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WATER USE EFFICIENCY OF TOMATO AND POTATO IN THE CONDITIONS OF SOUTHERN SERBIA

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Abstract

Water is a limited agricultural resource, so this study has been related to rational use of water in the intensive tomato and potato growing technology. By setting irrigation at different values of SWP (soil water potential), it have been studied their effects on yield, evapotranspiration and water use efficiency (WUE) of tomato and potato in the conditions of southern Serbia. The four-year investigation was carried out by a biological procedure – through field trials in the conditions with irrigation of tomato hybrid Amati F_1 and potato cultivar Kennebec, on alluvium soil type, in the river valley of Southern Morava, near Niš. Local coordinates of the studied area were the following: latitude 43º 19', longitude 21º 54', and altitude 194 m. The experimental field consisted of three treatments with irrigation (SWP of 20, 30 and 40 kPa), as well as unirrigated control. Tensiometers were installed at the depth of 20 cm within root system zone, and were read twice a day at $8^{\underline{00}}$ and $18^{\underline{00}}$. Irrigation was applied when a lower value than predetermined was read on the vacuummeter. The highest value of WUE in tomato (112.68 kg ha^{-1} mm^{-1}) was observed in 2006 at the variant with SWP of 30 kPa, while the lowest one (77.27 kg ha^{-1} mm^{-1}) was observed in 2007 at the variant with SWP of 40 kPa. Water use efficiency of potato during the studied period ranged from 81.23 to 98.21 kg ha^{-1} mm^{-1}.

Key words: soil water potential, tomato, potato, irrigation, water use efficiency.

Introduction

Climatic conditions of southern Serbia in the last few years were characterized by long drought periods without precipitation, and extremely high temperature during vegetation period. Optimal soil moisture for growing agricultural crops can only be reached in the conditions of irrigation. Insight in values of potential evapotranspiration (PET), or water demands by plants, is a necessary precondition for realizing an efficient water regime. Excessive irrigation leads to deep percolation of nutrients, higher potential for appearing plant diseases and pests, deterioration of soil structure and water losses, causing increased production costs. Determining irrigation term is important, because it is necessary to ensure the optimal soil moisture during vegetation, in order to supply the plants with enough available water. There are many methods of deciding irrigation term, but in agricultural practice the methods based on soil moisture measuring are regarded as the most reliable ones.
The most frequently used device for soil moisture measuring in irrigation practice is tensiometer. Efficiency of this method for deciding terms of vegetable crops irrigation is confirmed by numerous reports (Clark et al., 1994; Smajstrla and Locascio, 1996; Li et al., 1998; Shock et al., 2000; Wang et al., 2004; Kang et al., 2004; Kang and Wan, 2005; Muñoz-Carpena et al., 2004; etc.). Water is a limited agricultural resource, so this study has been

related to rational use of water in the intensive tomato and potato growing technology. By setting irrigation at different values of SWP (soil water potential), it have been studied their effects on fruit and tuber yield, evapotranspiration, water use efficiency (WUE), and irrigation water use efficiency (IWUE) of tomato and potato in the conditions of southern Serbia.

Material and methods

The four-year investigation was carried out by a biological procedure – through field trials in the conditions with irrigation of tomato hybrid Amati F_1 and potato cultivar Kennebec, on alluvium soil type, in the river valley of Southern Morava, near Niš. Local coordinates of the studied area were the following: latitude 43º 19', longitude 21º 54', and altitude 194 m. The experiments were set in random complete block design with four replications, where three irrigation variants were involved (SWP of 20 kPa, 30 kPa, 40 kPa) together with the unirrigated control. Irrigation was carried out by the drip irrigation system. Tensiometers were installed at the depth of 20 cm within root system zone, and were read twice a day at $8^{\underline{00}}$ and $18^{\underline{00}}$. Irrigation was applied when a lower value than predetermined was read on the vacuummeter.

Tomato was planted within optimal agrotechnical terms and contemporary tomato growing technology was applied. Elementary plot area was 10.5 m^2, with inter-row distance of 70 cm and within-row distance of 30 cm. After doing soil chemical analyses, basic amount of fertilizers was applied, and additional fertilization during vegetation period was done by fertigation. The total amounts of the applied nutrients were as follows: N – 283 kg ha^{-1}, P_2O_5 – 187 kg ha^{-1}, K_2O – 525 kg ha^{-1}, and MgO – 95 kg ha^{-1}.

Potato planting (distance 70 cm between rows and 30 cm in the row) was done in the first half of April in both investigation years, with the cultivar Kennebec, original category, where tuber size was from 35-55 mm. After soil chemical analyses soil was fertilized before cultivation, as well as during vegetation by water soluble fertilizers through irrigation systems. The total amount of nutrients deposited to soil was: N – 200 kg ha^{-1}, P_2O_5 – 120 kg ha^{-1}, K_2O – 300 kg ha^{-1}, CaO – 100 kg ha^{-1}, and MgO – 60 kg ha^{-1}. During vegetation, the all modern agrotechnique measures were applied, and tuber harvest was carried out in the third decade of August in both years of the study.

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). Precipitation was measured by a rain gauge at the experimental field.

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

where ET_{vp} is evapotranspiration for the vegetation period; W_1 is amount of water in soil to the depth of 1.2 m at the beginning of vegetation; W_2 is amount of water in soil to the depth of 1.2 m at the end of vegetation; P is water amount from precipitation; I is water amount from irrigation; D is water loss by deep percolation and runoff.

$$W = 100 \cdot h \cdot d \cdot s \text{ (mm)} \tag{2}$$

where W is amount of water in soil to the depth of 1.2 m; h is depth of soil; d is bulk density; s is soil moisture.

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

$$D = (W_1 + P) - FWC \text{ (mm)} \tag{3}$$

where D is deep percolation; W_1 is soil water amount to the depth of 1.2 m at the beginning of vegetation; P is precipitation amount (mm); FWC is field water capacity.

Rationality of water consumption is measured by water use efficiency (WUE) of tomato and potato. WUE is relationship between water consumption for evapotranspiration (ET) and yield, calculated as tomato fruit yield or potato tuber yield divided by ET. Irrigated water use efficiency (IWUE) was calculated as irrigated yield minus non-irrigated yield (control) divided by irrigation water amount (Schneider and Howell, 1998).

Data of tomato fruit yield and potato tuber 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 $P<0.01$.

Mechanical and water-physical properties of soil in the experimental field

The obtained values of texture analysis (table 1) were expected, because fractional relations confirm that this is a loamy alluvial soil.

Table 1. Mechanical properties of soil

Depth (cm)	Total sand (%) > 0.02 mm	Powder (%) 0.02-0.002 mm	Clay (%) < 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
100-120	33.6	29.7	36.7

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

Table 2. Water-physical properties of soil

Depth (cm)	FWC (weight %)	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

Results and discussion

The average water consumption of tomato for evapotranspiration, observing the whole investigated period, was 621.2 at the variant with SWP of 20 kPa, 583.9 mm at the variant with SWP of 30 kPa, and 556.5 at the variant with SWP of 40 kPa (table 3). During the vegetation period of 2007 higher ET values were measured in regard to 2006, at the all irrigated variants, which could be explained by a higher average temperature. Although higher ET values were observed in 2007 than in 2006 in the conditions of irrigation, it did not affect tomato fruit yield. The measured tomato evapotranspiration in the conditions of irrigation was between 555.9 and 637.6 mm. The greatest tomato fruit yield was observed when the average water consumption for ETP amounted 584 mm, so this value could be regarded as tomato’s demand for water in southern Serbia.

Similar values of tomato ET were reported by Pruitt et al. (1984), who by lysimeters measured water consumption of 515.8-614.7 mm for ET. Our values of tomato ET are greater than ET values (450-520 mm) found by Bošnjak and Pejic (1995) for the conditions of Vojvodina (Serbia). Hanson and May (2006), by the four-year investigation in the conditions of California, determined tomato water consumption for evapotranspiration of 528-752 mm, and the average value of ETP was 648 mm. Significantly lower tomato water consumption for ET (200-270 mm) in regard to our study was reported by Wang et al., (2007) for the conditions of North China Plain.

The two-year study showed high-significantly greater tomato fruit yield in the conditions of irrigation in regard to the unirrigated control (table 3). At the irrigation variant with SWP of 30 kPa also was reached high-significantly greater tomato fruit yield in regard to the variants with SWP of 20 and 40 kPa. Between the irrigation variants with SWP of 20 and 40 kPa there was not any significant difference. Highly significant difference in tomato fruit yield between the investigated years was observed at the all studied variants.

Table 3. Evapotranspiration, fruit yield, WUE, and IWUE of tomato

Year	SWP (kPa)	Soil water supplies (mm)	P (mm)	I (mm)	ET (mm)	Fruit yield (kg ha^{-1})	WUE (kg ha^{-1} mm^{-1})	IWUE (kg ha^{-1} mm^{-1})
2006	20	31.4	229.4	400	604.8	58146	96.14	53.63
	30	44.0	229.4	340	573.4	64614	112.68	82.12
	40	56.5	229.4	320	555.9	60627	109.06	74.79
	Control	78.3	229.4	-	307.7	36693	119.25	-
2007	20	33.4	208.2	440	637.6	46532	78.28	53.05
	30	40.2	208.2	390	594.4	53268	89.16	77.13
	40	56.9	208.2	340	557.1	43051	77.27	58.42
	Control	83.1	208.2	-	291.3	23189	79.60	-

LSD (yield)	SWP	Year	SWP x Year
0.05	2813.5	1989.5	3978.8
0.01	3796.9	2684.9	5369.6

Water use efficiency (WUE) of tomato was much higher in 2006 in regard to 2007 (table 3). The highest value of WUE (112.68 kg ha^{-1} mm^{-1}) was observed in 2006 at the variant with SWP of 30 kPa, while the lowest one (77.27 kg ha^{-1} mm^{-1}) was observed in 2007 at the variant with SWP of 40 kPa.

Calculated average value of IWUE (70.18 kg ha^{-1} mm^{-1}) in 2006 was higher than the average value of IWUE (62.87) in 2007. The lowest value of IWUE was noted in 2007 at the variant with SWP of 20 kPa, while the highest IWUE value was detected in 2006 at the variant with SWP of 30 kPa.

The established value of evapotranspiration of potato in our experimental field ranged from 294.4 mm at the variant without irrigation to 522.1 mm at the irrigated variant with SWP of 20 kPa (table 4). According to many researches water demands of potato vary over a great range, depending above all on studied environment. For high tuber yield vegetation demands of potato for water ranged from 500 to 700 mm, depending on climatic conditions (Doorenbos and Kassam, 1979). During a three-year investigation potato evapotranspiration in Wisconsin (USA) was between 293 and 405 mm (Tanner, 1981). Wright and Stark (1990) stated water consumption of potato for evapotranspiration from 640 to 700 mm in irrigated areas of

Oregon and Washington (USA). Pereira et al. (1995) found potato evapotranspiration of 283 mm. Kiziloglu et al. (2006) stated that in the conditions of Erzurum (Turkey) potato evapotranspiration ranged from 167 mm without irrigation to 610 mm in the conditions of irrigation. According to Erdem et al. (2006) in Trakia Region (Turkey) potato evapotranspiration was between 464 and 683 mm.

The highest and also stable tuber yield in the two-year period of study was reached when water consumption for evapotranspiration was between 491.3 and 498.6 mm, so that value could be considered as potential evapotranspiration (PET) of potato, i.e. its water demands in the conditions of southern Serbia. The measured value of potato PET in our study is greater in regard to the value of potential evapotranspiration (460-480 mm) established by Bošnjak and Pejic (1994) for the conditions of Vojvodina Province (northern Serbia).

Concerning the all irrigated variants, tuber yield was high-significantly higher in regard to the unirrigated control. The highest potato tuber yield was observed at the variant with soil water potential of 30 kPa (table 4). Statistically high-significantly important differences in tuber yield were observed between the treatment with SWP of 30 kPa and the treatments with SWP of 20 and 40 kPa. However, at the treatment with SWP of 20 kPa, tuber yield was significantly higher regarding the treatment with SWP of 40 kPa.

Table 4. Evapotranspiration, tuber yield, WUE and IWUE of potato

Year	SWP (kPa)	Soil water supplies (mm)	P (mm)	I (mm)	ET (mm)	Tuber yield (kg ha^{-1})	WUE (kg ha^{-1} mm^{-1})	IWUE (kg ha^{-1} mm^{-1})
2008	20	21.4	222.7	278	522.1	44710	85.63	70.68
	30	32.6	222.7	236	491.3	47640	96.97	97.96
	40	51.5	222.7	175	449.2	36490	81.23	68.40
	Control	65.4	222.7	-	288.1	24520	85.11	-
2009	20	27.8	231.2	256	515.0	45480	88.31	73.05
	30	48.4	231.2	219	498,6	48970	98.21	101.32
	40	53.1	231.2	184	468,3	39130	83.56	67.12
	Control	63.2	231.2	-	294.4	26780	90.96	-

LSD (yield)	SWP	Year	SWP x Year
0.05	1950	1390	2760
0.01	2150	1540	3050

In the conditions of irrigation the highest mean value of potato WUE of 97.59 kg ha^{-1} mm^{-1} was observed at the variant with SWP of 30 kPa (table 4). WUE values of potato obtained by this study (from 81.23 to 98.21 kg ha^{-1} mm^{-1}) were similar to the values reported by Wright and Stark (1990) and Beheral and Panda (2009).

Our values of potato WUE are not in accordance with the values stated by Wang et al. (2006) from 50.4 to 77.1 kg ha^{-1} mm^{-1} in season 2001 and 103.2-131.6 kg h^{-1}a mm^{-1} in season 2002 in the conditions of North China Plain. Values of WUE in our study were higher than the ones determined by Kiziloglu et al. (2006), which were from 40.2 to 63.4 kg ha^{-1} mm^{-1}, as well as the ones of Rashidi and Gholami (2008) who stated WUE ranging from 19.2 to 52.5 kg ha^{-1} mm^{-1}.

Conclusion

The highest values of WUE and IWUE for tomato and potato were reached in the variant with SWP of 30 kPa, meaning rational water consumption was enabled at this SWP value. Evapotranspiration values vary widely, which above all depends on climatic conditions, soil texture and area of investigation. Therefore, the established value of potential evapotranspiration of tomato and potato is important for irrigation practice in southern Serbia or in areas of similar soil and climatic conditions.

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