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Potential evapotranspiration of winter wheat in the conditions of south Serbia

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Abstract

Variable climatic conditions during vegetation in our country, where precipitation vary by amount and schedule, show a very great effect on winter wheat grain yield and quality. Establishing crop water requirements (ET_c) is an initial foundation for reaching grain yield adequate to high genetic potential of modern cultivars. 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. Trials included three irrigation variants with pre-irrigation soil moisture of 60%, 70% and 80% of FWC, as well as unirrigated control. Water used on evapotranspiration of winter wheat (289.5-410.7 mm) was measured by water balance method. Considering average for both investigated years, the highest grain yield of winter wheat was observed at the variant with pre-irrigation soil moisture 70% of FWC (7110 kg ha^{-1} and 7480 kg ha^{-1}), so measured values of ET at this variant from 381.1 to 393.1 mm represented potential evapotranspiration (PET) of winter wheat in southern Serbia. Calculated requirements for water of winter wheat by CROPWAT model for the season 2009/10 was 409.9 mm, while in the season 2010/11 calculated water consumption amounted 432.6 mm of water. Efficient use of CROPWAT model for calculation of winter wheat water requirements is possible, if calibration of crop coefficients (K_c) for agroecological conditions of southern Serbia is previously carried out.

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Introduction

Water deficiency during vegetation of winter wheat is an important limiting factor for achieving high and stable grain yield. If optimal water supply for plants is reached, i.e. if optimal soil humidity is kept, which one is able to do in the conditions of irrigation, then the water consumption would be at the level of plant demand, depending on plant phenological stages of growth and development, and energetic capability of the environment. This observed value of water consumption by plants, if maximal yield of high quality grains is reached, is called potential evapotranspiration (PET), and it, in fact, represents crop water requriments (Bošnjak, 1999).

Establishing potential evapotranspiration of winter wheat, is the initial base for planning production in the conditions of irrigation. Wheat evapotranspiration in various production areas are betwen 450-650 mm (FAO, 2013). Luchiari *et al.* (1997) found wheat water consumption for ET of 345–385 mm. In the conditions of northern Serbia, Vučić (1976) and Bošnjak (1999) observed wheat PET 320-360 mm. Dragović and Maksimović (2000), in the conditions of irrigation, estimated PET of wheat as 293–346 mm. Xiying *et al.* (2011) reported values of wheat PET from 401–458 mm. In a three year study, Haijun *et al.* (2011) observed PET of wheat within the range of 266–499 mm.

Potential evapotranspiration can be determined by direct measurement, usually carried out in research institutions, while in practice most frequently are used numerous indirect calculation procedures. Looking back at early attempts of calculating PET, one can see that the intention was to enable global use of the method. 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). Crop water requirements is then calculated as the product of ET_o and plant coefficients (K_c) for agricultural crops.

CROPWAT 8.0 is software for calculating crop water requirements and irrigation schedule, based on the data about soil, climate and agricultural crops (FAO, 2009). The all calculation procedures used in the software are based on FAO publications No 56 (Allen *et al.,* 1998) and No 24 (Doorenbos and Kassam, 1979). Many researchers used CROPWAT model to analyze crop water requirements in various regions of the world and recommend checking that it can be apply in different climate and soil conditions. (Dechmi *et al.,* 2003; Gouranga and Verma, 2005; Martyniak *et al.,* 2006).

Water use efficiency (WUE) is defined by yield divided by water consumed for evapotranspiration of winter wheat (Dorenbos and Pruit, 1977). Many researchers (French and Shultz, 1984; Steiner *et al.*, 1985; Cornish and Muray, 1989; Musick *et al.,* 1994; Zhu *et al.,* 1994; Li *et al.,* 2000; Kang *et al.,* 2002; Shao *et al.,* 2002) pointed out to importance of an efficient use of water (WUE) for reaching high wheat grain yield.

Importance of ratio between grain yield and evapotranspiration for wheat production in the conditions of irrigation is out of question. This study has been aimed to compare values of wheat PET observed by direct measurement with the values calculated by CROPWAT 8.0 software, and to establish possibility of this software's application in soil and climatic conditions of southern Serbia.

Material and methods

The experimental investigation through field trials has been carried out in the river valley of Južna Morava, municipality of Merošina, on the alluvium soil type, during 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 m², and during vegetation were carried out usual agrotechnical measures for wheat.

The winter wheat cultivar NS Rana 5 was sown at

October 12^{th} in 2009, and at October 17^{th} in 2010. Seeding rate was 500 germinative seeds per m^2. Harvest was carried out during second decade of July in both years of investigation.

Irrigation was carried out by spray irrigation method, and its term was determined by observing dynamics of soil humidity 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 and for vegetation period in whole (1), by balancing water from precipitation during vegetation period, soil supplies (2), irrigation, and potentially percolated or flown out water after heavy rains (3).

$ET_{vp} = (W_1 - W_2) + P + I - D$ (mm) (1)

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

$W = 100 \cdot h \cdot d \cdot s$ (mm) (2)

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:

$D = (W_1 + P) - FWC$ (mm) (3)

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

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, water-physical properties of soil in the experimental field were determined (table 2).

Water utilization efficiency of winter wheat (WUE) has been calculated as the observed wheat grain yield divided by water consumption for evapotranspiration according to Hussain *et al.* (1995).

$WUE = GY / ET$ (4)

where WUE is water utilization efficiency (kg ha^{-1} mm^{-1}); GY is wheat grain yield (kg ha^{-1}); ET is evapotranspiration (mm).

The collected data were processed by standard statistic methods usually used in biological studies, i.e. analysis of variance, and least significant differences for probability of error under 0.01 and 0.05 were presented.

Required meteorological data (average monthly values of minimum and maximum air temperature, wind speed, relative air humidity, and number of sunny hours) for feeding CROPWAT 8.0 software have been retrieved from internet site of the Republic Hydrometeorological Servis of Serbia (2014), for weather station Niš, except rainfall which was measured by rain gauge at the experimental field (table 3).

The first version of CROPWAT software was developed by FAO Land and Water Development Division (Smith, 1992). It contained a simple model of water balance, which enabled simulation of a crop in the conditions of water stress, estimation of grain yield decrease based on well-established methods for measuring crop evapotranspiration, as well as reaction of a crop to water (Doorenbos and Kassam, 1979).

CROPWAT 8.0 is the latest version of the software which is able to determine the following parameters: referent evapotranspiration (ET_o), crop water requirements (ET_c), irrigation term, moisture deficiency of soil at daily levels, as well as grain yield decrease caused by water stress. Crop coefficients for winter wheat (K_c) used for calculation of ET_c had been calibrated for soil and climatic conditions of northern Serbia (Jaćimović, 2012).

Results

Wheat grain yield was higher in the vegetation season 2009/10 in regard to the season 2010/11 at the level of significance P<0.01 (table 4). The highest difference between the investigated years was when control variants were compared, which was a consequence of different weather conditions and water supplies in soil. The highest average grain yield of 7295 kg ha^{-1} was achieved at the variant with pre-irrigation soil moisture 70% of FWC, and the difference was highly significant comparing with the other two irrigation variants and unirrigated control. Furthermore, grain yield was higher at the level of significance P<0.01 at the variant with pre-irrigation moisture 60% of FWC in regard to the variant where soil moisture was kept at 80% of FWC.

Table 1. Mechanical properties of soil.

Depth (cm)	*Total sand (%)*	*Silt (%)*	*Clay (%)*
	> 0,02 mm	0,02-0,002 mm	< 0,002 mm
0-20	42.1	40.5	17.4
20-40	40.3	37.8	21.9
40-60	38.7	36.3	25.0
60-80	36.7	35.9	27.4
80-100	35.1	32.3	32.6

Table 2. Water-physical properties of soil.

Soil depth (cm)	*FWC (%)*	*Specific weight (g cm^{-3})*	*Bulk density (g cm^{-3})*	*Total porosity (vol. %)*	*Capacity for water (vol. %)*	*Capacity for air (vol. %)*
0-20	27.32	2.65	1.35	49.05	36.88	12.17
20-40	25.94	2.58	1.34	48.06	34.76	13.30
40-60	24.44	2.56	1.34	47.65	32.75	14.90

FWC – field water capacity.

Water consumption for evapotranspiration of winter wheat (289.5-410.7 mm) was measured by water balance method. The highest values of winter wheat ET (table 5) for the studied period were observed at the variant with pre-irrigation soil moisture 80% of FWC (405.2-410.7 mm), while the lowest ET values were measured at the control (289.5 mm) and the variant with pre-irrigation soil moisture 60% of FWC (346 mm).

Considering average for both investigated years, the highest grain yield of winter wheat was observed at the variant with pre-irrigation soil moisture 70% of FWC (7110 kg ha^{-1} and 7480 kg ha^{-1}). At this irrigation variant also were measured the highest values of wheat WUE (18.65 and 19.03 kg ha^{-1} mm^{-1}), so measured values of ET at this variant from 381.1 to 393.1 mm represent potential evapotranspiration (PET) of winter wheat in southern Serbia. Increased soil moisture (80% of FWC) caused lower average grain yield in regard to the other two irrigation variants. Higher values of measured evapotranspiration and lower grain yield at the variant with pre-irrigation soil moisture 80% of FWC comparing with the irrigation variant 70% of FWC, point to an unreasonable consumption of water for irrigation at the variant 80% of FWC.

Winter wheat water requirements (ET_c) calculated by CROPWAT 8.0 software for the season 2009/10 amounted 409.9 mm, while for the season 2010/11 it was 432.6 mm (table 6). The average value of measured potential evapotranspiration of winter wheat (387.1 mm) for the studied period was by 34.1 mm lower than the average calculated value (421.2 mm) of wheat water consumption for evapotranspiration.

Table 3. Meteorological parameters for the investigated period.

Year	*2009/10*						*2010/11*					
Month	T_{min} (°C)	T_{max} (°C)	RH (%)	Wind (m/s)	Sun (hours)	Rainfall (mm)	T_{min} (°C)	T_{max} (°C)	RH (%)	Wind (m/s)	Sun (hours)	Rainfall (mm)
X	7.4	18.4	78	0.7	4.2	84	6.2	15.4	77	0.9	3.1	73
XI	4.0	14.5	82	0.5	3.0	101	7.2	18.9	71	1.2	3.5	44
XII	1.0	8.8	81	0.9	1.0	73	-1.2	7.7	79	1.3	1.4	72
I	-1.8	5.1	79	1.2	1.3	54	-2.7	4.8	83	0.8	1.7	24
II	-0.1	7.9	79	1.2	1.5	88	-2.6	4.4	80	1.4	2.0	43
III	3.1	13.2	68	1.4	4.3	52	2.2	12.7	69	1.4	5.0	30
IV	7.7	18.5	71	1.0	5.4	79	6.8	18.6	59	1.5	6.0	12
V	11.8	23.3	71	0.8	5.6	65	10.6	22.8	69	0.9	6.1	58
VI	15.5	27.2	72	0.8	7.3	53	14.9	27.4	63	1.0	7.6	42
VII	17.5	29.6	70	0.8	8.3	35	16.5	30.4	61	0.6	8.9	47
VIII	17.0	31.4	65	0.6	8.9	29	16.2	32.0	54	0.9	10.6	4
IX	12.2	25.2	67	0.8	3.2	14	14.5	29.7	58	0.7	8.8	38

T_{min} – Average monthly minimum temperature

T_{max} – Average monthly maximum temperature

RH – Mean relative humidity.

Discussion

Values of potential evapotranspiration observed in this investigation (381.1–393.1 mm) are higher than the ones reported by Bošnjak (1999). Measured PET in our study is similar to the values (345–385 mm) observed by Luchiari *et al.* (1997) and Balwinder *et al.* (2011), that in the conditions of irrigation determined crop water requirements within the range from 345 to 404 mm. Higher values of winter wheat evapotranspiration (401–458 mm) in regard to our investigation have been reported by Xiying *et al.* (2011). Haijun *et al.* (2011) also noticed a high value of wheat ET amounting 499 mm. various values of winter wheat potential evapotranspiration reported previously are a consequence of soil and climatic conditions of experimental areas.

Table 4. Grain yield of winter wheat (kg ha^{-1}).

Year (B)	*Pre-irrigation soil moisture (A)*				**Average (B)**
	FWC 80%	FWC 70%	FWC 60%	Control	
2009/10	6350	7480	6870	6070	6692.5
2010/11	6520	7110	6340	4780	6187.5
Average(A)	6435	7295	6605	5425	6440.0
LSD		A	B		AB
0,05		91.30	64.56		129.08
0,01		122.94	86.93		173.81

FWC – field water capacity.

The observed difference between measured potential evapotranspiration and the one calculated by CROPWAT software is in accordance with the findings of Ramezani *et al.* (2009), who stated that application of CROPWAT model without calibration of crop coefficients and soil characteristics could cause a significant estimation error. Najafi (2007) concluded, based on his investigation, that in arid and semiarid conditions CROPWAT model was not able to give good results in calculation of potential evapotranspiration. Smith *et al.* (2002) stated that CROPWAT model showed satisfactory results in providing reasonable irrigation regime, if calibration of plant coefficients is previously carried out.

Table 5. Evapotranspiration, grain yield and water use efficiency of winter wheat.

Year	*Pre-irrigation soil moisture*	*Soil water supplies (mm)*	*Precipitation (mm)*	*Irrigation (mm)*	*Grain Yield kg ha^{-1}*	*ET (mm)*	WUE kg ha^{-1} mm^{-1}
2009/10	80% FWC	51.2	279.5	80	6350	410.7	15.46
	70% FWC	63.6	279.5	40	7480	393.1	19.03
	60% FWC	84.0	279.5	20	6870	383.5	17.91
	Control	92.7	279.5	-	6070	372.2	16.31
2010/11	80% FWC	43,5	211.7	150	6520	405.2	16.09
	70% FWC	49.4	211.7	120	7110	381.1	18.65
	60% FWC	54.3	211.7	80	6340	346.0	18.32
	Control	77.8	211.7	-	4780	289.5	16.51

FWC – field water capacity

ET – evapotranspiration

WUE - water use efficiency.

Table 6. Winter wheat water requirements calculated by CROPWAT 8.0.

Month	*Kc*	*2009/10.*		*2010/11.*	
		ET_o mm day^{-1}	ET_c mm	ET_o mm day^{-1}	ET_c mm
X	0.75	1.15	15.52	1.19	12.49
XI	0.75	0.74	16.65	0.94	21.15
XII	0.70	0.59	12.80	0.70	15.19
I	0.40	0.56	6.94	0.47	5.83
II	0.70	0.75	14.7	0.67	13.13
III	0,78	1.61	38.93	1.57	37.96
IV	0.97	2.36	68.67	2.79	81.19
V	1.12	3.07	106.59	3.15	109.57
VI	0.92	3.90	107.64	4.13	113.99
VII	0.30	4.76	21.42	4.38	22.34
Total	409.86	432.64			

K_c – crop coeficient

ET_o – referent evapotranspiration

ET_c – crop water requirements.

The estimated WUE values were within the range from 15.46 to 19.03 kg ha^{-1} mm^{-1} and were close to the values reported by Liu *et al.* (2011). Much lower values of winter wheat WUE were reported by many researchers (Zang *et al.,* 2005; Sun *et al.,* 2006; Sun *et al.,* 2010; Fang *et al.,* 2010). The highest values of winter wheat WUE were observed in our experimental field at the variant with pre-irrigation soil moisture 70% of FWC, so that in order to reach high and stable grain yield of winter wheat in the conditions of southern Serbia one ought to keep soil moisture at that level.

Conclusion

Potential evapotranspiration of winter wheat (381.1–393.1 mm) in the conditions of southern Serbia has been measured by water balancing method at the variant with pre-irrigation soil humidity 70% of FWC. The difference between potential evapotranspiration measured by water balancing and the one calculated by CROPWAT 8.0 software has been established. An efficient exploitation of the CROPWAT model for calculating winter wheat water requirements in the agroecological conditions of southern Serbia is possible, if calibration of K_c coefficients is previously carried out. The observed values of PET, WUE and grain yield of winter wheat offer possibility of adequate exploitation of given agroecological conditions and reaching high and stable wheat grain yield, through further investigations with application of modern cultivation techniques and proper choice of cultivars.

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