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EFFECTS OF WATER STRESS ON WATER USE AND YIELD OF ONION

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Abstract

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The study of effects of water stress on yield and water use by onion plants was carried out at the experimental field of the Institute of Field and Vegetable Crops in Novi Sad in the period 2005-2007. Onion sensitivity to water stress was determined using a yield response factor (K_y). The values of K_y were derived from the linear relationship between relative evapotranspiration deficits ($1-ET_a/ET_m$) and relative yield decrease ($1-Y_a/Y_m$). To assess the irrigation effect on onion yield, irrigation water use efficiency (I_{wue}) and evapotranspiration water use efficiency (ET_{wue}) were determined. Values of K_y in the growing season (K_y 1**.78**) indicate that onion is highly sensitive to water stress under the climate conditions of the Vojvodina region. The amounts of water used on evapotranspiration under irrigation and non-irrigation conditions ranged from 448.4 to511.9 mm, and 290.2 to 393.9 mm, respectively. The values of I_{wue} and ET_{wue} varied from 4.35 to 28.05 kg ha^{-1}/m^{-3} and 7.87 to 19.51 kg ha^{-1}/m^{-3}, respectively, mostly depending on the favorableness of the year for the onion production and irrigation water applied. K_y, I_{wue} and ET_{wue} can be used as a good basis for onion growers in the region in terms of optimum irrigation water use, for the planning, design and operation of irrigation projects in the region, and also for the improvement the production technology of the crop.

Key words: onion, evapotranspiration, water stress, yield, 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). Onion (*Allium cepa* L.) is one of the chief horticultural crops of Serbia. It 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). In the Vojvodina region, onion is cultivated under both irrigated and non-irrigated conditions. Portable sprinkler irrigation systems are commonly used to grow onion. The onion yield in the Vojvodina region is less than half of the world average (17 t ha^{-1}) and four fold lower then those achieved in the European Union (30-35 t ha^{-1}, FAOSTAT 2007). The reasons for the lower yield of onion in the Vojvodina region are many including inadequate management practices, insufficient amount and unfavorable arrangement of precipitation in the growing season, as well as poor water management applied to onions grown from seed.

In order to approach the implementation of any idea on the intensive utilization of agroecological conditions or the development of new procedures for the irrigation regimes of crops, it is necessary to know precise water needs of plants, i.e. potential evapotranspiration (ETc). Water requirements of onion under agroecological conditions of the Vojvodina region vary from 450 to 540 mm for the yield of 30-40 t ha^{-1} (Pejić et al., 2011).

The actual evaluation of stress related to the yield due to soil water deficit during the onion-growing season can be obtained by the estimation of the yield response factor (K_y) that represents the relationship between a relative yield decrease ($1–Y_a/Y_m$) and a relative evaporation deficit ($1–ET_a/ET_m$). Doorenbos and Kassam (1986) estimate that the average values of K_y is 1.5 during the onion-growing season. Vaux and Pruitt (1983) suggest that it is highly important to know not only the K_y values from the literature but also those determined for a particular crop species under specific cli-

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matic and soil conditions. This is because K_y may be affected by other factors besides soil water deficiency, namely soil properties, climate (environmental requirements in terms of evapotranspiration), growing season length and inappropriate growing technology. Water deficit effect on crops yield can be presented in two ways, for individual growth periods or for the total growing season. Kobossi and Kaveh (2010) suggested K_y values for the total growing period instead for individual growth stages as the decrease in yield due to water stress during specific periods, such as vegetative and ripening periods, is relatively small compared with the yield formation period, which is relatively large.

The estimation of water use efficiency in relation to evapotranspiration (ET_{wue}) can show a more realistic evaluation of irrigation effects, i.e. of the irrigation regime applied in onion crops. In addition, the importance of analyzing ET_{wue} is illustrated by the efforts of numerous studies that consider the total water use for evapotranspiration towards transpiration use as to the productive part of water to plants (Wallace and Batchelor, 1977; Howell et al., 2001). The parameter ET_{wue} mostly depends on precipitation amount and distribution and establishes whether the growing period is favorable for plant production or not. Wang et al. (1996) pointed out that crop yield depends on the rate of water use and that the factors that increase yield and decrease water used for ET favorably affect the water use efficiency. Howell (2001) indicated that ET_{wue} generally is highest with less irrigation, implying full use of the applied water and perhaps a tendency to promote deeper soil water extraction to make better use of both the stored soil water and the growing-season precipitation.

An even clearer estimation of irrigation effects and the applied irrigation regime can be obtained by the evaluation of irrigation water use efficiency (I_{wue}) (Sarkar et al., 2008). If the irrigation regime is not synchronized with water needs of crops, water and physical properties of soil and weather conditions, the effect of irrigation can fail, that is the I_{wue} values can be bellow the optimum. The parameter, I_{wue}, generally tends to increase with a decline in irrigation if that water deficit does not occur at a single growth period (Howell, 2001).

The objective of the study was to estimate the yield response factor (K_y) and on the basis of this factor to analyse a seasonal onion response to water stress and in such a way to obtain additional information that can be useful in the improvement of onion growing practices under climate conditions of the Vojvodina region. The established values of ET_{wue} and I_{wue} will be used in analyses of the applied irrigation regime and effects of irrigation on onion yields with the aim to use water more efficiently in irrigation practice. Estimated values of water use on onion evapotranspiration will be compared with previously established in the Vojvodina and similar regions.

Materials and Methods

The trial was carried out on the calcareous chernozem soil at Rimski Šančevi experiment station of Institute of Field and Vegetable Crops (45°20' N latitude, 19°51'E longitude, 84 m above sea level), during the period 2005-2007. Furthermore, the trial was set up according to the block design and was adapted to sprinkler irrigation. There were two variants in the trial: irrigation with the pre-irrigation soil moisture of 80% of field water capacity (FWC) and control (non-irrigated variant).

Irrigation started when 30% of available soil water in the root zone was consumed or when the soil moisture status in the soil layer of 0.3 m was 21 weights percent. Soil moisture was measured gravimetrically at 3 to 5 day intervals to a depth of 0.3 m in 0.1 m increments in three replications during the entire growing season. Irrigation treatment was established to refill water in the 0.3 m rooting zone to the level of FWC. The irrigation rate was 25 mm.

The experiments included the onion cultivars Kupusinski jabučar and Alek, created at the Institute of Field and Vegetable Crops. 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 plots 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 region. Yield (kg ha^{-1}) was measured after naturally drying the bulbs for seven days.

Onion evapotranspiration (ET) was calculated using the water balance method (Simsek et al., 2005):

$$ET_m = P + I \pm S - D - Ro \quad (1)$$

$$ET_a = P + \pm S - D - Ro \quad (2)$$

$$\pm\Delta S = P + I - D - Ro - ET\ (ET_m \text{ or } ET_a) \quad (3)$$

ET_m (1) and ET_a (2) are evapotranspiration determined in irrigation treatment 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 (3), D is the drainage water (percolation) and Ro is surface run off which was set to zero.

The effect of water stress (K_y) during growing season (4) on onion yield was determined using the Stewart's model (Stewart et al., 1977) as follows:

$$\left(1-\frac{Y_a}{Y_m}\right)=K_y\left(1-\frac{ET_a}{ET_m}\right) \quad (4)$$

Where:

Y_a = the actual harvested yield (non-irrigated, kg ha^{-1}), Y_m = the maximum harvested yield (under irrigation, non limiting conditions, kg ha^{-1}), K_y = the yield response factor, ET_a = the actual evapotranspiration (mm) corresponding to Y_a, ET_m = the maximum evapotranspiration (mm) corresponding to Y_m, $(1–ET_a/ET_m)$ = the relative evapotranspiration deficit, and $(1–Y_a/Y_m)$ = the relative yield decrease

Irrigation water use efficiency (I_{wue}, kg ha^{-1}/mm) and evapotranspiration water use efficiency (ET_{wue}, kg ha^{-1}/mm) were estimated as Bos (1980, 1985), (5, 6):

$$I_{wue} = \frac{Y_m - Y_a}{I} \quad (5)$$

$$ET_{wue} = \frac{Y_m - Y_a}{ET_m - ET_a} \quad (6)$$

The experimental onion plots received conventional growing technology adjusted to the conditions of irrigation. Statistical processing of data was done by the analysis of variance (ANOVA) and testing the obtained results by the Fisher's LSD test, ($P< 0.05$ levels between the means). The relationship between crop yield and, water used by evapotranspiration, relative yield decrease and relative crop evapotranspiration deficit for onion growing season were evaluated using regression analysis.

The first two years of the study were characterized by growing season precipitation above the long-term average (328 mm, Figure 1a, 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). Because of the uneven seasonal distribution of precipitation and frequent drying of the topsoil (0.3 m), irrigations had to be performed each year (Table 1). High air temperatures (Figure 1a, b, c), especially in the summer period 2006 (25.4°C and 25.8°C in third decade of June and July, respectively, Figure 1b) affected the amount of water used for evapotranspiration and irrigation frequency.

Results and Discussion

The yield of onion bulb (Table 1) was significantly higher in irrigated than in rainfed (non-irrigated) conditions as onion

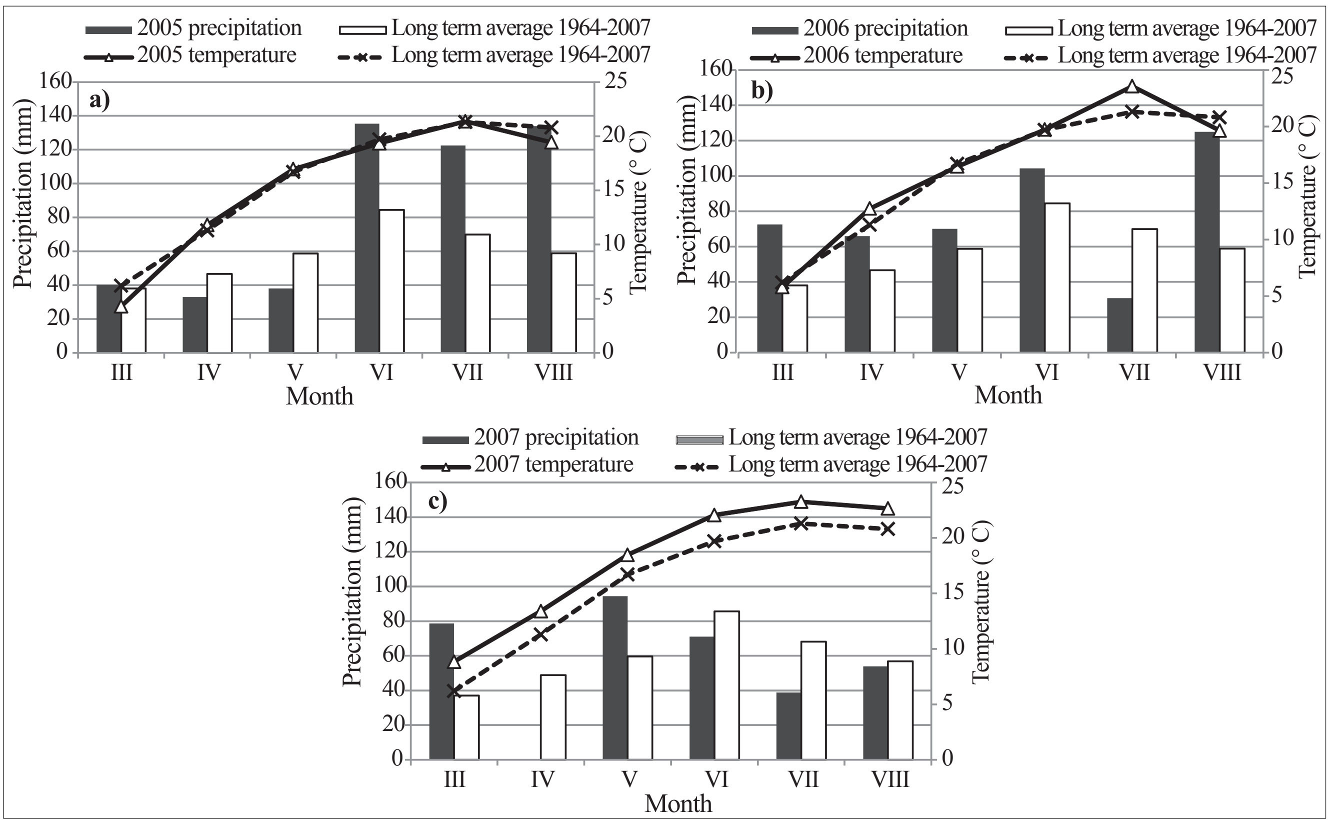

Fig. 1. Meteorological data for the experimental years

production from seed in the region depends directly on irrigation (Pejić et al., 2011). The lowest onion bulb yield in rainfed conditions of 10.10 t ha^{-1} and the highest yield of 40.96 t ha^{-1} in irrigation conditions were produced in the dry 2007 with limited precipitation and higher than average seasonal temperatures (Figure 1c) when compared with the yield in 2006 and 2005 with higher seasonal average precipitation (Figure 1a, b). Results are in agreement with those of Kadayifci et al. (2005) who 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. A large number of watering performed in rainy 2005 and 2006 years compared with dry 2007 (Table 1) confirms supplementary character of irrigation in the region (Pejić et al., 2011a, b, c). It means that not only quantity but also distribution of precipitation can seriously influence irrigation schedule of onion (Pejić et al., 2011).

Irrigation and rainfed ET values ranged from 448.4 to 511.9 mm and from 290.2 to 393.9 mm, respectively (Table 1). 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 t ha^{-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}.

The relationship between onion bulb yield and seasonal crop water use (ET - ETc and ETa) for studied period was linear ($r = 0.87$, $P < 0.05$) (Figure 2). A linear relationship between seasonal crop water use and yield of onion has been reported by other researchers (Al-Jamal et al., 2000; Ayas and Demirtas, 2009; Pejić et al., 2011; Igbadun et al., 2012).

Crop yield response factor (K_y) indicates a statistically significant linear relationship (at the 0.05 probability level for the 3 years) between the decrease in relative evapotranspiration deficit and the decrease in relative yield ($r = 0.74$, Figure 3). Obtained results are in agreement with Doorenbos and Kassam (1986), who stressed that for valid estimation of crop response to water stress, relative evapotranspiration deficit has to be linear and less than 50%. The obtained K_y of 1.78 for total onion growing season (Figure 3) is in agreement with 1.5 reported by Doorenbos and Kassam (1986) and Kadayifci et al. (2005). These findings revealed that onion is very sensitive to lack of soil water during the total growing season and confirm that onion produced from seed cannot be grown without irrigation in the climatic conditions of the Vojvodina region. Relative evapotranspiration decrease was 30.4% resulted with yield reduction of 52.0% (Table 1). This conclusion agrees with the statement given by Doorenbos and Kassam (1986) who underline that $K_y > 1.0$ indicates that the decrease in yield is proportionally greater with increase in water deficit. Determined K_y of onion could be used for the planning, design and operation of irrigation projects in the Vojvodina region, allows quantifications of water supply and water use in terms of crop yield and total production for the project area.

The best method to describe the role that irrigation has in water use efficiency (WUE) in irrigated agriculture is by expressions given by Bos (1980, 1985). Many researchers have evaluated water use efficiency in different ways (Begg and Turner, 1976; Bos, 1980, 1985; Howell, 2001; Pejić, 2010, Pejić; 2011). Consequently, care should be taken when comparing WUE values.

Many studies have been conducted to determine I_{wue} and I_{wue} 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

Table 1
Actual and maximum evapotranspiration (ET_a, ET_m), actual and maximum harvested yield (Y_a, Y_m), relative evapotranspiration deficit ($1-ET_a/ET_m$), relative yield decrease ($1-Y_a/Y_m$), yield response factor (K_y), irrigation water use efficiency (I_{wue}), evapotranspiration water use efficiency (ET_{wue}), irrigation water applied (I), and number of irrigations

Year	ET_m	ET_a	$1-ET_a/ET_m$	Y_m	Y_a	$1-Y_a/Y_m$	K_y	ET_{wue}	I_{wue}	I	No. of irrigations
2005	487.9	393.9	0.245	3022	2282	0.193	1,26	7.87	4.35	125 (45)	5
2006	511.9	351.8	0.313	3547	1370	0.614	1.96	13.60	14.51	150	6
2007	448.9	290.2	0.353	4096	1010	0.753	2.13	19.51	28.05	110	3
2005/7	482.7	345.3	0.304	3555*a	1554b	0.520	1.78	13.66	15.64	143 (35)	

Numbers followed by same letters in the same column are statistically non-significant by the LSD test at $P \leq 0.05$ different ($P < 0.05$)
()* irrigation performed after sowing with small amounts of water (5-10 mm) to ensure uniform sprouting of plants

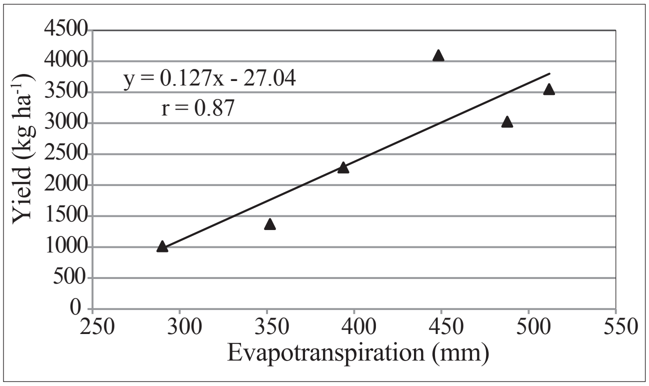

Fig. 2. Relationship between bulb yield (Y) and evapotranspiration (ET) of onion

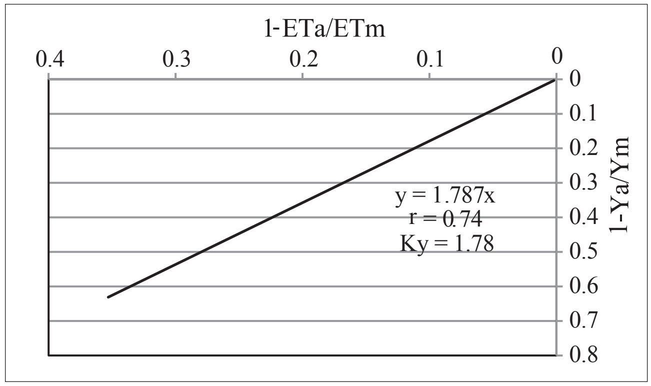

Fig. 3. Relationship between relative yield decrease and relative crop evapotranspiration deficit for onion growing season

and save water (Al-Jamal et al., 2001; Pelter et al., 2004; Kadayifci et al., 2005; Kumar et al., 2007, Sarkar et al., 2008).

I_{wue} and ET_{wue} in the study ranged from 4.35 to 28.05 kg mm^{-1} ha^{-1} and 7.87 to 19.51 kg ha^{-1}/mm respectively (Table 1). The highest values of both I_{wue} and ET_{wue} were obtained in 2007 because of obtained yield in irrigation (4096 kg ha^{-1}) and rainfed (1010 kg ha^{-1}) conditions and irrigation water applied of 110 mm. The results are in agreement with statement given by Howell (2001) that generally walues of I_{wue} and ET_{wue} tends to increase with a decline in irrigation.

Conclusions

Based on results gained on effects of water stress on water use and onion yields under climate conditions of the Vojvodina region it can be concluded that the onion bulb yield under rainfed conditions (1554 kg ha^{-1}) was significantly lower than the yield (3555 kg ha^{-1}) recorded under irrigation conditions. Evapotranspiration rate under irrigation conditions (ET_m) ranged from 448.9 to 511.9 mm, while they varied from 290.2 to 393.9 mm under non-irrigation conditions (ET_a). Irrigation water use efficiency (I_{wue}) ranging from 4.35 to 28.05 kg ha^{-1}/mm and evapotranspiration (ET_{wue}) varying from 7.87 to 19.51 kg ha^{-1}/mm. Values of K_y (1.78) in the onion growing season point to the fact that onion is very sensitive to water stress under climate conditions of the Vojvodina region and confirm that onion produced from seed can not be grown without irrigation in the climatic conditions in the region. The determined values of K_y, I_{wue} and ET_{wue} can be a good basis for onion growers in the region in relation to the optimum irrigation water use, planning, projecting and utilisation of irrigation systems, and also for the improvement the production technology of the crop.

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