Scientific Papers. Series A. Agronomy, Vol. LVII, 2014
ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785

ESTIMATION OF CROP EVAPOTRANSPIRATION IN BULGARIAN CLIMATE CONDITIONS

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Abstract

Precisely managed irrigation scheduling provides for on-time meeting of crop water needs, for high yields and high economic effect. Most important in crop water needs estimation is the right choice of an evapotranspiration calculation method. Comparative analyses of some calculation methods which are suitable for Bulgarian climatic conditions give advantage to the temperature-based ones. Since last decades, FAO Penman-Monteith method has been globally recognized as most accurate in various climatic conditions as it is based on great number of meteorological and plant factors. In this paper, decadal values of K_c factor in the course of vegetation of 25 crops, grown in Bulgaria – cereals, forage, industrial, vegetables, and berries are presented. Their accuracy is statistically evaluated. The standard error of the mean is mainly around 10%. A narrow correlation between the crop factors of FAO method and the temperature-base method, which is currently used in Bulgaria, has been established. Simulation of the irrigation scheduling of three crops by both methods is performed. The results show that FAO Penman-Monteith method is suitable for Bulgarian climatic conditions. The temperature-based method is simpler and easily maintained with meteorological information, hence it is recommended for practical purposes.

Key words: *FAO Penman-Monteith, K_c factor, correlation, simulation, Bulgaria.*

INTRODUCTION

Precisely calculated irrigation scheduling provides for on-time water application to the field. Precise irrigation contributes for high yield accumulation and high economic effect. Most important in crop water needs estimation is the right choice of an evapotranspiration calculation method. Since last decades, FAO Penman-Monteith evapo-transpiration calculation method proved to be the most accurate one and can be used in various climatic conditions (Allen et al., 1998). It reads the impact of several meteorological factors on crop evapo-transpiration. The method determines the evapotranspiration of a hypothetical crop (reference evapotranspiration), similar to grass, and transfers it into the evapotranspiration of a particular crop by a crop K_c factor. FAO suggests standard K_c factors for the main crops per phenological stages under different climatic conditions.

FAO Penman-Monteith method is not considered a new one, but in our country it is still poorly studied. A serious reason for that is that the meteorological information is hardly collected. Another reason is the lack of calibrated and verified for our soil-climatic conditions K_c crop factors. For many years, and still in use in Bulgaria, is Delibaltov-Hristov-Tzonev evapotranspiration calcula-tion method, which is based on the decadal totals of air temperature (Delibaltov et al., 1962). These totals used to be multiplied by a specific for every crop and decadal biophysical Z factor and thus the decadal evapotranspiration totals were calculated. Z biophysical factors of different crops under different soil moisture conditions were obtained as a result of a long-term research work (Zahariev et al., 1986). Recently, FAO Penman-Monteith reference evapotranspiration has been determined for 42 sites in the arable land of the country (Kazandjiev et al., 2010). Thus it became possible to develop a study which proved that Delibaltov-Hristov-Tsonev method was of similar accuracy like FAO Penman-Monteith method in Bulgarian climate conditions (Davidov, Moteva, 2010).

The goal of this paper is to calculate K_c crop factors for FAO Penman-Monteith evapotranspiration calculation method of some crops in the humid climatic regions of Bulgaria (4th Agroclimatic Group (Zahariev et al., 1986)) on the basis of long-term crop evapotranspiration data obtained from field experiments in Sofia region. Another goal is to assess the expedience for applying FAO method to Bulgarian irrigation practice by using statistical analyses.

Table 1. Data available and sources

Types of crops	Nb.	Crop	Period	Rows	Source
Cereals	1	Winter wheat	1971-1973	9	Al Shaua, 1974
			1975-1976		Zahariev, 1976
			1985-1988		Zhivkov, 1990
	2	Maize (grain) moderately early variety	1984-1988		Zhivkov, 1990
	3	Maize (grain) moderate late variety	1984-1988	13	Zhivkov, 1990
			1987-1989,1996-1998		Moteva, 2006
			1999-2000		Matev, 2001
	4	Maize (grain) late variety	1980-1983	9	Lazarov, 1984
			1984-1988		Zhivkov, 1990
	5	Winter barley			Zhivkov, 1990
	6	Spring barley			Zhivkov, 1990
Industrial crops	7	Sugar beet	1971-1976	12	Delibaltov, Zahariev, 1977
			1978-1980		Daher, 1981
			1980-1982		Lazarov et al., 1982
	8	Soybean	1984-1988	9	Zhivkov, 1990
			1991		Zhivkov, 1991
			1996-2000		Zhivkov Mladenova, 1994
Forage crops	9	Alfalfa 1st year	1971-1972	3	Mehandzhieva, 1974
	10	Alfalfa old	1972-1974	5	Mehandzhieva, 1974
			1981-1982		Mehandzhieva, 1982
			1978-1982		Gaidarova, 1988
	11	Maize for green	1984-1988	5	Zhivkov, 1990
	12	Maize 2nd crop	1984-1988	5	Zhivkov, 1990
	13	Pea-oats mixture 2nd crop	1984-1988	5	Zhivkov, 1990
	14	Pea-oats-sunflower mixture 2nd crop	1984-1988	5	Zhivkov, 1990
	15	Rye for green	1984-1988	5	Zhivkov, 1990
	16	Rye-pea mixture	1984-1988	5	Zhivkov, 1990
	17	Triticale (*Triticum aestivum* x *Secale cereale*)	1984-1988	5	Zhivkov, 1990
	18	Rape (*Brassica ssp. Spantula*) autumn period	1984-1988	5	Zhivkov, 1990
	19	Rape (*Brassica ssp. Spantula*) spring period	1984-1988	5	Zhivkov, 1990
Vegetables	20	Tomatoes	1996	1	Kireva, 2003
	21	Cucumber	1997, 1998	2	Kireva, 2003
	22	Moderately early potatoes	1984-1988	5	Zhivkov, 1990
	23	Early potatoes	1984-1988	5	Zhivkov, 1990
	24	Late cabbage	1984-1988	5	Zhivkov, 1990
Berries	25	Raspberries	1999-2003	5	Kireva, 2003

MATERIALS AND METHODS

Data of crop evapotranspiration (ET_c) were taken from series of field experiments which were conducted in the Sofia region during the period 1970-2010. They were composed in the following groups, shown in Table 1. Due to the short term of the field experiments, the rows of data are diverse, intermittent and inhomogeneous. Taking into account the fact that the data processed have been within the contemporary climate, and that principally it is hard to conduct long-term field experiments, we adopted homogeneous ranks for the statistical processing. Longest ranks drew the maize moderately late hybrid - 13 years, sugar beet - 12 years, and maize late hybrid, wheat and soybeans - 9 years each. Maize for green, triticale, spring barley, winter barley, early potatoes, rape, maize II crop, green rye, rye-pea mixture, pea-oat mixture, pea-oat-sunflower mixture and raspberries drew 5-year rows of statistics. Cucumbers and tomatoes grown in the open air allowed obtaining only approximate values of the coefficients K_c.

According to the vegetation period the crops fell into four groups: summer crops with vegetation periods from April to September; early-spring crops with April-July vegetation period, spring pre-crops with April-May vegetation period; late and post harvesting (second) crops with vegetation periods from July to October.

Reference evapotranspiration ET_o was calculated by FAO Penman-Monteith method. Meteorological data were taken from the data base of the National Institute of Meteorology and Hydrology – Bulgarian Academy of Sciences.

The decadal K_c factor was calculated as ratio of the decadal crop evapotranspiration total to the decadal reference evapotranspiration total:

$$K_c^i = \frac{\sum ET_{crop}^i}{\sum ET_o^i},$$

where: K_c^i – crop factor for i-decade; $\sum ET_{crop}^i$ - experimental crop evapotranspiration total for i-decade, mm; $\sum ET_o^i$ reference evapotranspiration for i-decade, mm. The standard error of the mean ($s_{\bar{x}}$) of the calculated K_c decadal values was determined as:

$$s_{\bar{x}} = \frac{s}{\sqrt{n}},$$

where: s– standard deviation, mm; n – number of cases (years).

K_c factors were compared to the analogous Z factors. Z factor originates from the temperature evapotranspiration calculation method and has been calculated as:

$$Z^i = \frac{\sum ET_{crop}^i}{\sum T^i},$$

where: Z^i - crop coefficient for i-decade, $\sum T^i$ - air temperature total of i-decade. Temperature method, also called Delibaltov-Hristov-Tzonev method, is currently in use in Bulgaria.

Simulations of the soil-water balance under winter wheat, maize moderately late hybrid and soybean, using both K_c and Z, was carried out in an EXCELL environment. The simulation was done after the water-balance equation:

$$SW_k^i = SW_{k-1}^i + R_k^i + m_k^i - ET_{crop,k}^i,$$

where: SW_k, SW_{k-1} - the available water of the 1-m soil layer on k and k-1 day of i-decade, mm; R_k – rainfall total on k day, mm; $ET_{crop,k}$ - crop evapotranspiration on k day, mm; m_k^i - irrigation application rate, mm (if any). If SW_k=0 (SW_k reaches zero-value), an application rate of 60-mm was given.

The perennial rows of experimental data are allied to years of different meteorological conditions (Figure 1). Some of the years were very wet (1971, 1973, 1976, 1977), other – moderate wet (1972, 1974, 1980). There were also moderately-dry and very dry years (1979, 1982, 1984, 1985, 1986, 1987), as well as moderate years (1975, 1977, 1978, 1981, 1983, 1988, 1978). As far as air temperature was concerned, the cool and moderate-cool years prevailed, while as far as vapor pressure deficit (VPD) was concerned – the years were basically moderately-wet and moderate.

RESULTS AND DISCUSSIONS

The seasonal course of K_c factors of the summer crops are synchronic to the dynamics of the meteorological factors, especially to the air temperature. They have the greatest values in the hottest summer months July and August.

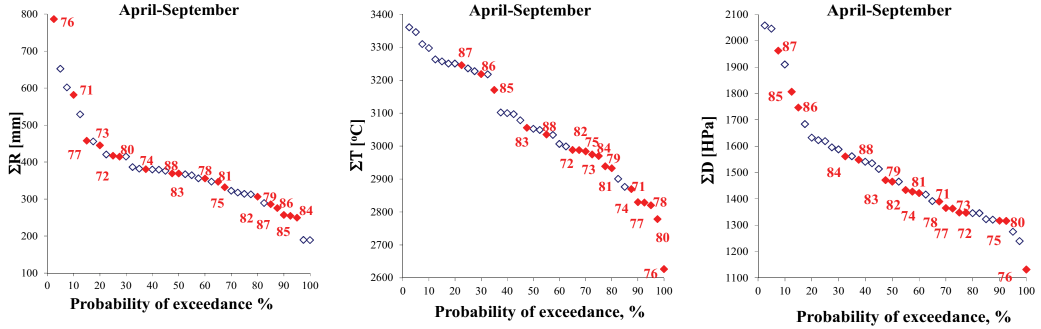

Figure 1. Probability of exceedance: Left to right: rainfall totals, air temperature totals and VPD totals

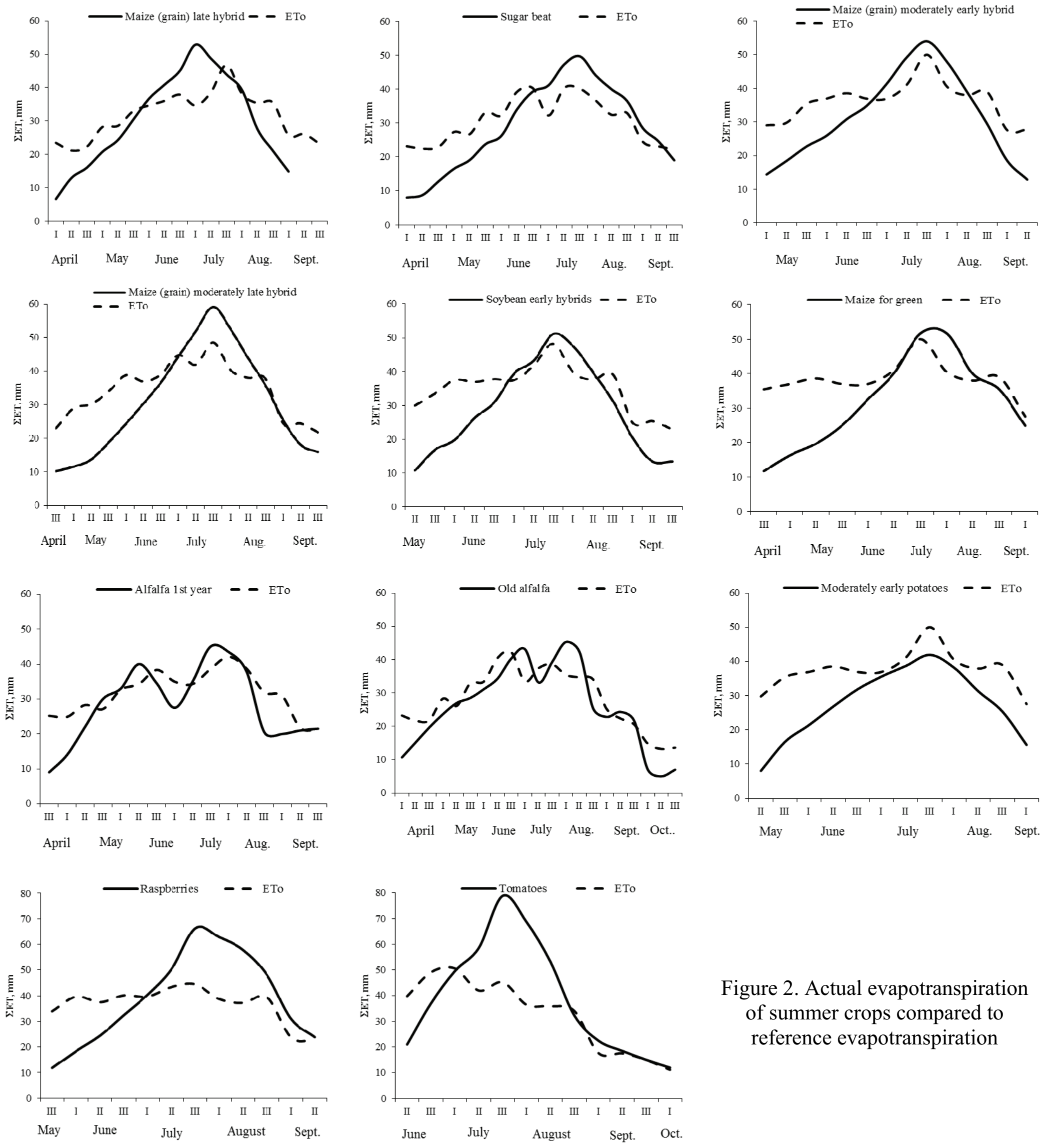

Figure 2. Actual evapotranspiration of summer crops compared to reference evapotranspiration

Table 2. K_c factors of late spring crops

Month	Decade	Maize (grain) moderately early	$S_{\bar{x}}$	Maize (grain) moderately late	$S_{\bar{x}}$	Maize (grain) late	$S_{\bar{x}}$	Maize for green	$S_{\bar{x}}$	Soybean	$S_{\bar{x}}$
April	I										
	II										
	III			0.45	0.05	0.32	0.03				
May	I	0.49	0.06	0.40	0.04	0.45	0.04				
	II	0.63	0.11	0.49	0.05	0.54	0.04			0.33	0.03
	III	0.63	0.08	0.57	0.06	0.64	0.07	0.32	0.10	0.47	0.05
June	I	0.72	0.14	0.65	0.06	0.70	0.05	0.46	0.15	0.53	0.06
	II	0.81	0.10	0.87	0.08	0.91	0.12	0.52	0.13	0.70	0.07
	III	0.95	0.06	0.97	0.07	1.00	0.08	0.68	0.14	0.83	0.07
July	I	1.13	0.06	1.01	0.05	1.19	0.06	0.90	0.20	1.00	0.07
	II	1.22	0.13	1.25	0.06	1.20	0.09	1.04	0.24	0.96	0.07
	III	1.10	0.09	1.24	0.05	1.14	0.05	1.06	0.13	1.22	0.09
Aug.	I	1.21	0.15	1.33	0.08	1.30	0.08	1.28	0.04	1.27	0.10
	II	1.14	0.32	1.18	0.08	1.27	0.06	1.11	0.20	1.09	0.09
	III	0.83	0.31	0.98	0.08	1.13	0.07	0.92	0.15	1.13	0.12
Sept.	I	0.68	0.16	1.00	0.12	1.09	0.10	0.89	0.22	0.75	0.07
	II	0.47	0.12	0.73	0.07	0.81	0.07			0.51	0.07
	III			0.75	0.06	0.65	0.07			0.33	0.07

Table 2. Continued….

Month	Decade.	Sugar beat	$S_{\bar{x}}$	Potatoes moderately early	$S_{\bar{x}}$	Alfalfa, Ist year	$\sigma_{\bar{x}}$	Alfalfa old	$S_{\bar{x}}$	Raspberries	$S_{\bar{x}}$	Tomatoes
April	I	0.30	0.03					0.46	0.09			
	II	0.43	0.08					0.70	0.11			
	III	0.59	0.09			0.17	0.09	0.93	0.10			
May	I	0.62	0.08			0.46	0.04	0.83	0.10			
	II	0.74	0.08	0.28	0.04	0.69	0.17	1.07	0.11			
	III	0.71	0.06	0.54	0.11	0.84	0.20	0.87	0.13	0.34	0.05	
June	I	0.81	0.07	0.61	0.15	0.94	0.10	0.95	0.08	0.45	0.09	
	II	0.91	0.10	0.75	0.17	1.16	0.10	0.87	0.08	0.64	0.11	0.53
	III	1.01	0.09	0.86	0.17	1.20	0.20	0.97	0.07	0.79	0.10	0.75
July	I	1.27	0.08	0.98	0.16	0.92	0.09	1.32	0.13	1.03	0.13	0.98
	II	1.19	0.08	1.07	0.13	0.81	0.09	0.90	0.09	1.16	0.10	1.40
	III	1.26	0.09	1.03	0.08	0.99	0.07	1.02	0.04	1.51	0.10	1.74
Aug.	I	1.24	0.10	0.77	0.08	1.26	0.12	1.33	0.13	1.64	0.08	1.88
	II	1.25	0.08	0.78	0.14	1.26	0.22	1.25	0.17	1.59	0.13	1.48
	III	1.11	0.07	0.67	0.10	0.67	0.11	0.77	0.11	1.25	0.10	0.95
Sept.	I	1.18	0.13	0.40	0.02	1.00	0.13	0.92	0.07	1.33	0.08	1.27
	II	1.06	0.09			1.07	0.11	1.14	0.14	1.06	0.08	1.06
	III	0.86	0.09			1.00	0.08	1.07	0.14			1.00
Oct.	I							0.49	0.00			1.08
	II							0.38	0.09			
	III							0.34	0.11			

During these months K_c is ≥1, i.e. the rate of crop evapotranspiration is greater than that of the reference evapotranspiration (Figure 2 and Table 2). The data available permitted K_c calculation with different accuracy. The long statistical rows gave more accurate results. The standard error of maize (grain) - late and moderate variety, sugar beet, 1st-year alfalfa and old alfalfa is less than 10%. Sorter rows, as those of green maize and moderate early potatoes demonstrated greater error – as much as 20% in some decades.

The spring crops of April-June vegetation were cultivated in years of dry to moderately dry conditions. Their maximal daily evapotranspiration occurred in the 3rd decade of May or in the 1st of June, mainly due to the development stage, while the course of ET_o was constantly increasing. This is evident from the illustrations on Figure 3 and the values of K_c factor (Table 3). The latter is >1 in May for all crops presented. Due to the great instability of the spring rainfalls, the accuracy of K_c of winter wheat is lower than that of the summer crops. The standard error of the decadal values of winter wheat is greatest in the 1st decade of June, of triticale and spring barley - in the 3rd of May. The values of K_c, obtained by us correspond to those suggested by FAO 56 (Allen et al., 1998): 1.15 in mid and 0.4 in late season for winter wheat; analogously 1.15 and 0.25 for barley; 1.15 and 0.75 for potatoes. $\sigma_{\bar{x}}$ of all crops in Table 2, except for spring barley, is >10%.

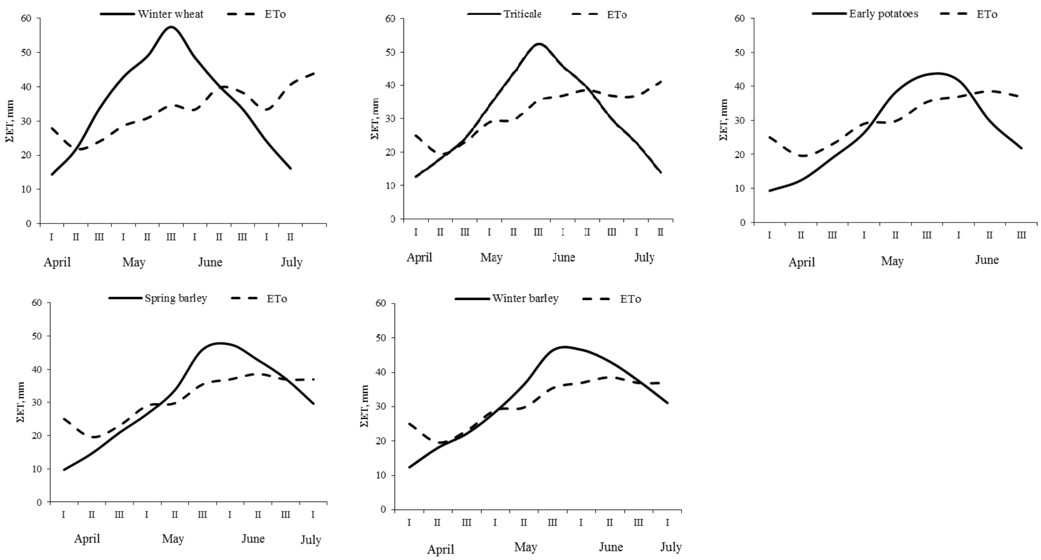

Figure 3. Actual evapotranspiration of early spring crops compared to reference evapotranspiration

Table 3. K_c factors of spring crops of April-July vegetation period

Month	Decade	Winter wheat	$s_{\bar{x}}$	Triti-cale	$s_{\bar{x}}$	Spring barley	$s_{\bar{x}}$	Winter barley	$s_{\bar{x}}$	Early potatoes	$s_{\bar{x}}$
April	I	0.52	0.12	0.53	0.16	0.40	0.04	0.53	0.11		
	II	1.01	0.17	0.91	0.15	0.76	0.09	0.95	0.14	0.47	0.12
	III	1.42	0.15	1.06	0.10	0.93	0.11	1.01	0.16	0.56	0.14
May	I	1.52	0.10	1.17	0.03	0.91	0.05	0.98	0.12	0.67	0.09
	II	1.60	0.09	1.50	0.14	1.17	0.15	1.25	0.12	0.90	0.10
	III	1.70	0.16	1.52	0.19	1.34	0.18	1.33	0.08	1.12	0.17
June	I	1.48	0.22	1.24	0.11	1.29	0.09	1.29	0.15	1.20	0.18
	II	1.04	0.11	1.03	0.16	1.12	0.08	1.14	0.15	1.09	0.17
	III	0.90	0.10	0.82	0.17	1.01	0.07	1.01	0.16	0.82	0.20
July	I	0.75	0.13	0.62	0.16	0.80	0.03	0.84	0.19	0.64	0.29
	II	0.40	0.09	0.36	0.12		0.04				

The spring pre-crops have a short vegetation period – from the beginning of April to the 2nd decade of May. The period April-May is predominantly dry to very dry. VPD is high. The course of ET_c is close to that of ET_o (Figure .4) hence K_c factors are around one (Table 4). The coefficients of spring rapeseed are with $s_{\bar{x}}$ >10%. The same is with the late crops and the second crops (Figure 5 and Table 5).

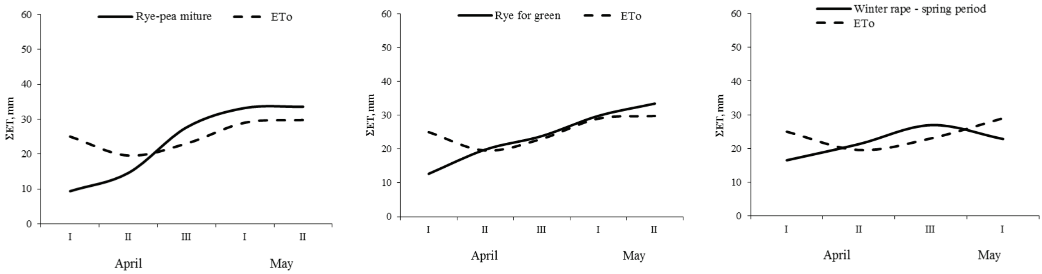

Figure 4. Actual evapotranspiration of spring pre-crops compared to reference evapotranspiration

Table 4. K_c factors of spring pre-crops of April-May vegetation period

Month	**Decade**	**Rape spring period**	$s_{\bar{x}}$	**Rye for green**	$s_{\bar{x}}$	**Rye-oats mixture**	$s_{\bar{x}}$
April	I	0.70	0.12	0.53	0.12	0.39	0.08
	II	1.11	0.23	1.03	0.17	0.74	0.12
	III	1.20	0.17	1.03	0.07	1.20	0.11
May	I	0.77	0.13	1.04	0.17	1.15	0.08
	II			1.11	0.15	1.13	0.06

The late crops and post-harvest second crops develop in the driest period of the year in nearly arid conditions. In most of the experimental years the period is moderately dry to very dry, and moderately warm to very warm. The daily crop evapotranspiration is highest during the 3rd decade of August and in September, while ET_o tends to lower values in autumn (Figure 5). This reflects on K_c which is >1 predominantly in September. The coefficients of rape and cabbage are similar to those suggested by FAO 56 (Allen et al., 1998): rapeseed - 1.5 for mid and 0.35 for late season; cabbage - 1.05 and 0.95 respectively.

A very narrow correlation between K_c and Z factors was established. The determination coefficients (Table 6) are in the range of 0.81-0.97 mainly. This is evidence for the like reading of the temperature factor in both calculation methods and for its main role in evapotranspiration formation.

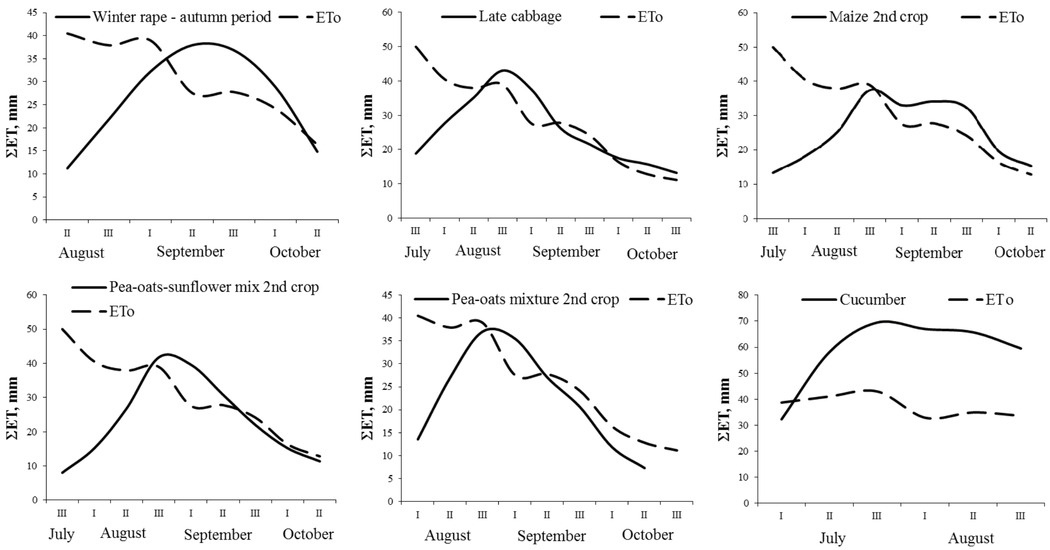

Figure 5. Actual evapotranspiration of second and other summer crops compared to reference evapotranspiration

Table 5. K_c factors of late crops and second crops of July-October vegetation period

Month	Dec	Maize 2nd crop	$s_{\bar{x}}$	Rape autumn period	$s_{\bar{x}}$	Late cabbage	$s_{\bar{x}}$	Pea-oats mixture 2nd crop	$s_{\bar{x}}$	Pea-oats-sunflower mixture 2nd crop	$s_{\bar{x}}$	Cucumber	$\sigma_{\bar{x}}$
July	III	0.28	0.06			0.40	0.10			0.17	0.04		
Aug.	I	0.46	0.11			0.69	0.07	0.33	0.12	0.38	0.06	0.83	0.02
	II	0.72	0.16	0.34	0.13	0.99	0.18	0.76	0.20	0.70	0.05	1.42	0.03
	III	0.99	0.20	0.58	0.12	1.13	0.18	0.99	0.13	1.06	0.11	1.62	0.10
Sept.	I	1.21	0.18	1.17	0.11	1.34	0.18	1.29	0.07	1.43	0.17	2.07	0.29
	II	1.24	0.18	1.37	0.13	0.94	0.19	0.97	0.10	1.10	0.16	1.89	0.11
	III	1.40	0.35	1.54	0.18	0.91	0.26	0.85	0.22	0.96	0.21	1.77	0.12
Oct.	I	1.22	0.17	1.75	0.31	1.15	0.31	0.76	0.31	0.94	0.21		
	II	1.23	0.17	1.11	0.25	1.25	0.36	0.56	0.28	0.89	0.22		
	III					1.18	0.35						

Table 6. Correlation between K_c and Z factors

Nb.	Crop	Regression equation	R^2
Late spring crops			
1	Maize (grain) moderately early	$K_c = 4.9561\ Z + 0.0645$	0.9212
2	Maize (grain) moderately late	$K_c = 4.8986\ Z + 0.0830$	0.9134
3	Maize (grain) late	$K_c = 5.4223\ Z + 0.0171$	0.9192
4	Maize for green	$K_c = 5.4559\ Z - 0.0143$	0.9483
5	Soybean	$K_c = 4.7968\ Z + 0.1191$	0.7814
6	Sugar beat	$K_c = 5.7113\ Z - 0.0687$	0.8767
7	Potatoes moderately early	$K_c = 5.4373\ Z - 0.0175$	0.9060
8	Alfalfa, Ist year	$K_c = 5.6327\ Z – 0.0594$	0.6734
9	Alfalfa old	$K_c = 4.6147\ Z + 0.1242$	0.5705
0	Raspberries	$K_c = 5.9481\ Z - 0.0412$	0.9224
11	Tomatoes	$K_c = 3.8531\ Z + 0.4111$	0.6938
Spring crops of April-July vegetation period			
12	Winter Wheat	$K_c = 4.7205\ Z + 0.0440$	0.9705
13	Triticale	$K_c = 4.8249\ Z + 0.0037$	0.9404
14	Spring Barley	$K_c = 5.1318\ Z - 0.0628$	0.9335
15	Winter Barley	$K_c = 4.8432\ Z - 0.0058$	0.8566
16	Early potatoes	$K_c = 4.2867\ Z + 0.096$	0.5387
Spring pre-crops of April-May vegetation period			
17	Rape spring period	$K_c = 3.312\ Z + 0.2308$	0.9739
18	Rye for green	$K_c = 3.8123\ Z + 0.168$	0.8167
19	Rye-pea mixture	$K_c = 4.5295\ Z + 0.0317$	0.9251
Late crops and second crops of July-October vegetation period			
20	Maize 2nd crop	$K_c = 7.3462\ Z - 0.1032$	0.8437
21	Rape autumn period	$K_c = 7.9507\ Z - 0.157$	0.9106
22	Late cabbage	$K_c = 5.7556\ Z + 0.1051$	0.6621
23	Pea-oats mixture 2nd crop	$K_c = 5.4351\ Z + 0.1283$	0.8609
24	Pea-oats-sunflower mixture 2nd crop	$K_c = 6.0777\ Z + 0.0584$	0.8541
25	Cucumber	$K_c = 5.4232\ Z + 0.0615$	0.8293

The simulation of the soil water balance under maize (grain), soybean and winter wheat by using the evapotranspiration data, calculated by both methods – FAO Penman-Monteith and Delibaltov-Hristov-Tsonev, shows similar results. The course of depletion of the readilyavailable water by both methods is parallel and the dates for giving application mismatch 4 days at worst.

The results from figure 6 show firstly, that both methods are similarly accurate and the chief formative factor for crop evapotranspiration is air temperature and secondly, that there is no need for substituting of Delibaltov-Hristov-Tzonev calculation method with FAO Penman-Monteith method. The first one is simpler and with easy maintainance with meteorological information.

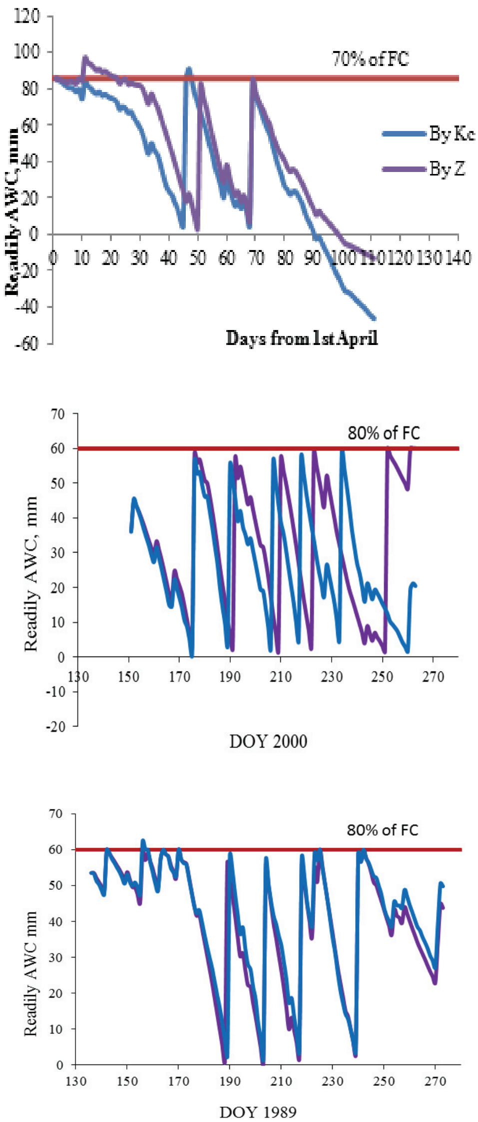

Figure 6. Soil water balance under winter wheat calculated with considering FAO 56 method and the method of air temperature totals. ET_o and ET_c of a) winter wheat; b) maize (grain) moderately late hybrid; c) soybean early hybrids

CONCLUSIONS

K_c values obtained correspond with those, suggested by FAO 56. They can be used for calculation of crop evapotranspiration in Bulgarian climate conditions. Their determination is a step for validation of FAO Penman-Monteith evapotranspi-ration calculation method to the regional climate peculiarities.

FAO Penman-Monteith method and Delibaltov-Hristov-Tzonev method for estimation of crop evapotranspiration have similar accuracy.

FAO Penman-Monteith method can successfully be used in Bulgarian climate conditions, but Delibaltov-Hristov-Tzonev one is considerably simpler and easy for maintenance with meteorological information. Hence there is no need for replacing it from practice.

REFERENCIES

Al Shaua F., 1974. PhD Thesis. Agricultural Academy „G. Dimitrov", S., p. 190.

Allen R.G., Pereira L.S., Raes D., Smith M., 1998. Crop evapotranspiration. Guidelines for computing crop water requirements. FAO Irrigation. and Drainage Paper 56, Rome, p. 300.

Gaidarova S., 1988. PhD Thesis. IHM, S., p. 235.

Daher F., 1981. PhD Thesis, Soil Science Inst. "N. Pushkarov", S., p. 210.

Davidov D., Moteva M., 2010. Comparison between the evapotranspiration, calculated by FAO 56 method and the method of temperature totals. Agricultural Engineering, 1, p. 102-106.

Delibaltov Y., Zahariev T., 1977. Sci. Report of IHM (unpublished data).

DelibaltovY., Hristov H., Tzonev I., 1962. Design irrigation scheduling for the agricultural crops. Proc. IHM, 3, p. 5-56.

Kazandjiev V., Moteva M., Georgieva V., 2010. Climate change, agroclimatic resources and agroclimatic zoning of the agricultural production. Agricultural Engineering, 3, p. 109-116.

Lazarov R., 1984. Sci. Report of IHM, S. (unpublished data).

Lazarov R., Mehandzhieva A., Zahariev T., Zhivkov Zh., 1982. Sci Report of IHM, S. (unpublished data).

Mehandzhieva A., 1974. PhD Thesis, IHM, S. Mehandzhieva, A. 1982. Report of IHM, S. (unpublished data).

Moteva M., Kazandjiev V., Zhivkov Zh., Georgieva V., Georgieva I. 2011. Irrigation scheduling on the base of differently estimated crop evapotranspiration. Journal Agri. Mach. Sci, 7, 3, 1, p. 225-230.

Zahariev T., 1977. PhD Thesis. IHM, S. p. 193.

Zahariev T., Lazarov R., Koleva S., Gaidarova S., Koychev Z. 1990. Zoning of the Irrigation Scheduling of the Agricultural Crops in Bulgaria. Zemizdat,. S., p. 646.

Zhivkov Zh., 1990. PhD Thesis., S., IHM, p. 176.

Zhivkov Zh., Mladenova B., 1994. Irrigation of soybean under conditions of water shortage. Proc. 17th ICID Eu. Reg. Conf., Varna, Bulgaria, p. 65-68.