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Irrigation Scheduling on the Base of Differently Estimated Crop Evapotranspiration

Milena MOTEVA[1], Valentin KAZANDJIEV[2], Zhivko ZHIVKOV[3], Veska GEORGIEVA[2], Iskra GEORGIEVA[4]
[1]Research Institute of Land Reclamation and Agricultural Mechanization, 3 Shose Bankya Str., 1331 Sofia-BULGARIA
[2]National Institute of Meteorology and Hydrology, 66 Tsarigradsko Shose, Blvd., 1784 Sofia, Bulgaria
[3]University of Forestry, 10 Kliment Ohridski, Blvd., 1734 Sofia, Bulgaria
[4]Institute for Maize Breeding, 5835 Knezha-BULGARIA
milena_moteva@yahoo.com

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Abstract: Precise planning of irrigation scheduling contributes for providing plants with necessary water amounts and for obtaining high yields. Comparative analyses of the crop evapotranspiration estimation methods in Bulgaria give advantage to the temperature based ones. A competitive method recognized as the most accurate in the world, is FAO Penman-Monteith method based on greater number of meteorological and plant factors. The goal of the paper is to explore 17-year (1984-2000) independent dataset of field experiments with maize (grain) and soybean for: (a) derivation of crop coefficients for FAO Penman-Monteith (K_c) and Delibaltov-Hristov-Tsonev (Z) methods; (b) analysis of the long-term variability of the coefficients and their relationships; (3) simulation of irrigation schedules on the basis of the two calculation methods; and (4) assessment of the expedience of either of the evapotranspiration calculation methods for optimizing of the irrigation scheduling through comparison with field experimental results. The field experiments were held in Sofia region. The data was processed in STATISTICA 8 and EXCELL environment. As a result, maize (grain) and soybean crop coefficients for the two evapotranspiration calculation methods have been obtained. It was established that Z is a more stable coefficient than K_c with smaller variability*.* K_c has close relationship to Z, which is evidence for analogous air temperature reading by FAO 56 method like by Delibaltov-Hrostov-Tsonev one. Delibaltov-Hristov-Tsonev and FAO 56 methods give identical simulation results about the dates of irrigation applications hence the first one, which is simpler, can successfully be used for management of crop irrigation scheduling in Bulgaria.
Key words: Crop coefficients, soil-moisture simulation, maize (grain), soybean, Bulgaria

INTRODUCTION

The comparative analyses, on the crop evapotranspiration estimation methods, held in Bulgaria, give advantage to those basing on the air temperature vs. those basing on another climatic factors like vapor pressure deficit, free water evaporation, evaporability, etc. (Lazarov et al., 1978; Mladenova, 1982; Zahariev, 1985). Davidov and Gaidarova (1983) assert that there is no statistically reliable calculation method. They say crop irrigation scheduling should be managed on the basis of lysimeter readings. The hetherto irrigation practice and irrigation system design in Bulgaria used Delibaltov-Hristov-Tsonev calculation method (Delibaltov et al., 1962), which was a basis for elaboration of zoning of the irrigation scheduling (Zahariev et al., 1986) for 33 crops in 97 regions of particular environmental conditions and related to 3 kinds of yearly moisture conditions. Varlev and Popova (2004) established that the evapotranspiration estimates by Delibaltov-Hristov-Tsonev method are subjected to ±20-50% error. Recently, FAO Penman-Moteith method (Allen et al., 1994) has gained popularity as the most accurate one, because of accounting for a set of meteorological and plant factors.

The goal of the paper is to explore 17-year independent dataset of field experiments with maize (grain) and soybean for: (a) derivation of crop coefficients for FAO Penman-Monteith (K_c) and Delibaltov-Hristov-Tsonev (Z) methods; (b) analysis of the long-term variability of the coefficients and their relationships; (3) simulation of irrigation schedules on the basis of the two calculation methods; and (4) assessment of the expedience for use of either of the evapotranspiration calculation methods for optimizing of the irrigation scheduling through comparison with field experimental results.

MATERIALS and METHOD

Long-term data (1984-2000) of maize (grain) and soybean evapotranspiration, established in field experiments in Sofia region, were used for determining of K_c and Z coefficients:

$$K_c^i = \frac{\sum ET_{crop}^i}{\sum ET_o^i} \qquad (1)$$

$$Z^i = \frac{\sum ET_{crop}^i}{\sum_{j=1}^{n} T_j^i} \qquad (2)$$

KEY:

K_c^i , Z^i crop coefficients for i-period (decade);

$\sum ET_{crop}^i$ i-period total of the experimental daily ET_{crop};

$\sum ET_o^i$ i-period total of daily FAO Penman-Monteith reference evapotranspiration;

$\sum_{j=1}^{n} T_j^i$ i-period total of daily mean air temperature;

n=10(11) days of the period.

By using the above mentioned coefficients, ET_{crop} was simulated and the soil water balance was performed with a daily time step:

$$SW_k^i = SW_{k-1}^i + R_k^i + M_k^i - ET_{crop,k}^i , \qquad (3)$$

KEY:

SW_k, SW_{k-1} readily available water content ($RAWC$) on days k and k-1 (mm),

R_k rainfall on day k (mm),

$ET_{crop,k}$ crop evapotranspiration on day k (mm), estimated as average of ET_{crop}^i .

An application depth of 60 mm (=$RAWC_{max}$) was appointed at SW_k=0. The data was processed in STATISTICA 8 and EXCELL environment.

The rainfall total of the cropping season April-September varies from 180 mm to 765 mm (1959-2008), and the rainfall total of the irrigation season July-August - from 13 mm to 400 mm. The smallest decadal quantity appears in the third decade of July –

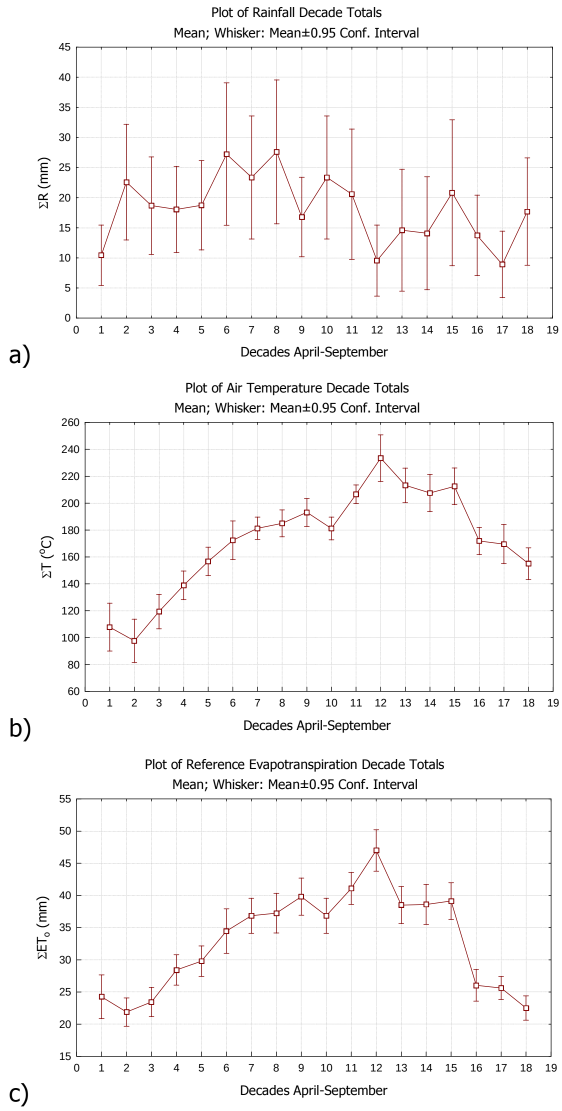


Figure 1. Mean decadal totals of rainfall (a), air temperature (b) and reference evapotranspiration (c) at Sofia station, period 1984-2000

9.5 mm, the highest – in the third decade of May and the second one of June – 27.2 mm and 27.6 mm respectively (Fig.1a). The 17-year studied period consists of years of different moisture peculiarities, as seen in the probability of exceedance curve on Fig. 2.

The temperature sum for the cropping season May-September averages 2744.6 °C (from 2363.6 °C – 1978 - to 3054.4 °C – 1994) (Fig. 1b).

Reference evapotranspiration follows the dynamics of air temperature. It is highest in the third decade of July – from 40.3 mm (1984) to 60.4 mm (1987). The April-September sum varies from 544.1 mm (1989) to 651.7 mm (1993) – average 597.8 mm (Fig. 1c).

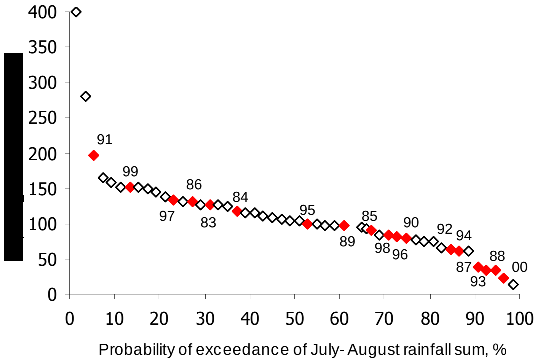


Figure 2. Probability of exceedance of July-August rainfall totals in Sofia Region.

RESULTS and DISCUSSION

For both crops the decadal evapotranspiration from the field experiments is maximal in the third decade of July– 59.9 mm for maize and 51.2 mm for soybean (Fig. 3). It is seen on Fig. 3 that in dry years: ET_{maize} in July-August has higher rate than in wet years; $ET_{soybean}$ has lower rate allover the vegetation season than in wet years.

The calculated by equations (1) and (2) crop coefficients are presented in Tables 1-2 for maize (grain) and Tables 3-4 for soybean. K_c keeps >1 from the first decade of July to the third one of August for soybean and to the first one of September for maize. The results correspond to those, given in FAO 56 (Allen et al., 1998). Z coefficients correspond to the given in Zahariev et al. (1986) long-term values.

The variability of K_c for both crops is higher than those of Z (Fig. 4). The average variance coefficient of $K_{c,maize}$ is 33.0 %, and of Z_{maize} – 29.6 %. Analogously, the variance coefficient of $K_{c,soybean}$ is 34.9 % and of $Z_{soybean}$ - 32.1 %.

Maize crop coefficients vary a lot in the initial and end vegetation stages, but are stable in midseason, particularly in the third decade of July. Soybean coefficients vary in all phenological stages. In midseason $K_{c,soybean}$ varies from 27 % to 39 % and $Z_{soybean}$ - from 20 % to 24 %. The end-season values of the coefficients refer to a stage of harvesting at high grain moisture.

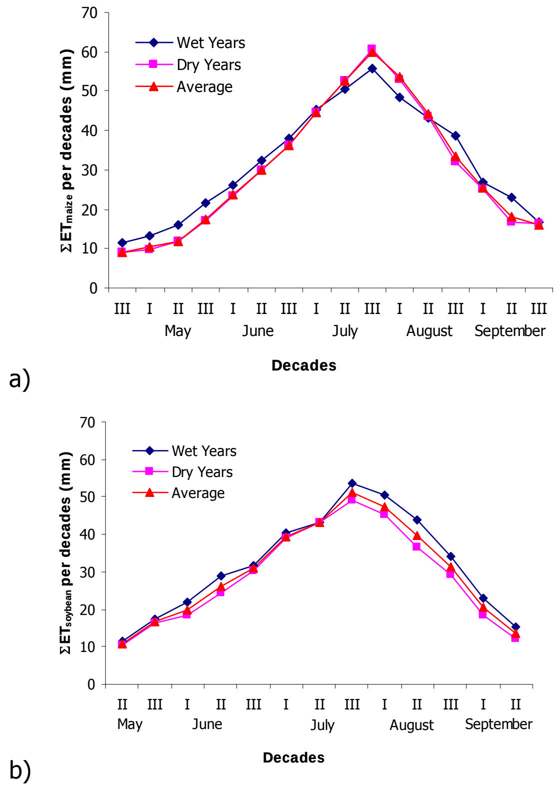


Figure 3. Dynamics of average (1984-2000) crop evapotranspiration per decades: (a) maize (grain); (b) soybean

On Figs 6 and 7, the simulated dynamics of the readily available water content and the relevant irrigation schedules vs. measured ones under maize and soybean in a year of medium probability of exceedance of rainfalls (1989) and in a dry year (1998 and 2002 resp.) are plotted. Crop evapotranspiration is calculated through the relevant for medium and dry year coefficients because the simulations with the average for the studied period coefficients caused great inaccuracy in the dates of applications. It is seen that: 1) simulations give an application more, but irrigation in Bulgaria is usually practiced till 15^{th} August to let the crops ripen hence there is one last irrigation application usually missed; 2) the simulated and the experimented dates of applications within the reproductive stages are very close, almost coincide, which is evidence for the accuracy of the calculated long-term crop coefficients; 3) the dates of the applications, predicted by using Z and K_c almost overlap, which stands for the accuracy of the simpler Delibaltov-Hristov-Tsonev method. This one can successfully be applied in the soil and climatic conditions of Bulgaria.

Table 1. $K_{c,maize}$ **per decades**

Month	Decade	Wet years	Dry years	Ave
April	III	0.53	0.39	0.45
May	I	0.48	0.35	0.40
	II	0.60	0.43	0.49
	III	0.67	0.51	0.57
June	I	0.74	0.59	0.65
	II	0.97	0.75	0.87
	III	0.99	0.93	0.97
July	I	1.15	0.92	1.01
	II	1.33	1.20	1.25
	III	1.30	1.17	1.24
Aug.	I	1.44	1.25	1.33
	II	1.31	1.11	1.18
	III	1.11	0.92	0.98
Sept.	I	1.04	0.90	1.00
	II	0.85	0.65	0.73
	III	0.77	0.67	0.75

Table 2. Z_{maize} **per decades**

Month	Decade	Wet years	Dry years	Ave
April	III	0.11	0.08	0.10
May	I	0.09	0.07	0.08
	II	0.10	0.08	0.09
	III	0.12	0.10	0.11
June	I	0.15	0.12	0.13
	II	0.18	0.16	0.17
	III	0.20	0.18	0.19
July	I	0.23	0.20	0.21
	II	0.25	0.25	0.25
	III	0.25	0.24	0.24
Aug.	I	0.24	0.24	0.24
	II	0.22	0.21	0.21
	III	0.19	0.16	0.17
Sept.	I	0.15	0.16	0.15
	II	0.13	0.10	0.11
	III	0.12	0.09	0.11

Table 3. $K_{c,\ soybean}$ **per decades**

Month	Decade	Wet years	Dry years	Ave
May	II	0.34	0.31	0.33
	III	0.48	0.43	0.47
June	I	0.60	0.48	0.53
	II	0.78	0.65	0.70
	III	0.86	0.79	0.83
July	I	1.08	0.97	1.00
	II	1.08	0.91	0.96
	III	1.46	1.06	1.22
Aug.	I	1.34	1.18	1.27
	II	1.20	0.98	1.09
	III	1.26	1.10	1.13
Sept.	I	0.83	0.68	0.75
	II	0.59	0.46	0.51

Table 4. $Z_{soybean}$ **per decades**

Month	Decade	Wet years	Dry years	Ave
May	II	0.08	0.07	0.07
	III	0.10	0.10	0.10
June	I	0.12	0.10	0.12
	II	0.15	0.13	0.14
	III	0.17	0.16	0.17
July	I	0.22	0.18	0.20
	II	0.21	0.20	0.21
	III	0.25	0.19	0.21
Aug.	I	0.24	0.20	0.22
	II	0.21	0.16	0.18
	III	0.17	0.13	0.15
Sept.	I	0.13	0.10	0.11
	II	0.08	0.07	0.07

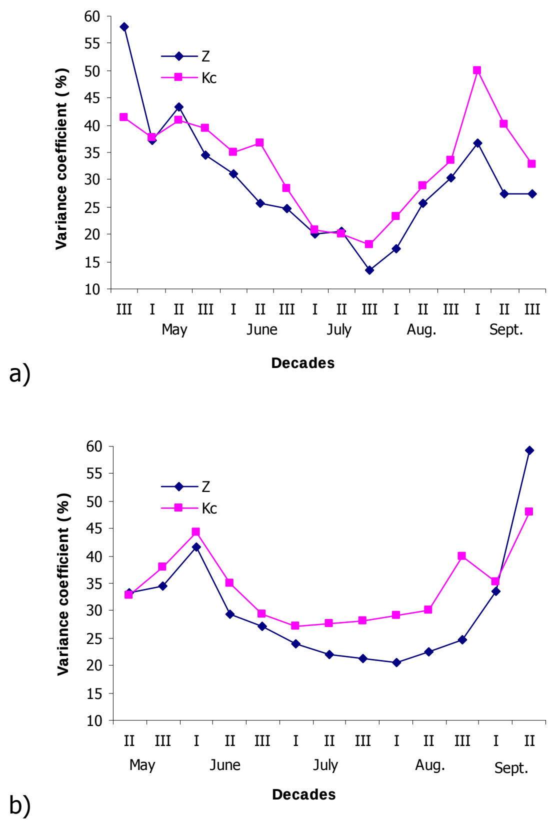
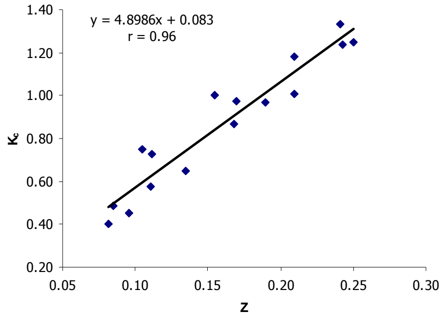


Figure 4. Variance of Z **and** K_c**: (a) maize (grain); (b) soybean**



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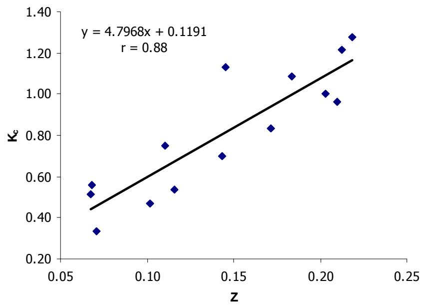
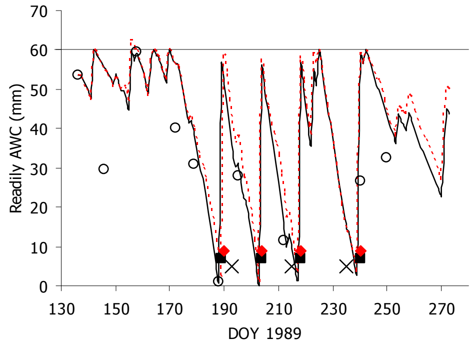


b)

Figure 5. Ratio between *Z* and K_c: (a) maize (grain); (b) soybean



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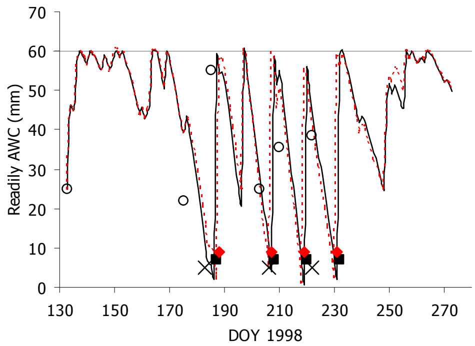
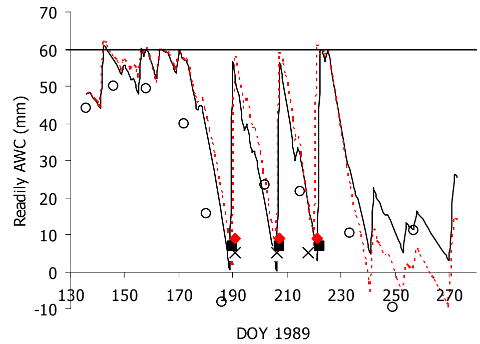


b)

Figure 6. Simulated vs. observed soil moisture under maize (grain): a) 1989; b) 1998.



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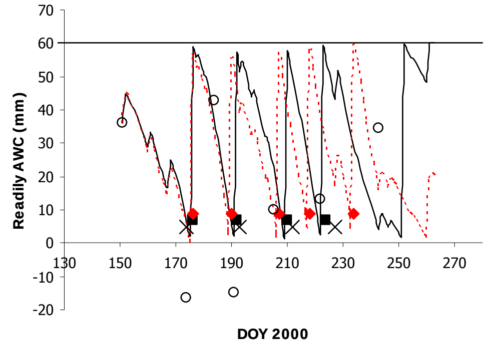

b)

Figure 7. Simulated vs. observed soil moisture under soybean: a) 1989; b) 2002.

<u>KEY to Figs. 6 and 7</u>:

—— simulated soil moisture by using Delibaltov et al. method for ET_{crop} calculation

- - - simulated soil moisture by using FAO Penman-Monteith method for ET_{crop} calculation

o observed soil moisture

x observed applications;

■ simulated applications, by using *Z*;

◆ simulated applications, by using K_c;

CONCLUSIONS

- Based on 17-year field experiments and meteorological data maize (grain) and soybean crop coefficients for FAO 56 (K_c) and Delibaltov-Hristov-Tsonev (*Z*) evapotranspiration calculation methods have been calculated.
- *Z* is a more stable coefficient than K_c, with smaller variability.
- K_c has close relationship to *Z*, which is evidence for analogous air temperature reading by both evapotranspiration calculation methods - FAO 56 and Delibaltov-Hrostov-Tsonev.

- Delibaltov-Hristov-Tsonev and FAO 56 methods give identical simulation results about the terms of irrigation applications hence the first one, which has been traditionally used in our country and is simpler, can successfully be used for management of crop irrigation scheduling.

ACKNOWLEDGEMENTS

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