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Crop Coefficients of Winter Wheat under South Serbia Conditions

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ABSTRACT— ***Field trials with irrigation of winter wheat have been set in the river valley of Southern Morava, near Niš, at the alluvium soil type, in the period 2009-2011. Irrigation was carried out by sprinkler irrigation method, and its term was determined by observing dynamics of soil moisture down to 60 cm of depth. Considering both investigated years, the highest grain yield of winter wheat was reached at the irrigated variant with pre-irrigation soil moisture 70% of FWC (8678 kg ha^{-1} and 9180 kg ha^{-1}), and for that reason the observed values of ET at this variant from 381.1 to 393.1 mm represent potential evapotranspiration (PET) or CWR of winter wheat for the conditions of southern Serbia. The values of $K_{c\ ini}$ (0.53), $K_{c\ mid}$ (1.10) and $K_{c\ end}$ (0.28) obtained by our experimental study are different from those developed for other areas. The development of regionally based K_c exceptionally helps in irrigation management and gives precise application of water in these areas.***

Keywords— Winter Wheat, Crop Coefficient, Potential Evapotranspiration, Irrigation.

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1. INTRODUCTION

Water deficiency during winter wheat vegetation is an important limiting factor in achieving high and stable grain yield. Optimal soil moisture for growing agricultural crops can only be reached in the conditions of irrigation. Water consumption of winter wheat for evapotranspiration (ET), in the conditions of optimal soil humidity during whole vegetation period, is called potential evapotranspiration (PET). Determining value potential evapotranspiration or crop water requirements (CWR), is the initial base for planning production in the conditions of irrigation. CWR is defined as "the depth of water needed to meet the water loss through evapotranspiration of a crop, being disease-free, growing in large fields under non restricting soil conditions, including soil water and fertility, and achieving full production potential under the given growing environment" (Doorenbos and Pruitt, 1984). PET values ar obtained by direct measurement or by calculation based on climate data. Direct measurements of PET are complex and are done in research institutions. Therefore, in order to simplify the determination of CWR, it was proposed a number of indirect methods of calculation.

The concept of expressing crop water requirements through reference evapotranspiration (ET_o) was accepted at the research institutions and irrigation practices. Analysis of numerous data of referent evapotranspiration (ET_o), obtained by various calculation methods and direct observations, was the base for recommendation of FAO Penman-Monteth equation as the standard method for calculating ET_o (Allen *et al.,* 1998). The crop water requirements or evapotranspiration crop (ET_c) is calculated by multiplying the reference crop evapotranspiration by a crop coefficient.

Crop coefficient (K_c) during the growing season varies and depends on the growth stages of crops. The vegetation period is divided into four distinct growth stages: initial, crop development, mid-season and late season. For the calculation of daily ETc is necessary to determine the daily value of K_c value, using the curve coefficient crops. Only three values for Kc are required to describe and construct the crop coefficient curve: those during the initial stage ($K_{c\ ini}$), the mid-season stage ($K_{c\ mid}$) and at the end of the late season stage ($K_{c\ end}$) (Savva and Frenken, 2002). The values of K_c affect crop species and varieties, soil properties, climatic conditions and growing practice of crop. Therefore, the values of Kc obtained in earlier studies (Doorenbos and Pruitt, 1977; Doorenbos and Kassam, 1979; Wright, 1982; Pruitt, 1986;

Snyder *et al.*, 1989) have been calibrated by experimental research for different pedoclimatic conditions by many authors (Tarantino and Onofrii, 1991; Cavazza, 1991; Annandale and Stockle, 1994; Cornic and Massassi, 1996; Bruce, 1997; Allen *et al.*, 1998; Paço *et al.*, 2004; García and Castel, 2007; Conceição, 2008; Piccinni, 2009; etc.).

The aim of the research is that in terms of irrigation, using the method of soil water balance determines the demand of winter wheat water and calculating reference evapotranspiration for the conditions of southern Serbia. Obtained potential evapotranspiration of winter wheat and reference evapotranspiration will be used for calculating the crop coefficients.

2. MATERIALS AND METHODS

Field trials with irrigation of winter wheat have been set in the river valley of Southern Morava, near Niš, at the alluvium soil type, in the period 2009-2011. The trials were set at 198 m of altitude, 43°19' N of latitude and 21°54' E of longitude, in random complete block design (RCBD) with five replications. Areas of elementary plots were 35 m^2, and during vegetation were carried out usual agrotechnical measures for wheat.

The winter wheat cultivar NS Rana 5 was sown on October 12th in 2009, and on October 17th in 2010. Seeding rate was 500 germinative seeds per m^2. The harvest was carried out during the second decade of July in both years of investigation.

Irrigation was carried out by sprinkler irrigation method, and its term was determined by observing dynamics of soil moisture down to 60 cm of depth. Soil moisture content was measured by thermogravimetric analysis in the oven at 105-110°C. Trials included three irrigation variants with pre-irrigation soil moisture 60%, 70% and 80% of FWC, as well as unirrigated control.

Calculation of water consumption for evapotranspiration in the conditions of irrigation was done for each month (1) and for vegetation period in whole (2), by balancing water from precipitation during vegetation period, soil supplies (3), irrigation, and potentially percolated or flown out water after heavy rains (4).

$$\boldsymbol{ETv = (W_1 - W_2) + P + I - D} \text{ (mm)} \tag{1}$$

$$\boldsymbol{ETm = (W_1 - W_2) + P + I - D} \text{ (mm)} \tag{2}$$

where *ETv* is evapotranspiration for vegetation period (mm); *ETm* is evapotranspiration for month W_1 is amount of water in soil to the depth of 2 m at the beginning of month and vegetation period (mm); W_2 is amount of water in soil to the depth of 2 m at the end of month and vegetation period (mm); *P* is water amount from precipitation (mm); *I* is water amount from irrigation (mm); *D* is water loss by deep percolation (mm).

$$\boldsymbol{W = 100 \cdot h \cdot d \cdot s} \text{ (mm)} \tag{3}$$

where *W* is amount of water in soil (mm) to the depth of 2 m ; *h* is depth of soil (m); d is bulk density (g cm^{-3}); *s* is soil moisture (%).

Following heavy precipitation, water percolation into deeper soil layers was calculated:

$$\boldsymbol{D = (W_1 + P) - FWC} \text{ (mm)} \tag{4}$$

where *D* is deep percolation (mm); W_1 is soil water amount to the depth of 2 m at the beginning of month and for vegetation period (mm); *P* is precipitation amount (mm); *FWC* is field water capacity (%).

$$\boldsymbol{ETd = ETm / n} \tag{5}$$

where *ETd* – average daily evapotranspiration (mm), *n* – number of days in the month (for October and July, the number of days of crops in the field).

The obtained values of texture analysis (Table 1) were expected, because fractional relations confirmed that this is a loamy alluvial soil. Immediately before the study began, physical properties of soil in the experimental field were determined (table 1).

Table 1. Mechanical and physical properties of soil

Depth (cm)	Total sand (%) > 0,02 mm	Silt (%) 0,02-0,002 mm	Clay (%) < 0,002 mm	Field water capacity (%)	Specific weight (g cm^{-3})	Bulk density (g cm^{-3})	Total porosity (vol. %)
0-20	42.1	40.5	17.4	17.4	17.4	17.4	17.4
20-40	40.3	37.8	21.9	21.9	21.9	21.9	21.9
40-60	38.7	36.3	25.0	25.0	25.0	25.0	25.0

Reference evapotranspiration has been calculated by the method FAO Penman-Monteith:

$$ET_o = \frac{0,408\Delta\,(R_n - G) + \gamma \frac{900}{T+273} u_2\,(e_s - e_a)}{\Delta + \gamma\,(1 + 0,34\,u_2)} \tag{6}$$

where ET_o is reference evapotranspiration (mm dan^{-1}), R_n is net radiation at the crop surface (MJ m^{-2} dan^{-1}), G is soil heat flux density (MJ m^{-2} dan^{-1}), T means daily air temperature at 2 m height (°C), u_2 is wind speed at 2 m height (m s^{-1}), e_s is saturation vapour pressure (kPa), e_a is actual vapour pressure (kPa), e_s-e_a is saturation vapour pressure deficit (kPa), Δ is slope vapour pressure curve (kPa °C^{-1}), γ is psychrometric constant (kPa °C^{-1}).

Required meteorological data for calculating reference evapotranspiration, have been retrieved from internet site of the Republic Hydrometeorological Servis of Serbia (2015), for weather station Niš, except rainfall which was measured by rain gauge at the experimental field (Table 2).

The values of crops coefficients were determined by months and stages of development of winter wheat (initial, crop development, mid-season, late season). Crop coefficients were calculated by equation:

$$K_c = PET / ET_o \quad (7)$$

where K_c is crop coefficient ET_o is reference evapotranspiration (mm dan^{-1}), PET is potential evapotranspiration.

Table 2. Meteorological parameters for the investigated period

Year	2009/10								2010/2011							
Month	T_{mean} (°C)	T_{min} (°C)	T_{max} (°C)	RH (%)	Wind (m/s)	Sun (hours)	Rainfall (mm)	e_a (kPa)	T_{mean} (°C)	T_{min} (°C)	T_{max} (°C)	RH (%)	Wind (m/s)	Sun (hours)	Rainfall (mm)	e_a (kPa)
X	12.1	7.4	18.4	78	0.7	4.2	84	1.1	10.1	6.2	15.4	77	0.9	3.1	73	0.9
XI	8.3	4.0	14.5	82	0.5	3.0	101	0.9	12.1	7.2	18.9	71	1.2	3.5	44	0.9
XII	4.5	1.0	8.8	81	0.9	1.0	73	0.7	2.8	-1.2	7.7	79	1.3	1.4	72	0.6
I	1.2	-1.8	5.1	79	1.2	1.3	54	0.6	0.6	-2.7	4.8	83	0.8	1.7	24	0.5
II	3.5	-0.1	7.9	79	1.2	1.5	88	0.6	0.3	-2.6	4.4	80	1.4	2.0	43	0.5
III	7.6	3.1	13.2	68	1.4	4.3	52	0.7	6.9	2.2	12.7	69	1.4	5.0	30	0.7
IV	12.9	7.7	18.5	71	1.0	5.4	79	1.0	12.5	6.8	18.6	59	1.5	6.0	12	0.8
V	17.2	11.8	23.3	71	0.8	5.6	65	1.4	16.4	10.6	22.8	69	0.9	6.1	58	1.3
VI	21.0	15.5	27.2	72	0.8	7.3	53	1.8	21.2	14.9	27.4	63	1.0	7.6	42	1.6
VII	23.0	17.5	29.6	70	0.8	8.3	35	1.9	23.5	16.5	30.4	61	0.6	8.9	47	1.7
VIII	23.6	17.0	31.4	65	0.6	8.9	29	1.8	24.2	16.2	32.0	54	0.9	10.6	4	1.5
IX	17.9	12.2	25.2	67	0.8	3.2	14	1.3	21.6	14.5	29.7	58	0.7	8.8	38	1.4

T_{min} – Average monthly minimum temperature, T_{max} – Average monthly maximum temperature, RH – Means relative humidity, e_a – Actual vapour pressure.

Data of winter wheat grain yield were processed by analysis of variance, and significance of differences in yield was determined by comparing them with LSD values for P<0.05 and P<0.01. The effect of pre-irrigation soil moisture and evapotranspiration on winter wheat grain yield was analyzed by regression analysis.

3. RESULTS AND DISCUSSION

Grain yield of winter wheat was high-significantly greater at the variant with pre-irrigation soil moisture 70% of FWC in regard to the other two irrigated variants and unirrigated control (Table 3). Comparing variants with pre-irrigation soil moisture 60% and 80% of FWC, grain yield was higher in the former than in the latter one, at the level of significance P<0.05. In the production season 2009/10, when precipitation pattern was favorable, grain yield was higher at unirrigated control in regard to the irrigated variant with pre-irrigation soil moisture 80% of FWC. Grain yield increase by irrigation in the season 2009/10 was from 1.57% to 4.93% comparing with unirrigated control. The effect of irrigation on grain yield increase in regard to the control ranged between 19.05% and 32.85% in the season 2010/11.

Table 3. Sources of water used for evapotranspiration of winter wheat as affected by pre-irrigation soil humidity

Year	Pre-irrigation soil moisture	Soil water supplies (mm)	Precipitation (mm)	Irrigation (mm)	Grain Yield kg ha^{-1}	ET (mm)
2009/10	80% FWC	51.2	279.5	80	6350	410.7
	70% FWC	63.6	279.5	40	7480	393.1
	60% FWC	84.0	279.5	20	6870	383.5
	Control	92.7	279.5	-	6070	372.2
2010/11	80% FWC	43,5	211.7	150	6520	405.2
	70% FWC	49.4	211.7	120	7110	381.1
	60% FWC	54.3	211.7	80	6340	346.0
	Control	77.8	211.7	-	4780	289.5
LSD (grain yield)		FWC	Year	FWC x Year		
0.05		91.30	64.56	129.08		
0.01		122.94	86.93	173.81		

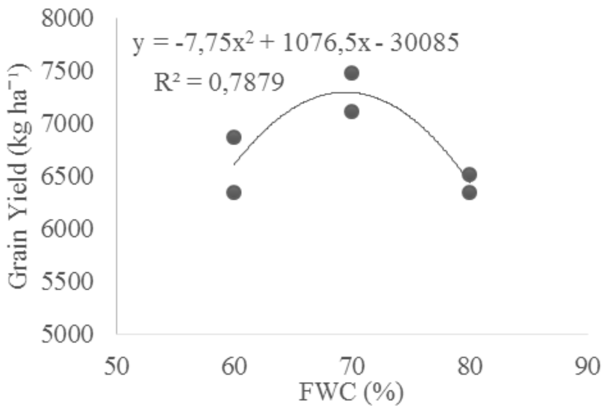
FWC – field water capacity, ET – evapotranspiration

Having in mind that the highest grain yield was reached at pre-irrigation soil moisture 70% of FWC, this value represents a proper term for irrigation of winter wheat in edaphic and climatic conditions of southern Serbia. Sources of water spent for evapotranspiration of winter wheat are given in Table 3.

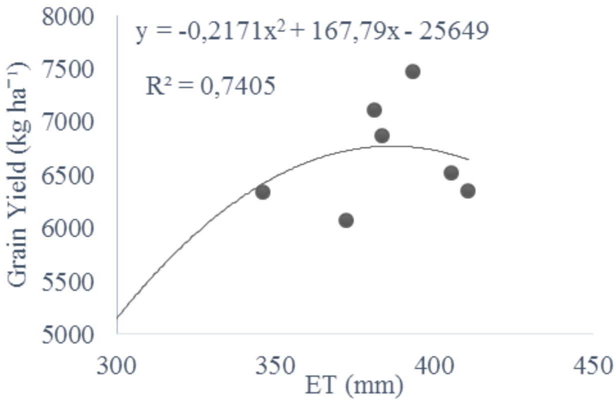
Water consumption of winter wheat for evapotranspiration (289.5-410.7 mm) was measured by the method of water balance. Highest values of wheat ET were observed at the irrigated variant with pre-irrigation soil moisture 80% of FWC (405.2-410.7 mm), while the lowest ET values were found at the control (289.5 mm) and the variant with pre-irrigation soil humidity 60% of FWC (346 mm).

Considering both investigated years, the highest grain yield of winter wheat was reached at the irrigated variant with pre-irrigation soil moisture 70% of FWC (8678 kg ha^{-1} and 9180 kg ha^{-1}), and for that reason the observed values of ET at this variant from 381.1 to 393.1 mm represent potential evapotranspiration (PET) or CWR of winter wheat for the conditions of southern Serbia.

The observed values of potential evapotranspiration are higher than the values reported by Vučić (1976) and Bošnjak (1999). Measured PET of winter wheat presented in our study is similar to the values (345-385 mm) reported by Luchiari *et al.* (1997) and Balwinder *et al.* (2011). Higher values of winter wheat evapotranspiration in regard to our study were found by Liu *et al.* (2002), Kang *et al.* (2003) and Haijun *et al.* (2011).



Graph 1. The effect of pre-irrigation soil moisture on wheat grain yield



Graph 2. The effect of ET on wheat grain yield

Polynomial regression analysis of the effect of pre-irrigation soil moisture on grain yield (Graph 1) pointed out to a high level of interconnectedness between wheat grain yield and soil moisture. Regression analysis of the effect of ET on wheat grain yield showed parabolic curve (Graph 2), which pointed to a fact that increased water consumption for ET of wheat was not efficiently used for increasing grain yield.

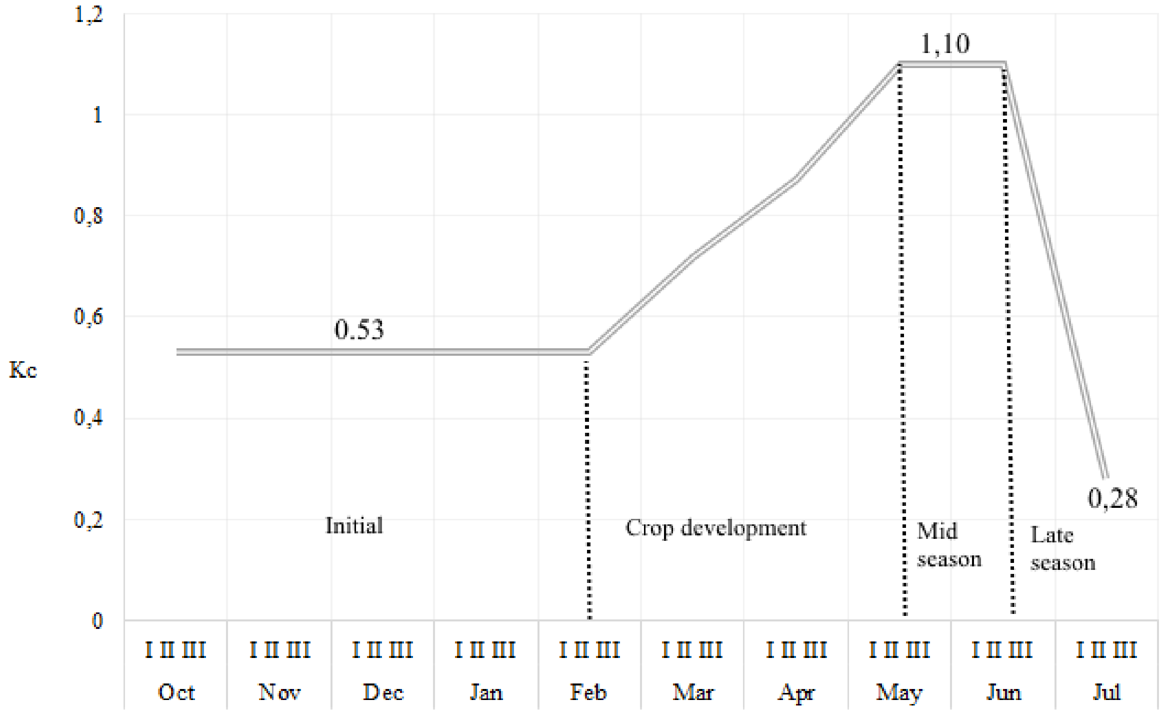
The measured values of PET winter wheat (1) and calculated ET_o (6), is used, in the equation (7) for calculating the value of K_c. The average value of K_c winter wheat increased from 0.35 in the initial stage (owerwintering) to 1.10 in stage mead-season, and then decreased to 0.28 late stage (Table 4). K_c and stage mead-season reaches its maximum value and relates to the period of vegetation that is most important for irrigation and is of great importance for the correct assessment of crops water requirements. For the practice of irrigation of winter wheat in southern Serbia are important monthly values of K_c for May and June, when there is a deficit of soil moisture.

Table 4. K_c, potential and reference evapotranspiration of winter wheat

Month	2009/10			2010/11			Average
	ET_o (mm)	PET (mm)	K_c	ET_o (mm)	PET (mm)	K_c	K_c
X	20.7	13.5	0.65	20.2	10.9	0.54	0.60
XI	22.2	14.1	0.63	28.2	13.6	0.48	0.55
XII	18.3	10.2	0.56	21.7	10.7	0.49	0.52
I	17.4	6.4	0.37	14.6	4.8	0.33	0.35
II	21.0	13.7	0.65	18.8	11.3	0.60	0.62
III	49.9	37.4	0.75	48.7	33.9	0.70	0.72
IV	70.8	66.2	0.93	83.7	68.2	0.81	0.87
V	95.2	104.6	1.10	97.6	101.0	1.10	1.10
VI	117.0	107.6	0.92	123.9	105.4	0.85	0.88
VII	67.8	19.4	0.29	78.8	21.3	0.27	0.28
Total	500.3	393.1		536.2	381.1		

K_c – crop coefficient, ET_o – referent evapotranspiration, PET – potential evapotranspiration

Identifying the winter wheat growth stages and determining their lengths were carried out at the experimental field. K_c curve (graph 3) was constructed using the average monthly value of K_c from the table 4. Calculated values of K_c at stages of development ($K_{c\ ini}$, $K_{c\ mid}$, $K_{c\ end}$) of winter wheat for semi-arid climate conditions in southern Serbia are shown on the curve of Kc. The values of $K_{c\ ini}$ (0.53), $K_{c\ mid}$ (1.10) and $K_{c\ end}$ (0.28) obtained by our experimental research are smaller than those given in the FAO-56 (Allen, *et al.*, 1998). Our values ($K_{c\ ini}$, $K_{c\ mid}$, $K_{c\ end}$) are also similar from the value (0.70, 1.15 and 0.30) that have been determined Jaćimović (2012) for the conditions of northern Serbia. Equal to our values for $K_{c\ ini}$ and $K_{c\ mid}$ were determined by the conditions of Texas (Ko, *et al.*, 2009) while the value of K_c end was higher (0.40). The differences between the values of K_c in our studies and those in earlier research are expected. Varying the values of K_c is a result of the influence of changed climate conditions, applied cropping practices, irrigation methods and characteristics of the variety, on the development of crops or value K_c.



Graph 3. K_c curve of winter wheat research period 2009-2010

4. CONCLUSION

On the basis of the investigation results obtained in the conditions of wheat irrigation the following conclusion can be drawn out:

Irrigation regime based on monitoring dynamics of soil moisture is efficient, and the best term for wheat irrigation in the conditions of southern Serbia is when soil moisture is 70% of FWC. Potential evapotranspiration of wheat is established (381.1–393.1 mm) as well as its significant effect on grain yield.

The need for regionalized value K_c is demonstrated by the comparison between K_c developed in northern Serbia and those obtained in our research in southern Serbia. The development of regionally based K_c exceptionally helps in irrigation management and gives precise application of water in these areas.

The research results enable us to realize with established K_c values an efficient water regime of winter wheat in the conditions of southern Serbia or areas with similar agroclimatic condition.

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