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TOMATO FRUIT YIELD AND EVAPOTRANSPIRATION IN THE CONDITIONS OF SOUTH SERBIA

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Abstract

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Water is a limited agricultural resource, so this study has been related to rational use of water in the intensive tomato growing technology. The two-year investigation was carried out by a biological procedure – through field trials in the conditions with irrigation of tomato hybrid Amati F_1, on alluvium soil type, in the river valley of Southern Morava, near Nish. 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. Observing both investigation years, the highest fruit yield was reached at the variant with SWP of 30 kPa, while in variants with higher (SWP of 20 kPa) and lower (SWP of 40 kPa) soil moisture fruit yield decreased. 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 south Serbia. The highest values of WUE and IWUE for tomato were reached in the variant with SWP of 30 kPa, meaning rational water consumption was enabled at this SWP value. The study results have shown that, using tensiometer, tomato irrigation regime can be successfully kept at SWP of 30 kPa, on alluvium soil type in south Serbia.

Key words: soil water potential, tomato, evapotranspiration, fruit yield
Abbreviations: ET = evapotranspiration; ETP = potential evapotranspiration; SWC = soil water capacity; WUE = water use efficiency; IWUE = irrigation water use efficiency; FWC = field water capacity; LSD = least significant difference; P = water amount from precipitation; I = water amount from irrigation

Introduction

High yield of quality tomato fruits can only be reached in the conditions of optimal soil moisture, so tomato production, based on intensive growing technology, must be organized in the conditions of irrigation. Soil water deficiency causes fruit yield decrease and fruit quality deterioration. Overmoisturing pushes out air from soil macropores and root respiration weakens, which leads to stop of its absorption activity. Applying of abundant water doses is a way of nonrational water consumption, and nitrates and other available nutrients are washed by gravity into deeper layers.

Determining irrigation term is important, because it is necessary to ensure the optimal soil

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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.).

If the optimal soil moisture is kept, water will be consumed by plants according to their needs, depending on phenophase and environmental energetic capacity, which leads to maximal yield of good quality fruits. Water consumption by plants in such conditions is called potential evapotranspiration (ETP) and, in fact, it represents real need of plants for water (Bosnjak, 1999).

Water is a limited agricultural resource, so this study has been related to rational use of water in the intensive tomato growing technology. By setting irrigation at different values of SWP (soil water potential), it have been studied their effects on fruit yield, evapotranspiration, water use efficiency (WUE), and irrigation water use efficiency (IWUE) of tomato in the conditions of South Serbia.

Material and Methods

The two-year investigation was carried out by a biological procedure – through field trials in the conditions with irrigation of tomato hybrid Amati F_1, on alluvium soil type, in the river valley of Southern Morava, near Nish. 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. Elementary plot area was 10.5 m^2, with inter-row distance of 70 cm and within-row distance of 30 cm. Dynamics of soil moisture was observed by tensiometers, measuring soil water potential. Tensiometers were installed at the depth of 20 cm within root system zone, and were read twice a day at 8 and 18 o'clock. 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. 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}.

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).

$$ET_{vp} = (W_1 – W_2) + P + I – D \text{ (mm)}, \quad (1)$$

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.

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

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 was calculated:

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

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

Data of tomato fruit yield were processed by analysis of variance, and significance of differences in fruit yield was determined by comparing them with LSD values for $P<0.05$ and $P<0.01$. The effect of ET on tomato fruit yield was analyzed by regression analysis.

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.

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

Meteorological conditions of the studied years

Precipitation was measured by a rain gauge at the experimental field (Table 3). Precipitation is the basic source of soil moisture, and its efficiency depends on rainfall amount and timing. Despite the precipitation deficiency in May 2006, soil water supplies were sufficient to fulfill tomato's demand

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

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	13.3
40-60	24.44	2.56	1.34	47.65	32.75	14.9

Table 3

Precipitation amount (mm) during vegetation period (experimental field)

Year	Months					Total
	May	June	July	August	September	
2006	35.4	53.7	32.9	89.4	18.0	229.4
2007	95.0	14.4	7.5	32.6	58.7	208.2
1961-1990	72	73	45	44	43	277

Table 4

The average daily air temperature (°C) during vegetation period (Nish)

Year	Months					Average
	May	June	July	August	September	
2006	17.0	20.0	22.9	21.2	18.3	19.9
2007	18.8	23.6	26.2	24.6	16.1	21.9
1961-1990	17.1	19.3	21.2	21.0	17.3	19.2

for water during this month. From June until the end of vegetation period (September), tomato was not able to satisfy its demand for water out of precipitation and soil water supplies. Abundant precipitation in May 2007 enabled proper growth and development of tomato, as well as an increase of soil water supplies. June, July and August had very low amount of precipitation, which showed the negative effect on fruit yield in the conditions without irrigation.

Air temperature was observed at meteorological station Nish (Table 4). In May 2006 average daily air temperature did not much differ from 30-year average values. In the second half of June extremely high temperature was observed (36ºC), which, together with precipitation deficiency, had a negative effect on tomato growth and development. From July to the end of vegetation period thermal conditions were favorable.

Average daily air temperature during vegetation of 2007 was significantly above the long-term mean, except in September (Table 4). In July and August there was a period of 17 days with temperature from 35-45ºC, and that with simultaneous precipitation deficiency influenced decrease of tomato fruit yield.

Results

The two-year study showed high-significantly greater tomato fruit yield in the conditions of irrigation in regard to the unirrigated control (Table 5). 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.

The data concerning water consumption by tomato plants on evapotranspiration (ET) for three irrigation variants and the control are presented in Table 6. During May and September, lower values of ET were observed, which was expected, because the beginning and the end of vegetation coincided with those periods. During summer months the greatest water consumption on ET was noticed, which was in accordance with the observed values of meteorological elements and developmental stages of tomato. In the conditions of irrigation, the highest monthly ET value of 161.7 mm was observed in August 2007, at the variant with SWP

Table 5

Tomato fruit yield (kg ha^{-1}) as affected by soil water potential

Year	Soil water potential				Average (B)
	20 kPa (A_1)	30 kPa (A_2)	40 kPa (A_3)	Control (A_4)	
2006 (B_1)	58146	64614	60627	36693	55020
2007 (B_2)	46532	53268	43051	23189	41510
Average (A)	52339	58941	51839	29941	48265
LSD		A	B	AB	
0.05		2813.5	1989.5	3978.8	
0.01		3796.9	2684.9	5369.6	

Table 6

The evapotranspiration of tomato (mm) as affected by SWP

Year	Variant	Months					Total
		V	VI	VII	VIII	IX	ET
2006	20 kPa	80.7	134.7	147.2	148.8	93.4	604.8
	30 kPa	76.0	124.3	143.8	139.2	90.1	573.4
	40 kPa	74.3	122.5	134.8	136.7	87.6	555.9
	Control	76.3	56.5	52.1	78.3	44.5	307.7
2007	20 kPa	84.4	138.4	156.0	161.7	97.1	637.6
	30 kPa	82.2	128.0	145.3	147.5	91.4	594.4
	40 kPa	76.5	120.6	136.5	137.7	85.8	557.1
	Control	78.1	50.3	56.1	62.3	44.5	291.3

of 20 kPa. 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. 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.

Regression analysis defined fruit yield dependency on water consumption for ET as follows: $y=-100,997.2+613.7x-0.6x^2$ (Figure 1). Correlation between these two parameters was high and positive (r=0.86**).

Water use efficiency (WUE) of tomato was much higher in 2006 in regard to 2007 (Table 7). 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 (Table 7). 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. In both years of investigation the greatest values of WUE and IWUE in the conditions of irrigation were reached at the variant with SWP of 30 kPa.

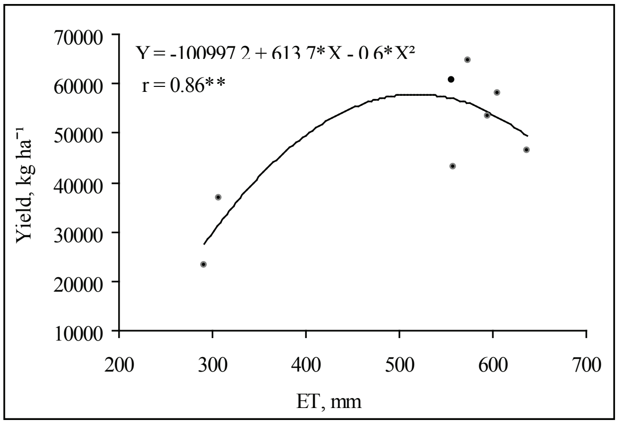

Fig. 1. Relation between evapotranspiration and tomato fruit yield (2006-2007)

Discussion

Observing both studied years and all irrigated variants, the greatest fruit yield was reached at the variant with SWP of 30 kPa, while in variants with higher (SWP of 20 kPa) or lower (SWP of 40 kPa) soil moisture fruit yield decreased (Table 5). A drop of tomato fruit yield caused by excess water in the zone of root system was reported by Wang et al. (2004), which is in accordance with our findings. Our results are also in accordance with previous study of Navarro and Newman (1989) that stated, for the conditions of Royal Chico (USA), that excess or lack of soil water decreased tomato fruit yield, and they dealt with treatments at SWP of 20, 40 and 60 kPa. Our findings oppose statements of Sanders (1993), who claimed that irrigation should be applied at SWP of 45 kPa. Lower values of SWP (15-20 kPa) than in our study, but for sandy soils, have been reported by Clark et al. (1988), Li et al. (1998), Simonne (2004), Munoz-Carpena et al. (2003), Munoz-Carpena et al. (2005) etc. Differences in estimated optimal values of SWP for tomato, existing among various reports, are caused above all by variability of soil texture, position and depth of tensiometer installation, as well as by specificity of the investigated area.

The measured tomato evapotranspiration in the conditions of irrigation was between 555.9 and 637.6 mm. At the variant with SWP of 30 kPa, measured ET was from 573.4-594.4 mm, and those values gave the highest fruit yield (Table 7). Similar values of tomato ET were reported by Pruitt et al. (1984), who measured by lysimeters 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 Bosnjak 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 on evapotranspiration of 528-752 mm, and the average value of ETP was 648 mm. Significantly lower tomato water consump-

Table 7
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	111.06	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	-

tion on ET (200-270 mm) in regard to our study was reported by Wang et al. (2007) for the conditions of North China Plain.

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 is important for irrigation practice in south Serbia or in areas of similar soil and climatic conditions.

Conclusion

Fruit yield of tomato in the conditions of irrigation was higher by 73.1-96.8%. The highest fruit yield was reached at SWP of 30 kPa, so that value could be recommended as an indicator for beginning of tomato irrigation on alluvium soil type. 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 south Serbia. The highest values of WUE and IWUE for tomato were reached in the variant with SWP of 30 kPa, meaning rational water consumption was enabled at this SWP value.

The study results have shown that, using tensiometer, tomato irrigation regime can be successfully kept at SWP of 30 kPa, on alluvium soil type in south Serbia.

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