_s

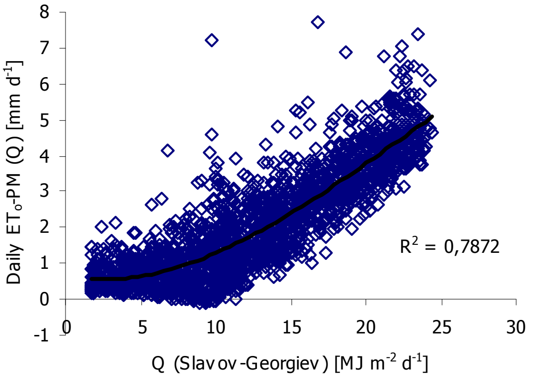

Figure 5. Relation between daily ET_o-*PM* (by Q) and Q

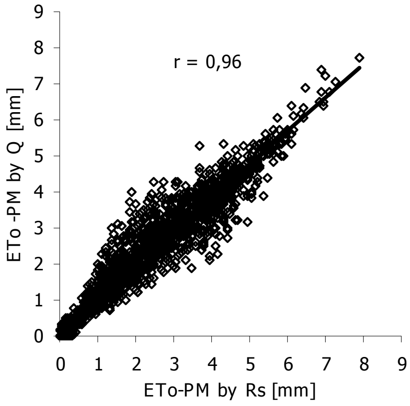

Figure 6. ET_o-*PM*, calculated with Q (Slavov-Georgiev) vs. *ETo-PM*, calculated with R_s (FAO)

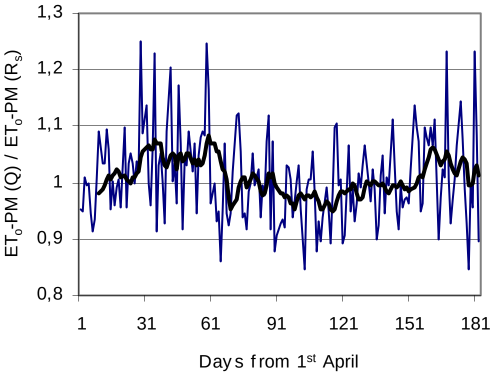

Figure 7. Ratio of *ET_o-PM* by FAO *R_s* and ET_o-PM by Slavov-Georgiev *Q* with moving 10-day average

The correlation between the two alternative estimates of *ET_o-PM* is high (r=0,96), shown on Fig. 6.

In spring months April and May *ET_o-PM*, calculated by *Q*, possesses higher values than *ET_o-PM,* calculated by *R_s*. In June and August the estimates are almost equal – their ratio slightly fluctuates around 1. And in July *ET_o-PM* (by *Q*) is lower than *ET_o-PM* (by *R_s*) (Fig. 7).

Table 1 *K_c* coefficients, obtained when *R_s* and *Q* are used

Month	Decade	K_c (by R_s)	K_c (by Q)
April	III	0,20	0,20
May	I	0,34	0,35
	II	0,38	0,40
	III	0,56	0,61
June	I	0,67	0,66
	II	0,83	0,85
	III	0,88	0,87
July	I	0,91	0,89
	II	1,23	1,18
	III	1,47	1,44
August	I	1,41	1,43
	II	1,12	1,10
	III	0,90	0,90
September	I	0,99	1,08
	II	0,72	0,74
	III	0,61	0,63

The crop coefficients *K_c*, obtained by the two alternative *ET_o-PM* estimates are very close to each other (Table 1). So are the terms of the irrigation applications, calculated by usage of these coefficients (Table 2). The irrigation scheduling parameters, as far as the results are generalized per decades, are alike.

DISCUSSIONS AND CONCLUSIONS

Agriculture in every part of the planet needs local scientific results, dependencies, coefficients, parameters and calibrated models in support of the production in order to obtain high and sustainable yields. Contemporary science makes attempts to draw general theoretical conclusions and to reveal the regularity of nature phenomena that determine the production processes, but an essential part of it is to adapt the assessments as close as possible to the local conditions.

Equation (6) is worked out for Bulgarian latitude and its function and exponents reflect the exact sunshine duration and the parameters of sun movement above our geographical location. Equation (5) contains recommended generalized for larger territories in our planet regional parameters and coefficients. It is seen from Fig. 1 the accuracy of each equation estimates, assessed in comparison with measured data. While the summed up radiation, calculated by Slavov-Georgiev equation almost cover the measured values, FAO estimates are a bit higher. In the annual course of these values, *Q* varies from min. 3,4 to max. 20,7 MJ m^{-2} d^{-1} and the measurements – from 3,5 to 20,9 MJ m^{-2} d^{-1}, but *R_s* varies from 4,4 to 24,2 MJ m^{-2} d^{-1}. No doubt that Slavov-Georgiev equation gives more accurate estimates for the summed up radiation. It is seen also from Fig. 2, where the ratio of both kinds of estimates with the measured values is plotted. That is why the question emerged if we substitute *Q* for *R_s* in FAO calculation procedures, should we obtain more precise estimates for the reference evapotranspiration, hence – a more adequate to crop water needs irrigation scheduling? *ET_o-PMs*, calculated by means of *R_s* and *Q* are seen on Fig. 3. Much to our surprise, they are very close. Their difference is greatest in summer months *R_s* is greater from 0,1 to max 0,7 mm d^{-1} than *Q*. This presupposes overestimation of *ET_{crop}*, when related on FAO procedures with *R_s*. But *R_s* in spring months is lower than *Q* with -0,1 to max -0,6 mm d^{-1}.

This probably would impact for lower ET_{crop} estimates than the real ones in spring period. This regularity is shown by the ratio between the two kinds of estimates on Fig. 4. The average ratio for the whole potential vegetation period is 1,01, for the summer months it is 0,98, and for the spring months – 1,03. Figs 4-6 prove the fact that the impact of solar radiation on the resulting estimates in both cases is one and the same. So ET_o-*PM*, calculated by Q can also be used for estimation of ET_{crop}.

In spite of the considerable differences between the summed up solar radiation estimates, the crop transition coefficients K_c per decades does not differ so much (Table 1). This is probably because the impact of solar radiation on ET_o-*PM* is in combination with the impacts of some other meteorological elements in FAO Penman-Monteith equation (*Moteva et al., 2008*). On the contrary of our expectations, the predicted irrigation scheduling on the base of ET_o-*PM,* by Q is the same as that in which R_s takes part. Both of them are close to the experimental one, considered as a standard (Table 2). The colored part of the table marks the drought periods of the years. In three of the years the vegetative stage, tasseling and milk maturity fall in those periods and in the other three – only the vegetative stage and tasseling do. In all the years the predicted application terms are slightly different from those in the experiment. But probably this is because in this investigation they are determined very roughly – per decades. If the water balance is daily done, the predicted dates would much more coincide with the experimental ones. The lack of full coincidence of the predicted and experimented dates is probably due to a certain error in estimation of the evapotranspiration in the experiment. Its calculation and approximation is a separate process from the direct management of the irrigation scheduling. The dates for application are determined by tracing out the status of soil moisture. Further, the irrigation in the experiment has been managed till 15th August, considering the production practices in Bulgaria. Maize (grain) is irrigated mainly till this term. Hence, the experimental application number is minus 1 from the predicted ones, seen in Table 2. But recently, on the base of long-term experimental data, it has been proved by Popova (2008) that the best term of stopping irrigation in Sofia region is 30th August. If one more application would be given after 15th August, the yield would be a little greater but the expenses would increase too.

Table 2 Irrigation Scheduling as predicted by FAO reference evapotranspiration

Month	Decade	1987			1988			1989			1996			1997			1998		
		Field experiment	Calculated with ET_o-*PM*		Field experiment	Calculated with ET_o-*PM*		Field experiment	Calculated with ET_o-*PM*		Field experiment	Calculated with ET_o-*PM*		Field experiment	Calculated with ET_o-*PM*		Field experiment	Calculated with ET_o-*PM*	
			R_s	Q		R_s	Q		R_s	Q		R_s	Q		R_s	Q		R_s	Q
May	I																		
	II																		
	III																		
June	I																		
	II																		
	III		60	60							v	60	60	60v	60	60	v		
July	I	60v			v									60			60	60	60
	II		60	60	60			60	60	60	60				60	60	t		
	III	60t	120	120	60t	60	60	v	60	60	60	60	60	60t	60	60	60	60	60
August	I	60	60	60	60m	60	60	60t	60	60	t	60	60				60m	60	60
	II	60m				60	60				60			m				60	60
	III		60	60	60			60			m	60	60						
Sept.	I	60																	
	II							m											
	III																		
Total water amount used		300	360	360	240	180	180	180	180	180	180	240	240	180	180	180	180	240	240

v – vegetative stage
t – tasseling
m – milk maturity

If any inaccuracy would occur in evapotranspiration estimation, it would impact the crop coefficients K_c. ET_o-PM also bares the errors of the meteorological elements measurement and of the equation itself. What further could be done before any recommendations is a detailed water balance of soil moisture with the daily precipitation quantities and with so estimated K_c coefficients in order to fix the dates of application more precisely. Then the analysis would be much reliable and the conclusions much more correct. The water amounts spent for irrigation would be more precisely determined and might one application rate be saved for other crops and purposes. Expenses and energy from the application not implemented might be saved for other agricultural practices.

Finally, our contribution in this investigation is: 1) two kinds of K_c coefficients are presented, one of them when ET_o-PM, is calculated by means of a local solar radiation equation; 2) the irrigation scheduling predicted on the base of FAO Penman-Monteith reference evapotranspiration is reliable, because the applications cover the drought periods of the years tested and support the plants in the critical for water periods; 3) more detailed daily investigation of the predicted irrigation scheduling should be done in order to make reliable conclusions about the error and the possibilities for saving water and energy for the economy of the country.

ACKNOWLEDGEMENTS

The authors express their high appreciation to the Bulgarian National Science Fund for its financial support (Project NI SS 1606/06: Agroclimatic Resources in Bulgaria for Field Crop Cultivation under Irrigated and Rain-Fed Conditions).

REFERENCES

Allen, R.G., Pereira, L.S., Raes, D., and Smith, M. 1998. *Crop evapotranspiration. Guidelines for computing crop water requirements.* FAO Irrig. And Drainage Paper No. 56, Rome, 300 pp.

Moteva, M., V. Georgieva, V. Kazandjiev. 2008. Interaction between Reference Evapotranspiration and the Meteorological Parameters in FAO 56 Penman-Monteith Equation. Global Environmental Change: Challenges to Science and Society in Southeastern Europe International Conference, Sofia, 19-21 May, 2008, CD Version

Slavov, N., G. Georgiev, 1985. Estimating Photosynthetic Active Radiation (PHAR) by Sunshine Duration. Plant Physiology, v. XI, No. 4: 65-71 (in Bulgarian)

Slavov, N., M. Moteva. 2005. Computing Solar Radiation in Order to Estimate FAO Penman-Monteith Reference Evapotranspiration in Bulgaria. Agricultural Engineering, № 2: 45-51

Popova, Z. 2008. *Optimization of Irrigation Scheduling, Yields and Their Environmental Impacts by Crop Models.* Synthesis of Dissertation Thesis for the Scientific Degree "Doctor of agricultural Sciencies, S., "Poushkarov" Soil Science Institute, 101 pp.