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Effect of irrigation schedules on yield and water use of onion *(Allium cepa* L.)

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In order to study the effect of different irrigation schedules on yield and water use of onion (*Allium cepa* L., cv. Alek and Kupusinski jabučar), a field experiment was conducted on the calcareous chernozem soil in the Institute of Field and Vegetable Crops, Novi Sad in Serbia during 2005, 2006 and 2007 growing seasons. The experiment was arranged in a randomized complete block design and adapted to conditions of sprinkling irrigation. Three irrigation treatments according to available soil water depletion (T_1 30, T_2 50 and T_3 70%) and a rainfed treatment (T_0) were included. Results showed that onion yield was significantly affected by irrigation. The highest onion bulb yields of 30.22 and 34.99 t ha^{-1} were obtained from treatment T_1 and T_3, respectively, in 2005. However, the highest onion bulb yields of 38.46 and 40.07 t ha^{-1} were obtained from T_2 and T_3 treatment in 2006 and 40.96 t ha^{-1} from T_1 treatment in 2007, respectively. The lowest yield of 10.10 t ha^{-1} was obtained from T_0 treatment in 2007 with limited precipitation and higher than average seasonal temperatures. The seasonal evapotranspiration values of irrigated (ETirr) and non irrigated (ET_O) onions ranged from 435.6 to 542.9 mm and 290.2 to 393.9 mm, respectively. The highest and lowest water use efficiency (WUE) of 91.35 kg and 34.80 kg ha^{-1} mm^{-1} was obtained in irrigation and rainfed conditions in 2007, respectively. The highest irrigation water use efficiency (IWUE) of 280.54 kg ha^{-1} mm^{-1} was obtained from T_1 treatment in 2007, while the lowest value of 45.83 kg ha^{-1} mm^{-1} was obtained from T_1 treatment during the rainy period of 2005. High yields of bulbs produced from treatments T_1, T_2 and T_3 in different years indicated that amount and distribution of precipitation seriously affected the soil water regime and irrigation schedule of onion in the region. Therefore, irrigation schedule of onion has to be adjusted to climatic conditions of each year, mostly to amount and distribution of precipitation.

Key words: Onion yield, irrigation scheduling, evapotranspiration, water use efficiency.

INTRODUCTION

Considering the production volume and importance, onion is seen as a major horticultural crop in many countries. During the last 25 years, continuous increase of onion acreage has been registered (FAOSTAT, 2007). In Serbia, onion is grown on 20,400 ha with an average yield of 6.21 t ha^{-1}. In the Vojvodina Province, that is, northern part of the Republic of Serbia, the acreage is 5,800 ha and the yield is 8.90 t ha^{-1} (Statistical Yearbook of Serbia Republic, 2007). Low average yields, four to five fold lower than those achieved in the leading onion-growing countries (Japan 41.4 t ha^{-1}, the Netherlands 36.7 t ha^{-1}, Egypt 28.0 t ha^{-1}), are the consequence of onion growing from sets, inadequate management practices, insufficient amount and unfavorable arrangement of precipitation in the growing season and inappropriate irrigation scheduling applied to onions grown from seed.

In arid and semiarid areas, irrigation may supply all or

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Abbreviations: WUE, Water use efficiency; **IWUE,** irrigation water use efficiency; **FC,** field capacity; **ET,** evapotranspiration; **Y,** yield.

most of the crops water needs. In most humid production areas, irrigation is used primarily to supplement infrequent or irregular precipitation during short-term droughts. Due to the unpredicted amount and distribution of precipitation in the growing season, irrigation in the Vojvodina region is mainly supplemental. It is used primarily to supplement infrequent or irregular precipitation during drought periods (Pejić et al., 2008).

Onions are considered as shallow-rooted crop. Drinkwater and Janes (1955) found that although the maximum root penetration was 0.76 m, most of the roots were in the top 0.18 m of soil, whereas only few roots were found below 0.31 m. Irrigation water that moves below 0.76 m is most likely not available to the onion crop. Greenwood et al. (1982) showed that 90% of the root system of the onion plant was concentrated at the top 0.4 m of soil and only 2 - 3% of the total root length was recorded below 0.6 m depth, which indicates that very little water could be extracted from soil depths below 0.6 m.

Irrigation scheduling is one of the most important tools for developing best management practices for irrigated areas (Vučić, 1976; Hedge, 1986; Olalla et al., 1994; Al-Jamal et al., 1999). If shortage of readily available soil water is eliminated and the technological and biological characteristics of the crop are taken into account, it is possible to achieve high and stable yields of irrigated onions, at the level of 40 t ha^{-1} or higher (Imtiyaz et al., 2000; Halim and Ener, 2001; Meranzova and Babrikov, 2002; Kanton et al., 2003; Pejić et al., 2008). Many growers obtain much lower yields, primarily because of inadequate irrigation scheduling (Mermoud et al., 2005).

Several authors and research groups reported results of experiments aimed at determining optimum soil moisture under different environmental and technical conditions (Hegde, 1986; Shock et al., 1998a; Halim and Ener, 2001). Because of a shallow root system, the common practice, therefore, is to apply slight and frequent irrigation rates (Pelter et al., 2004). An experiment conducted by Shock et al. (2000b) in eastern Oregon, using a subsurface drip-irrigation system, revealed that the soil water potential should not be reduced below -20 kPa at 0.2 m soil depth during the onion growing period. Halim and Ener (2001) pointed out the advantages of high pre-irrigation soil moisture and frequent irrigations, using drip irrigation in the production of onions under arid climatic conditions in Turkey. Therefore, drip-irrigation systems are well suited for this crop (Al-Jamal et al., 2000, 2001; Chopade et al., 1998). Assuming high irrigation frequency, better scheduling may be expected to increase applied fertilizer use efficiency, to reduce leaching and improve onion yields by increasing bulb size (Renault and Wallender, 2000).

Dragland (1974) recommended irrigation of up to field capacity (FC) whenever the soil metric potential at 0.15 m soil depth falls below -40 kPa. Another study under a furrow-irrigation system suggested a lower threshold level, approximately -45 kPa at 0.08 m soil depth (Hedge, 1986). Mermoud et al. (2005) also claimed that onions prefer longer intervals between irrigations but deeper depths of irrigation. The irrigation frequency was found to be important with irrigating twice a week instead of once a day, leading to increase of the root-zone water storage, better crop water availability through the whole root zone and higher yields. It appears that, in the specific climatic context of the study area, frequent application of small irrigation depths cause the irrigation water to remain near the soil surface where it is subsequently evaporated.

A preliminary step to a more intensive exploitation of the available agroecological conditions or to the development of irrigation schedules for any crop implies a study of crop requirements for water, that is, the evapotranspiration (ET) for any particular crop. To fully utilize the genetic yield potentials of onion and achieve high and stable yields, it is necessary to gain knowledge of the crop's capabilities under conditions of dry farming and irrigation. Many factors can affect the amount of ET occurring in any particular vegetable crop. These include plant, soil, cultural and environmental factors (Jones et al., 1984). The applied irrigation system can also affect the ET of a vegetable crop under specific conditions (Geraldson, 1980, Al-Jamal et al., 2000). Under no limiting irrigated conditions, daily ET rates for individual vegetable crops are directly related to the meteorological processes affecting evaporative demand and to the existing stage of growth development or percent crop coverage (Blaney and Criddle, 1962). Any estimation of ET requirements for vegetable crops must be accom-panied by a description of the associated conditions. A seasonal ET of 337.8 mm for onions irrigated with microsprinklers between April and July in an arid Bulgariien environment was reported by Meranzova and Babrikov (2002). Pelter at al. (2004) recorded an onion ET of 597 mm when irrigated by drip-irrigation system at Columbia Basin, Washington State, USA. In Oregon, an average ET of 791 mm was measured from onions producing an average marketable yield of 95 t ha^{-1} (Shock et al., 2004). Olalla et al. (2004) reported the water requirements of onion in Albacete (Spain) producing an optimum yield of 75 t ha^{-1} were 662 mm of water when using drip irrigation. In eastern India, the average ET value (calculated by the water balance method) during the entire growing period of onion was 225 - 250 mm, and the productivity was about 10 t ha^{-1} (Bandyopadhyay et al., 2003).

The importance of analyzing water use efficiency (WUE) is illustrated by the efforts of numerous researchers to direct total water use for evapotranspiration towards transpiration as the productive part of water for plants. WUE coefficients define whether the growing period is favorable for plant production or not, mostly depending on precipitation amount and distribution. Furthermore, these parameters precisely assess the applied management practices in relation to the obtained yields of growing plants. Arnon (1975) pointed out that crop yield depends on the rate of water use, and that all factors increasing yield and decreasing water used for ET favorably affect the water use efficiency. The irrigation water use efficiency

(IWUE) coefficients provide a more realistic assessment of the effectiveness of irrigation, that is, of the effect of the applied irrigation schedule on growing plants (Sarkar et al., 2008). If irrigation schedule is not adapted to crop requirements for water, water-physical soil properties and weather conditions, and effects of irrigation may be negligible or altogether missing. Many studies have been conducted to determine the water use efficiency characteristics of onion crops in different climate and soil conditions under different irrigation systems (Al-Jamal et al., 2001; Kadayifci et al., 2005; Kumar et al., 2007; Bekele and Tilahun, 2007).

Based on the results from the literature suggesting that onion production from seed requires high pre-irrigation soil moisture, the aim of the study is to determine whether lower values of pre-irrigation soil moisture are applicable in onion production or not, having in mind that irrigation in Vojvodina is supplementary in character and that precipitation can affect the soil water regime and irrigation schedule of onion. On the basis of determined water requirements of onion and calculated water use coefficients, water productivity as an important factor in analysis of performed irrigation schedule will be discussed in order to find which of the different irrigation schedules best fits onion production in climatic conditions of Vojvodina.

MATERIALS AND METHODS

Trials were conducted in 2005, 2006 and 2007 at the experiment field of the Institute of Field and Vegetable Crops in Novi Sad. The experiment site is situated on a low, slightly inclined south-eastern edge of a loess terrace, near the town of Novi Sad (Rimski Šančevi) and the Danube River (45°20' N latitude, 19°51'E longitude, 84 m above sea level). To characterize the climate of the experimental area, data gathered by a meteorological station at Rimski Šančevi in a 43-year period (1964 - 2007) were used. The climate is moderate, with four marked seasons. The mean annual precipitation is 598.7 mm (328 mm or 56% in the growing season, March - August) and the mean air temperature is 11.2°C (17,8°C in the growing season). The first two years of the study were characterized by growing season precipitation above the long-term average (328 mm, Figure 1a and b). The 2005 growing season received 462.5 mm of precipitation or 134.5 mm above average (Figure 1a). The 2006 season received 345.6 mm of precipitation or 17.6 mm above average (Figure 1b). The 2007 season received 312.9 mm of precipitation or 15.1 mm less than the average (Figure 1c). Due to the uneven seasonal distribution of precipitation and frequent drying of the topsoil (0.3 m), irrigations had to be performed each year (Table 4). High air temperatures (Figure 1a, b and c), especially in the summer period of 2006 (25.4 and 25.8°C in the third decade of June and July, respectively) (Figure 1b) affected the amount of water used for evapotranspiration and irrigation frequency. The soil of the experimental site is highly calcareous loamy (Table 1). Structural stability to 0.6 m is good, with 60 - 71% of soil aggregates larger than 0.25 mm being persistent in water (Pejić et al., 2005). Concerning the physical and water properties (Table 1) as well as the chemical properties (Table 2), this soil is quite suitable for any crop and irrigation system (Živković et al., 1972).

The experiment was arranged in a randomized complete block design and adapted to conditions of sprinkling irrigation. Three irrigation treatments according to available soil water depletion and a rainfed treatment (T_0) were included. Irrigations were scheduled on the basis of soil moisture monitoring in the soil layer of 0.3 m. Irrigation started when 30% (T_1), 50% (T_2) and 70% (T_3) of available soil water in the root zone were consumed or when the soil moisture status in the soil layer of 0.3 m was 21, 18 and 16 weight percent, respectively.

Soil moisture was measured gravimetrically throughout the 3-year investigation period. Soil samples were taken from the protected area of each plot which consists of three rows for both cultivars, at 3 to 5 day intervals to a depth of 0.6 m in 0.1 m increments in three replications from each experimental plot during the entire growing season. Irrigation treatments were established to refill water in the 0.3 m rooting zone to the level of FC. The irrigation rates were 25 mm, (l^{-1} m^{-2}), (T_1), 30 mm (T_2) and 35 mm (T_3). The experiments included two onion cultivars, Kupusinski jabučar and Alek, developed at the Institute of Field and Vegetable Crops, Novi Sad. The cultivar, Kupusinski jabučar is moderately hot cultivar, successfully established from seed or seed sets. The outer leaves of the appleshaped bulb are brown-yellow. The cultivar Alek has an elongated, yellow-brown bulb. The elongated shape of the bulb and the upright position of the leaves make it possible to grow this variety in a denser stand than others. The onion cultivars were sown with a hand-held seeder on 30 March 2005, 29 March 2006 and 8 March 2007 and harvested by hand after more than 50% of the plants had lodged on 26 August 2005, 22 August 2006 and 10 August 2007. The row spacing was 0.30 m and a final plant population density was 45 - 50 plants m^{-2}. The size of the experiment unit was 10.8 m^2 (12 x 0.9 m) and was replicated four times. All sites received a seasonal total of 137 kg nitrogen, 90 kg phosphorus and 90 kg potassium per hectare. The onions were grown using commercial weed and pest management practices typical for the Vojvodina province. Yield (t ha^{-1}) was measured after naturally drying the bulbs for seven days. In the laboratory, the onions were topped and their roots removed for measuring bulb weight, height and diameter. Total soluble solids in the bulb were estimated using a hand held refractometer (Herlich, 1990). Onion evapotranspiration was calculated using the water balance method (Simsek et al., 2005):

$$ETirr = P + I \pm \Delta S - D - R_o$$

$$ET_O = P + \pm \Delta S - D - R_o$$

$$\pm \Delta S = P + I - D - R_o - ET\ (ETirr\ or\ ET_O)$$

ETirr and ET_O are evapotranspiration determined in irrigation treatments and on treatment without irrigation for the growing season, respectively; P is the precipitation; I is the irrigation water applied; ±ΔS represents the change in root zone water storage over a given time interval; D is the drainage water (percolation) and R_o is surface run off which was set to zero.

WUE and IWUE were estimated as (Hillel and Guron, 1975; Kadayifci et al., 2005)

WUE = Yirr, Ydry/ETirr, ET_O (Hillel and Guron, 1975; Kumar et al., 2007)

IWUE = (Yirr – Ydry)/I

Where, WUE is water use efficiency (kg ha^{-1} mm^{-1}), IWUE is irrigation water use efficiency (kg ha^{-1} mm^{-1}), Yirr is the bulb yield of irrigated onions (t ha^{-1}), Ydry is the bulb yield of non-irrigated onions (t ha^{-1}). Data reported for yield, yield components and morphological characteristics of onion bulbs were assessed by analyses of variance (ANOVA) and Fisher's LSD test was used for any significant differences at the P< 0.05 levels between the means. All the analyses were conducted using software package statistika 8.0 series 608c (StatSoft Inc. USA). The relationship between water

Table 1. Physical and water properties of the soil at the experiment site.

Depth (cm)	Textural status (%)			Bulk density (g cm^{-3})	Total porosity (volume %)	Air porosity (volume %)	Field capacity (weight %)	Wilting point (weight %)	Total available soil water (mm)
	Sand	Silt	Clay						
0 - 30	34	48	18	1.27	54.9	21.9	26.0	10.9	57.5
30 - 60	29	44	27	1.31	48.8	14.1	26.5	11.2	60.0

Table 2. Chemical properties of the soil at the experiment site.

Depth (cm)	pH		$CaCO_3$ (%)	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})	Organic matter (%)
	KCl	H_2O					
0-30	7.15	7.95	1.95	70.1	931.5	1113.8	2.63
30-60	7.09	8.02	3.79	55.1	854.1	1042.5	2.03

used by evapotranspiration, precipitation and irrigation water applied and bulb yield was evaluated using regression analysis.

RESULTS AND DISCUSSION

Onion yield and yield characteristics

The yield of onion bulb (Table 3) was significantly higher in irrigated (T_{irr}) than in rainfed conditions (T_0) as onion production from seed in the region depends directly on irrigation. The lowest onion yield in rainfed conditions (T_0) of 10.10 t ha^{-1} was produced the dry 2007 with limited precipitation and higher than average seasonal temperatures (Figure 1c) when compared with the yield in 2006 (13.74 t ha^{-1}) and 2005 (22.82 t ha^{-1}) with higher seasonal average precipitation (Figure 1a and b). The highest yields of onion bulbs of 30.22 and 34.99 t ha^{-1} were produced at treatment T_1 and T_3 respectively, in 2005; at T_2 treatment, it was 38.46 t ha^{-1} and at T_3 it was 40.07 t ha^{-1} in 2006 and 40.96 t ha^{-1} at T_1 treatment in 2007. In years with precipitation above the long-term average (2005 and 2006), the highest yield was produced at treatments with lower pre-irrigation soil moisture (T_2 and T_3), but in dry years (2007), higher values of pre-irrigation soil moisture (T_1), slight irrigation rates and frequent irrigations were preferred. In such conditions, irrigation water refreshes the plants, increases the relative air humidity and decreases the air temperature in the crop stand, helping plants to maintain their vital functions in operation (stomata conductance and photosynthesis), which ultimately improves the yielding performance of plants. High yields of bulbs produced at treatments T_1, T_2 and T_3 in different years indicate that amount and distribution of precipitation seriously affected the soil water regime and irrigation schedule of onion in the region. Therefore, irrigation schedule of onion has to be adjusted to climatic conditions of each year, mostly to amount and distribution of precipitation. Results are in agreement with those of Shock et al. (1998a) who emphasized that under warm and dry growing conditions, an irrigation threshold higher than -12.5 kPa was recommended, as the optimum yield was still compatible with best storage performance. Under cooler and more humid conditions, marketable yields and profits were maximized by a calculated threshold of -27 kPa. At higher irrigation thresholds under these conditions, more onions deteriorated during storage. Halim and Ener (2001) stressed the advantages of high pre-irrigation soil moisture, slight irrigation rates and frequent irrigations in the production of onions under arid climatic conditions in Turkey. Kadayifci et al. (2005) reported that in Turkey, onion is cultivated under non-irrigated and irrigated conditions with yield of 10 to 40 t ha^{-1}, respectively and pointed out the influence of environmental conditions of each year both on yield and evapotranspiration of onion.

Yield components and morphological characteristics of onion bulbs were affected by irrigation (Table 3).The values of total soluble solids in bulbs in the investigated period were higher in years with less precipitation in relation to years with increased precipitation during the growing season and in the treatment without irrigation (T_0), as compared with the irrigated treatments (T_{irr}). There was no difference between the cultivars, Alek and Kupusinski jabučar, with respect to yield and bulb weight (Table 3), but differences exist in bulb diameter, bulb height and soluble solids

Table 3. Bulb weight, bulb diameter, bulb height, total soluble solids in the bulb and onion yield under different irrigation treatments.

Year	Treatment	Bulb weight (g)	Bulb diameter (cm)	Bulb height (cm)	Total soluble solids in the bulb (%)	Yield (t ha^{-1})
2005	T_0	53.3c	3.84c	5.08c	12.00a	22.82c
	T_1	72.3a	4.74b	5.80a	11.37b	30.22ab
	T_2	73.6a	4.58b	5.85a	11.43b	29.21b
	T_3	76.3a	5.17a	5.31b	11.40b	34.99a
	Cultivar					
	Alek	68.6a	4.51a	5.92a	10.60b	30.27a
	K. jabucar	66.3a	4.66a	5.10b	12.19a	28.35a
2006	T_0	48.5d	4.17c	4.71b	14.37a	13.74c
	T_1	70.2ab	4.77b	5.26a	13.58a	35.47b
	T_2	73.5ab	4.87a	5.30a	14.35a	38.64ab
	T_3	76.8a	5.08a	5.36a	14.15a	40.07a
	Cultivar					
	Alek	68.9a	4.61b	5.45a	14.17a	30.89a
	K. jabucar	65.2a	4.83a	4.87b	14.06a	33.07a
2007	T_0	45.6c	4.28c	4.72c	15.85a	10.10c
	T_1	105.6a	5.90a	5.92a	14.53b	40.96a
	T_2	97.8b	5.62b	5.99a	14.08b	34.97b
	T_3	97.7b	5.26bc	5.64b	14.10b	34.90b
	Cultivar					
	Alek	86.3a	5.16a	5.83a	14.30b	30.94a
	K. jabucar	85.2a	5.37a	5.30b	14.98a	29.52a

Numbers followed by same letters in the same column are statistically non-significant by the LSD test at $P \leq 0.05$ difference ($P < 0.05$).

in the bulb (%) with the consequence of some specific cultivar properties. Halim and Ener (2001), Kumar et al. (2007) and Enciso et al. (2009) found that irrigation highly affected the total onion yield, yield components and morphological characteristics of onion bulbs, but did not affect the level of soluble solids in bulbs. As irrigation has a supplementary character in the studied region, the onion yields, yield components and morphological characteristics of onion bulbs varied both in years and irrigation treatments.

Water use of onion and WUE characteristics

Irrigation and rainfed ET values ranged from 435.6 to 542.9 mm and from 290.2 to 393.9 mm, respectively (Table 4). Doorenbos and Kassam (1986) have reported that onion yields of 35 - 45 t ha^{-1} could be obtained with 350 - 550 mm of water using furrow irrigation. They advise that soil water depletion should not be allowed to drop below 25% of available water for optimum yield. Results are also in agreement with those of Halim and Ener (2001) who recorded seasonal ET of onion in irrigated conditions from 394 to 438 mm and from 177 to 266 mm in conditions without irrigation for a yield of 35.8 – 43.1 and 13.9 – 17.4 t ha^{-1}, respectively, under arid climatic conditions in Turkey. Kadayifci et al. (2005) also reported that seasonal ET of onion in Turkey ranges from 350 - 450 mm for bulb yield of 40 t ha^{-1}.

WUE values clearly defined the growing period as favorable for plant production, mostly depending on precipitation amount and distribution. The highest and the lowest WUE of 91.35 and 34.80 kg ha^{-1} mm^{-1} was obtained in irrigation and rainfed conditions in dry 2007, respectively (Table 4). Obtained results are in agreement with the statement that crop yield depends on the rate of water use, and that all factors increasing yield and decreasing water used for ET favorably affected WUE (Arnon, 1975). Kumar et al. (2007) obtained similar results of WUE and reported the highest values of 89.1 and 101.6 kg ha^{-1} mm^{-1} in two years, using micro-sprinklers in arid climate of India.

IWUE coefficient offer a clear picture of the effectiveness of irrigation and irrigation schedule applied. The highest IWUE of 280.54 kg ha^{-1} mm^{-1} was obtained from T_1 treatment in dry 2007, while the lowest value of 45.83 kg ha^{-1} mm^{-1} was obtained from T_1 treatment in rainy 2005 (Table 4). Many studies have been conducted

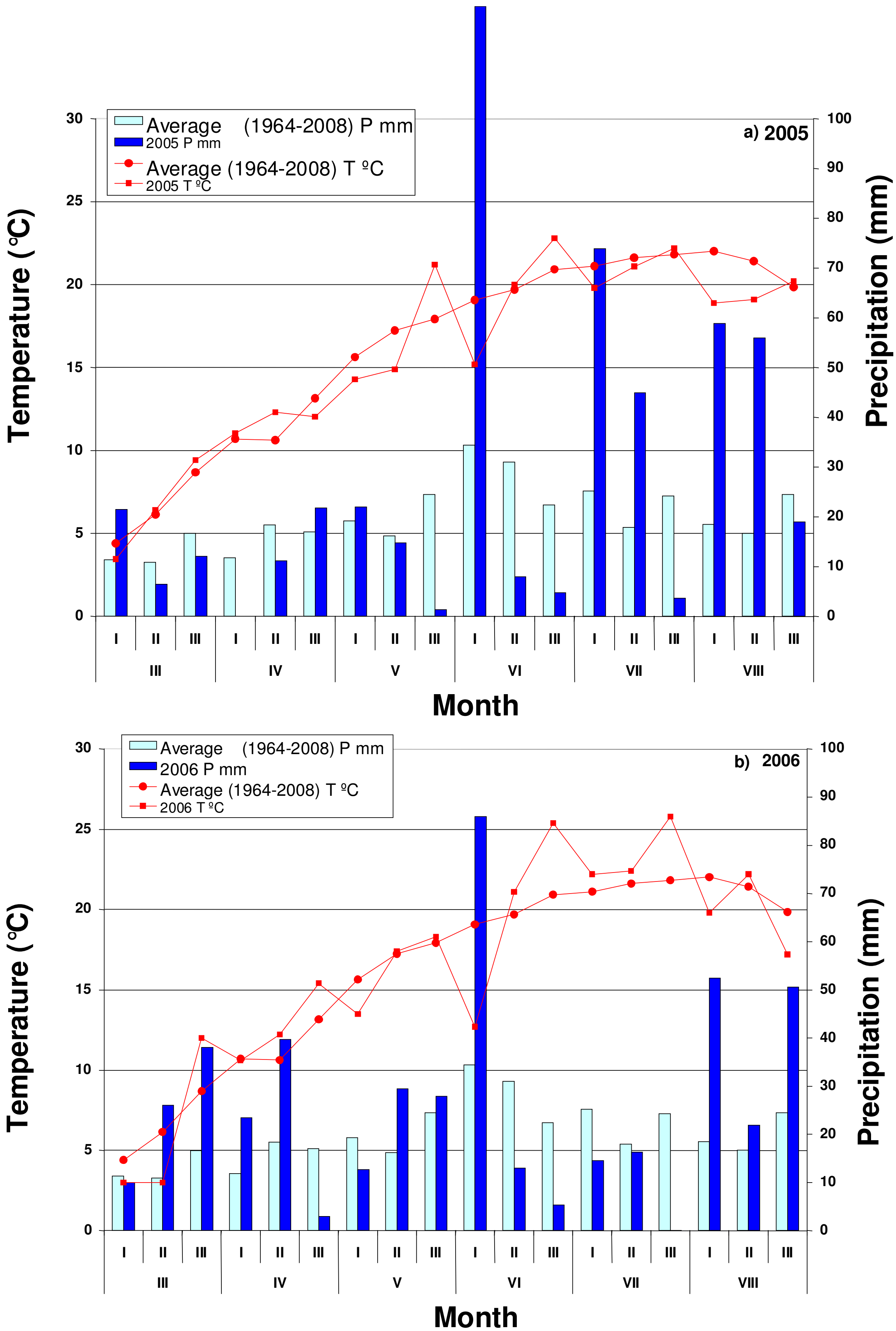

Figure 1. Meteorological data for the experimental years.

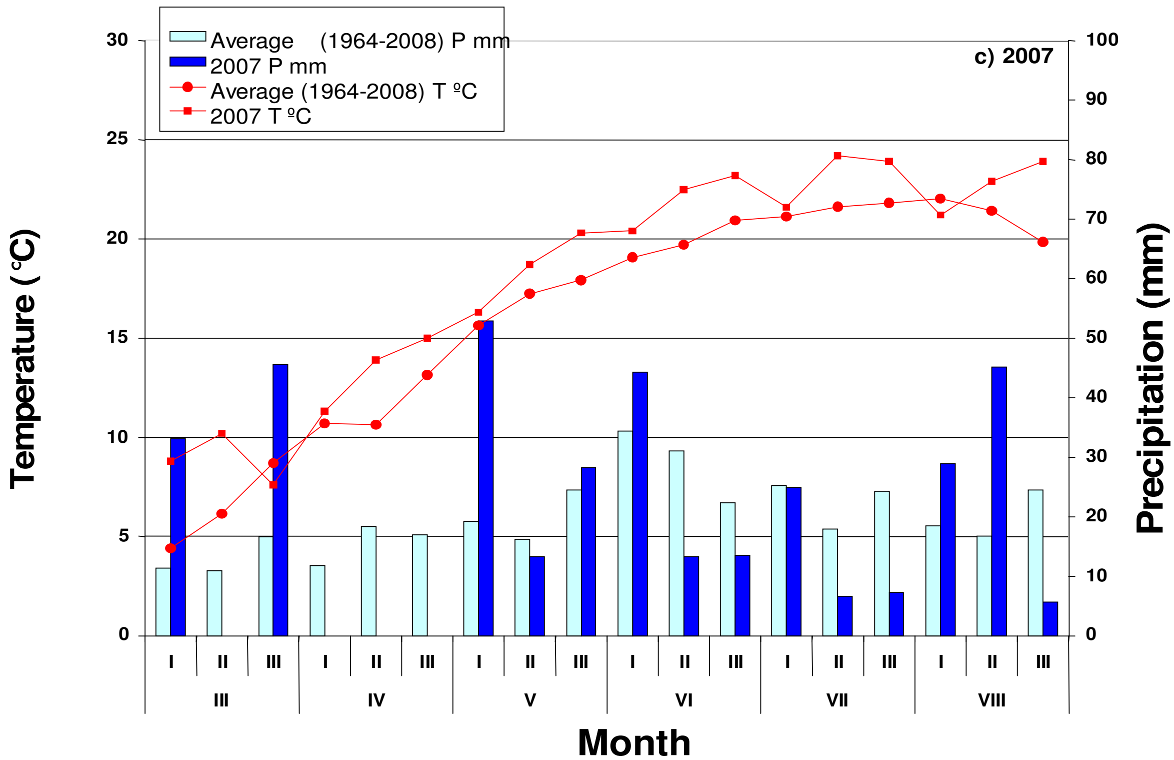

Figure 1. Continued.

Table 4. Evapotranspiration of onion and water use efficiency characteristics.

Year	Treatment	P	D	±ΔS (mm)	I (mm)	No. of irrigation	ET_m (mm)	ETa (mm)	WUE (kg ha^{-1} mm)	IWUE (kg ha^{-1} mm)
2005	T_0	462.5	88.6	20.0	-	-	-	393.9	57.93	-
	T_1	462.5	152.5	7.9	125 (45)*	5	487.9	-	61.94	45.53
	T_2	462.5	132.5	13.3	90 (45)	3	476.3	-	61.33	47.33
	T_3	462.5	137.5	17.5	105 (45)	3	492.5	-	71.04	81.13
2006	T_0	323.7	-	28.1	-		-	351.8	39.06	-
	T_1	345.6	-	16.3	150	6	511,9	-	69.29	144,87
	T_2	345.6	-	17.8	150	5	513,4	-	73,81	166.00
	T_3	345.6	-	22.3	175	5	542,9	-	39,06	150.46
2007	T_0	254.2	-	36.0	-	-	-	290.2	34.80	-
	T_1	312.9	-	25.5	75 (35)	3	448.4	-	91.35	280.54
	T_2	312.9	-	27.7	60 (35)	2	435.6	-	80.28	261.79
	T_3	312.9	-	28.1	70 (35)	2	446.0	-	78.25	236.19

()*, Irrigation performed after sowing with small amounts of water (5 - 10 mm) to ensure uniform sprouting of plants; D, drainage water, excess water which cannot be held in the soil depth of 0.6 m after heavy rain.

to determine IWUE of onion crops, mostly in semi-arid and arid climates, with the aim of suggesting irrigation schedule which fits best to climate and soil conditions in order to improve productivity and save water (Al-Jamal et al., 2001; Kadayifci et al., 2005; Kumar et al., 2007; Pelter et al., 2004). Different IWUE values in the different irrigation treatments during the investigation period revealed that irrigation is supplemental in character meaning that amount and distribution of precipitation seriously affected the soil water regime and irrigation schedule of onion in the region. Determined IWUE values in the investigated period, especially in dry 2007 (236.19 – 280.54 kg ha^{-1}

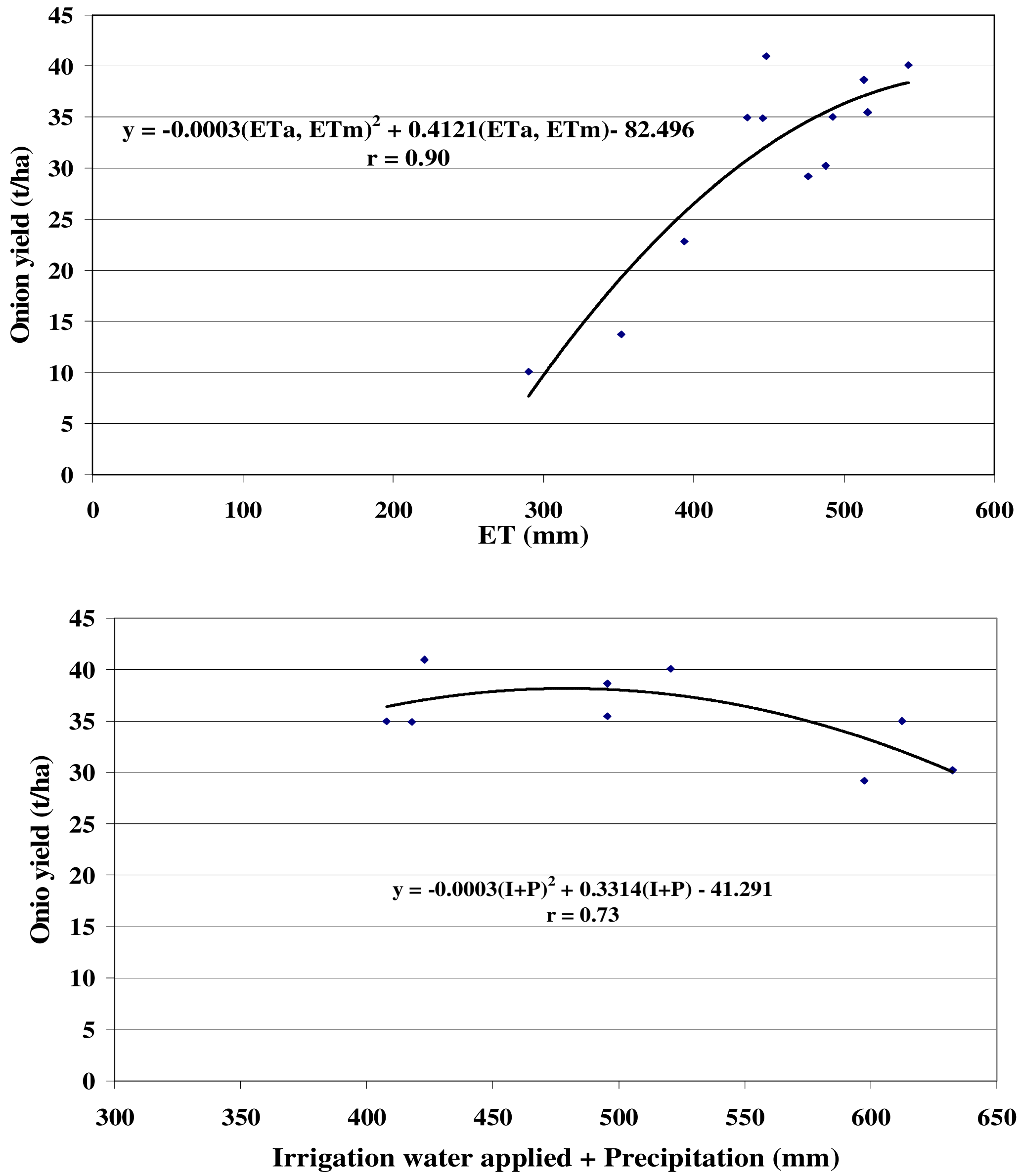

Figure 2. Relationships between (a) onion yield (Y) and evapotranspiration (ET) and (b) onion yield (Y) and irrigation water applied (I) + precipitation (P).

mm^{-1}) were higher than those obtained in arid climate (Kumar et al., 2007) as a consequence of higher yields on one hand and lower irrigation water applied on the other hand. It means that in the regions where irrigation is supplemental, water is used more efficiently when compared with arid regions where irrigation is a pre-requisite for onion growing.

Relationships between yield (Y) and ET, irrigation water applied (I) and precipitation (P) were determined by regression analysis (Figure 2a and b). The significant coefficient, 0.90**, (Figure 2a) indicates that the increase in onion yield was proportional to the increment of evapotranspiration. The highest yields were obtained in the range between 450 - 550 mm. These values are a good predictor for the onion growers in the Vojvodina province, but also create a good platform for the whole region around this area, that is, Serbia as well as neighboring countries. The significant coefficient, 0.73**, (Figure 2b) clearly indicates that the increased water supply causes the increase in yield of onion only to certain limit, after which it stagnates and decreases. It means that, in the region, onion yields are adversely affected by excessive precipitation.

Conclusions

Based on the obtained results of the effect of different irrigation schedules on yield, yield components and morphological characteristics of onion bulbs, as well as total soluble solids in bulbs, it was concluded that irrigation had highly significant effect on all studied parameters, except for soluble solids in bulbs. To achieve a high production potential of onion, appropriate soil moisture should be maintained during the entire growing season. High yields of bulbs in treatments with high (T_1) and low (T_3) pre-irrigation soil moisture levels confirm supplementary characteristic of irrigation in the region and also indicate that the watering regime of onion has to be adjusted to climatic conditions of the year, mostly to distribution of precipitation. Differences in bulb yields between T_i and T_0 treatments indicate that high and reliable yields of onion grown from seed in the region could be achieved only under irrigation conditions. The values of evapotranspiration of 450 - 500 mm could be used as a good platform for onion growers in the region in terms of maximum yield and optimum utilization of irrigation water.

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