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EFFECTS OF SURFACE AND SUBSURFACE DRIP IRRIGATION ON THE YIELD, VEGETATIVE GROWTH AND WATER PRODUCTIVITY OF ONIONS*

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Summary: The objective of this study, conducted in the northern Serbian province of Vojvodina, was to analyze the effect of surface and subsurface drip irrigation (with drip lateral placement depths of 0.05 and 0.1 m) on the yield and water productivity of onions (Allium cepa L., var. 'Holandski žuti'). The irrigation applied was scheduled on the basis of the water balance method. The daily evapotranspiration rate was computed using the reference evapotranspiration (ET_o) based on the Hargreaves equation and the crop coefficient (kc). The irrigation rate was 30 mm, whereas the amount of water added by irrigation during the season was 150 mm. According to the results obtained, the onion yield under irrigated conditions was significantly higher than that under non-irrigated (control) conditions. Differences in the yield obtained using surface and subsurface irrigation were non-significant. The amounts of water used for evapotranspiration under irrigated and non-irrigated conditions were 363 mm and 220 mm, respectively. The value of the surface irrigation yield response factor (K_y) was 0.62, whereas the values of the subsurface irrigation yield response factor (K_y) were 0.61 (0.05 m) and 0.79 (0.1 m). Consequently, onions grown from sets proved moderately sensitive to water stress under regional climate conditions and could be grown without irrigation. The value of the irrigation water use efficiency (I_{wue}) ranged from 3.55 to 4.97 kg m^{-3}, whereas the value of the evapotranspiration water use efficiency (ET_{wue}) ranged from 3.72 to 5.22 kg m^{-3}. The highest yield of onions was obtained using a drip lateral placement depth of 0.1 m, which is recommended for high-yielding onion production.

Key words: onion, irrigation, yield, water productivity

INTRODUCTION

The onion (*Allium cepa* L.) is one of the leading horticultural crops in Serbia. Over the last five years, a total of 5,050 hectares were devoted to onions in the country (with an average yield of 7.48 t ha^{-1} and an annual production of 32,000 t). According to the Statistical Office of the Republic of Serbia, a total of 1,834 hectares were devoted to onions in the northern Serbian province of Vojvodina (with an average yield of 10.50 t ha^{-1} and an annual production of 19,500 t). Lower average onion yields in Serbia, compared to those achieved in the leading onion growing countries (South Korea 67.2 t ha^{-1}, USA 53.9 t ha^{-1}, Japan 53.9 t ha^{-1}, Germany 45.6 t ha^{-1} FAOSTAT), are primarily a consequence of inadequate management practices, insufficient amount and unfavourable distribution of precipitation in the growing season, as well as poor optimization of the irrigation regime.

In the Vojvodina region, the onion is mostly cultivated under rainfed conditions, as well as in constantly increasing irrigated areas. Various studies conducted in a wide range of environments have demonstrated that onion yields increase with irrigation (Halim and Ener 2001, Kadayifci et al., 2005, Kumar et al. 2007, Enciso et al. 2009, Pejic et al., 2014). The sprinkler method is commonly used for onion irrigation. Due to numerous advantages, drip irrigation, both surface and subsurface, has recently been applied, especially in the cultivation of vegetables. Drip irrigation is considered superior to surface and sprinkler irrigation (Camp, 1998) due to lower water requirements

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and the possibility of placing water and other chemicals precisely (Bartolo, 2005) with a high degree of uniformity (Camp et al., 1997). Moreover, drip irrigation has proven much more efficient (Ellis et al., 1986, Camp, 1998). The subsurface drip system is the latest method of irrigation. By providing water directly to the root zone, it minimizes evaporative losses (Patel and Rajput, 2009), thus conserving substantial amounts of water (Ayars et al., 1999) and preventing crust formation which hinders soil aeration and rainwater infiltration (Kalfountzos et al., 2007). Subsurface irrigation lessens surface runoff, deep percolation, wind drift, overspray, vandalism and damage by animals. Using the subsurface drip system can result in yields equal to or even higher than those obtained by applying surface drip irrigation (Singh et al., 2006).

The depth and spacing of laterals in subsurface irrigation depends on the cultivated plants and physical properties of the soil. All the depths (ranging 2-70 cm) and spacings (ranging 0.25-5 m) provide overlapping wetted areas along the laterals for most of the row crops (Camp et al., 2000) as the number of drippers, the discharge and the irrigation frequency (as adjustable parameters) can be customized to any possible situation (Camp and Lamm, 2003). To produce high onion yields, Patel and Rajput (2009) recommend the placement of drip laterals at a shallow depth. Al-Jamal et al. (2001) also suggest the shallow depth placement of drip laterals as the base plate must be kept wet and this can only happen if the water subs to the surface. Ruskin (2000) argues that, when using subsurface drip irrigation, water should be applied in small and frequent amounts since its movement in unsaturated soil conditions is mainly governed by capillary forces. Consequently, the wetted spherical soil volume, i.e. the available soil volume for root development, is higher, whereas the wetted radius and soil moisture are lower in subsurface than in surface drip irrigation.

Subsurface irrigation contributes to higher production and water use efficiency more than any other irrigation method (Sammis, 1980). However, this is strongly associated with the prevailing weather and soil conditions, as well as the design and management of irrigation systems (Kalfountzos et al., 2007). Wang et al. (1996) emphasize that crop yields depend on the rate of water use, and that the factors which increase yield and decrease water used for ET favourably affect the water use efficiency. Al-Jamal et al. (2001) claim that only by breeding onion varieties which transpire less water, while maintaining the photosynthesis rate, can WUE be increased because stressing a crop causes the stomata to close and reduces the rate of transpiration, as well as the rate of photosynthesis and yield potential.

The information on the reaction of onion plants to water stress and irrigation could be obtained using the yield response factor (K_y). Doorenbos and Kassam (1979) estimated an average K_y value of 1.5 during the onion growing season. Cakir (2004) reported that the K_y values of a given crop and locality varied from year to year even at the same location. The values of K_y are strongly related to soil water deficit, soil properties, environmental requirements and production technology. Therefore, K_y values should be determined for crops grown under specific climatic and soil conditions (Vaux and Pruitt, 1983). The calculation of K_y values for the total growing period suggested by Kobossi and Kaveh (2010) is better than for individual growth stages as the decrease in yields due to water stress in the vegetative and ripening periods is smaller compared to that recorded in the yield formation period. Pejić et al. (2014) obtained a K_y value of 1.78 for onions grown from seeds, which confirms that the onion is very sensitive to soil water deficits at all stages of growth and development, and cannot be grown without irrigation under the climatic conditions of the Vojvodina region.

The objective of this study was to determine the effects of surface and subsurface irrigation, as well as different lateral placements depths, on the yield, vegetative growth and water productivity of onions. The results obtained could enhance the optimization of onion production with regard to higher yields and irrigation water requirements.

MATERIAL AND METHODS

A trial with irrigated onions was conducted on a private farm in Bački Jarak (45°22' N latitude, 20°18' E longitude and 84 m.a.s.l.) near Novi Sad, in the Calcic Chernozem soil according to the WRB (FAO, 2006), in 2017. In the period 1964-2016, the annual mean air temperature, precipitation and relative humidity were 11.2 °C, 598.7 mm and 76%, respectively. In the growing season (March-July), the mean air temperature and total rainfall were 16.7 °C and 200 mm, respectively. Insufficient rainfall in the region inevitably leads to water deficits, which can be attenuated by irrigation. The amount of irrigation water applied was 150 mm (Figure 1, Table 1). Daily precipitation was measured at the experimental plot site by a rain gauge, whereas the air temperature data were obtained from a weather station located at Rimski Šančevi, near the experimental field (Figure 1).

The previous crop was the potato. The soil was ploughed at a depth of 0.3 m in the autumn and prepared for planting using the disc method in March. The onion cultivar ‘Holandski žuti’ was planted by hand on 16 March. All recommended agronomic practices regarding cultivation and plant protection were applied at the experimental plot. The plants were irrigated using the drip irrigation system with laterals placed on the soil surface and subsurface at depths of 0.05 m and 0.1 m. The drip irrigation system consisted of laterals (16 mm in diameter) with in-line emitters spaced 0.20 m along the line, with a discharge rate of 3.0 1 h^{-1} at a pressure of 100 kPa. The spacing between two laterals was 0.3 m. The volume of irrigation water was measured by flow meters installed in the hose nozzle used for irrigation. Irrigation was withheld two weeks before harvest.

Table 1. Irrigation water applied and the duration of each onion crop development stage

Crop development stage	Duration		Rainfall (mm)	Irrigation water applied (mm)	No. of irrigations
	Date	The length of the period (days)			
Initial	17.03-11.04.	26	9	20	2*
Crop development	12.04-14.05.	33	91	10	1*
Mid season	15.05-19.06.	36	100	120	4
Late season	20.06-04.07.	15	0	0	0
Growing season	17.03-04.07	110	200	150	7

*****Irrigation after planting with small amounts of water (10 mm) was performed to ensure the uniform germination and successful initial growth of plants

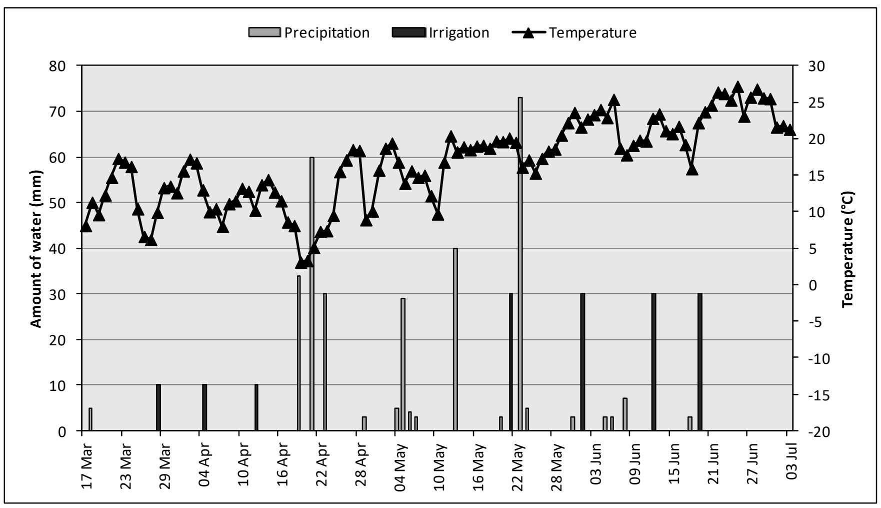

Figure 1. Irrigation schedules, irrigation water applied and meteorological data for the experimental year

The experiment was set up as a block system with three replicates and adapted to the technical specifications of drip irrigation. The size of the experimental unit was 3 m^2 (2 x 0.3 m x 5 m). The trial also included the non-irrigated, control plants. Plants were harvested by hand after more than 50% of the plants lodged on 4 July. The plant height and the number of leaves per plant were detected before the plants lodged on the ground. The onion plants were dried in the field and the yield (t ha^{-1}) was computed on the basis of the yield measured at the experimental plot. The bulb weight was measured after removing leaves and roots of the plants. Total soluble solids in the bulb were estimated using a hand held refractometer.

Irrigation was scheduled on the basis of the water balance method using the reference evapotranspiration (ET_o) and crop coefficients (kc). ET_o was calculated by the Hargreaves equation (Hargreaves and Samani, 1985).

$$ET_o = 0.0023(T_m + 17.8)(\sqrt{T_{max} - T_{min}})R_a$$

ET_o – reference evapotranspiration (mm day^{-1}), T_m – the average daily air temperature (^{0}C), T_{max} – the maximum daily temperature (^{0}C), T_{min} – the minimum daily temperature (^{0}C), R_a – the extraterrestrial radiation (MJ·m^{-2}).

The amount of daily water used for evapotranspiration was calculated by multiplying ETo by the following kc values (according to FAO): 0.5 for the initial stage, 0.75 for the crop development stage, 1.05 for the mid-season stage, and 0.85 for the late season stage. Irrigation started when the readily available water in the soil layer of 0.3 m was completely absorbed by plants.

Yield response factor: The yield response factor (K_y) for the total growing season was determined using the Steward's model (Doorenbos and Kassam, 1979) as follows:

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

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.

***Water productivity*:** The irrigation water use efficiency (I_{wue}, kg m^{-3}) and the evapotranspiration water use efficiency (ET_{wue}, kg m^{-3}) were estimated as Bos (1980, 1985). The calculation of I_{wue} was based on the increase in bulb yield (kg ha^{-1}) and the amount of irrigation water applied (I, m^3 ha^{-1}). ET_{wue} was computed as the ratio between the increase in bulb yield (kg ha^{-1}) and the evapotranspiration deficit.

The data obtained were subjected to a standard analysis of variance (ANOVA), and the treatments were compared by Duncan's LSD test at a probability level of 5%.

RESULTS

Yield, yield components and morphological characteristics of onions. Irrigation has significantly increased the yield of onions. The yield under irrigated conditions was statistically significant and higher by 32.9 to 45.4% compared to the control onion plants without irrigation. However, statistical differences were not detected between different lateral placements (Table 2). Yield components and morphological characteristics, namely the weight of bulbs and the height of plants, were also significantly influenced by irrigation. Both irrigation and lateral placement had no influence on the dry matter content in onion bulbs (Table 2).

Table 2. Yield, yield components and morphological characteristics of onions

Variant	Replicates	Yield (t ha^{-1})	Plant height (cm)	Number of leaves per plant	Bulb weight (g)	Dry matter in bulbs (%)
Surface drip	1	23.02	57.0	7.2	59.9	14.5
	2	20.90	57.0	6.9	60.6	14.1
	3	21.60	56.6	7.3	60.1	14.9
	Average	**21.84a**	**56.9a**	**7.1a**	**60.2a**	**14.5a**
Subsurface drip (5 cm)	1	23.91	55.6	7.9	69.8	15.0
	2	20.79	56.5	7.7	68.7	14.5
	3	20.55	57.2	7.8	70.2	13.9
	Average	**21.75a**	**56.4a**	**7.8a**	**69.6b**	**14.5a**
Subsurface drip (10 cm)	1	24.96	60.4	8.6	73.5	13.0
	2	23.19	56.3	7,4	67.6	14.5
	3	23.52	57.1	7.9	69.8	13.5
	Average	**23.89a**	**57.9a**	**8.0b**	**70.3b**	**13.7a**
Non-irrigated	1	15.57	46.8	7.2	53.1	14.5
	2	16.89	46.2	7.0	51.1	14.0
	3	16.83	49.0	7.6	48.6	13.5
	Average	**16.43b**	**47.3b**	**7.3a**	**50.9c**	**14.0a**

Seasonal evapotranspiration, yield response factor and water use efficiency.

In the period under consideration, the evapotranspiration rates under irrigated (ET_m) and rainfed control (ET_a) conditions were 363 mm and 220 mm, respectively (Table 3 and 4). The highest evapotranspiration rate was detected in the mid-season amounting to 184 mm. On average, the highest value of daily water used for the evapotranspiration of onions under irrigated conditions was detected in the mid-season stage (5.1 mm), but the average value for the entire growing season was 3.3 mm (Table 3). The maximum daily evapotranspiration value of 6.6 mm was detected 92 days after planting (Figure 2).

Table 3. Onion evapotranspiration

Crop development stage	ET_o (mm)	ET_m (mm)	ET_a (mm)	Water used on ET_m (%)	Average daily ET_m (mm)
Initial	67	34	29	9.4	1.3
Crop development	104	78	78	21.5	2.4
Mid season	175	184	113	50.7	5.1
Late season	79	67	0	18.5	4.5
Growing season	425	363	220	100	3.3

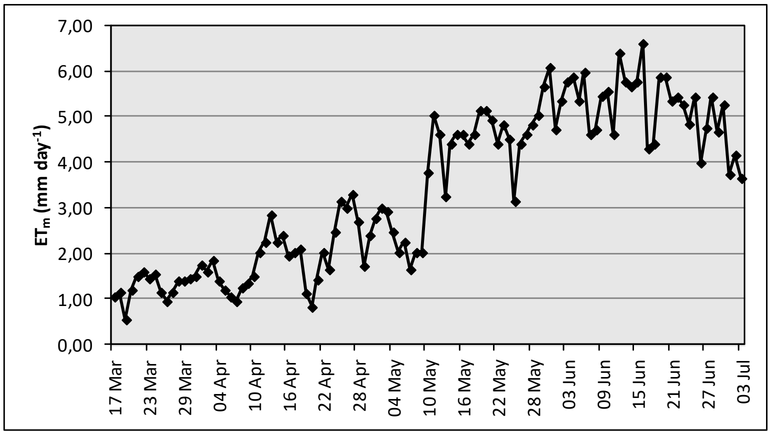

Figure 2. Daily evapotranspiration rates under irrigated conditions (ET_m)

In the total crop growing period, the yield response factor (K_y) for surface drip and subsurface drip with laterals placed at depths of 0.05 m and 0.1 m were 0.62, 0.61 and 0.79, respectively (Table 4). ET_{wue} and I_{wue} as the key indicators that reveal the optimal use of water for plant production ranged from 3.72 to 5.22 (kg m^{-3}) and from 3.55 to 4.97 (kg m^{-3}), respectively (Table 4).

Table 4. Yield response factor and water productivity of onions

Variant	ET_m	ET_a	Y_m	Y_a	1-ET_a/ET_m	1-Y_a/Y_m	K_y	I	I_{wue}	ET_{wue}
Surface irrigation	363	220	21.84	16.43	0.39	0.25	0.62	150	3.61a	3.78a
Subsurface irrigation (0.05 m)	363	220	21.75	16.43	0.39	0.24	0.61	150	3.55a	3.72a
Subsurface irrigation (0.01 m)	363	220	23.89	16.43	0.39	0.31	0.79	150	4.97a	5.22a

DISCUSSION

The yield of onion bulbs under irrigated conditions (21.75-23.89 t ha^{-1}) was significantly higher compared to non-irrigated, control onion plants (16.43 t ha^{-1}, Table 2). Studies conducted in a wide range of environments confirm that irrigation can significantly increase the yield of onions (Halim and Ener, 2001, Kadayifci et al., 2005, Kumar et al., 2007, Enciso et al., 2009, Pejić et al., 2011, Pejić et al., 2014). The lower yields of onions obtained in the study year are attributable to heavy rain followed by hail. The irrigation with 30 mm of water performed on May 21 was followed by 73 mm of rain two days later (Figure 1), which resulted in flooded plants, damaged by hail. In the variable climate of Vojvodina, no long-term rainfall prediction is possible. Due to the possibility of irrigation and heavy rain overlapping, irrigation is of supplementary character in this region. Kadayifci et al. (2005) and Pejić et al. (2011) stressed the influence of local environmental factors both on the yield and evapotranspiration of onions.

Differences in the yield obtained using surface and subsurface irrigation were not significant. The highest yield of onions was obtained using a drip lateral placement depth of 0.1 m (23.89 t ha^{-1}, Table 2), which is consistent with the results of Patel and Rajput (2009). These authors also argue that the placement of drip laterals at a shallow depth is recommended in the sandy-loam soil as the greater vertical movement of water is influenced by gravity rather than capillary forces.

The results obtained show that irrigation enables a substantial increase in the yield components and morphological characteristics of onions, namely bulb weight and plant height. The statistical differences were not detected in the number of leaves per plant and the dry matter in bulbs (Table 2). Halim and Ener (2001), Enciso et al. (2009), Pejić et al. (2011) also found that the application of irrigation significantly affected the total onion yield, as well as yield components and morphological characteristics of onion bulbs, but the content of soluble solids in the bulbs remained unchanged.

The ET_m under irrigated conditions was higher than the ET_a under rainfed conditions as precipitation rarely meets the needs of onion plants in the region. In onion production from sets, irrigation is used primarily to minimize the lack of precipitation during short-term droughts. The amounts of water used for the evapotranspiration of onions grown from sets ranged from 220 mm under rainfed conditions to 363 mm under irrigated conditions. This is in agreement with the results of Halim and Ener (2001) who conducted a study under arid climatic conditions in Turkey. They recorded a seasonal ET value of 438 mm for irrigated onions and 266 mm under rainfed conditions for a yield of 43.1 t ha^{-1} and 17.4 t ha^{-1}, respectively. A maximum daily evapotranspiration value of 6.6 mm recorded in our research is in accordance with the environmental requirements and growth stages of onions. Similar values of the maximum daily water used for onion evapotranspiration (6-7 mm) were recorded by Nagaz et al. (2012) in the arid region of Tunisia.

The yield response factor for the total crop growing period (0.61-0.69) reveals that onions from sets could be grown without irrigation in the temperate climate of the Vojvodina region. However, the statistically significant lower onion yields obtained under rainfed conditions indicate that irrigation is necessary for achieving high and stable yields. Irrigation is the only option for seed-grown onions in the region as Pejić et al. (2014) detected a K_y value of 1.78.

The values of I_{wue} (3.55 to 4.97 kg m^{-3}) and ET_{wue} (3.72 to 5.22 kg m^{-3}) obtained in this study approximate to those found in other studies. Nagaz et al. (2012) reported the I_{wue} and ET_{wue} of 4.94-5.51 kg m^{-3} and 4.58-5.01 kg m^{-3} respectively for onion grown in the arid region of Tunisia.

CONCLUSION

On the basis of the results obtained, it can be concluded that the onion bulb yield under rainfed conditions (16.43 t ha^{-1}) was significantly lower than the yield recorded under irrigated conditions (21.75-23.89 t ha^{-1}). Differences in the yield obtained using surface and subsurface irrigation were non-significant. The amounts of water used for onion evapotranspiration under irrigated and non-irrigated conditions were 363 mm and 220 mm, respectively. The value of the irrigation water use efficiency (I_{wue}) ranged from 3.55 to 4.97 kg m^{-3}, whereas the value of the evapotranspiration water use efficiency (ET_{wue}) ranged from 3.72 to 5.22 kg m^{-3}. The value of the surface irrigation yield response factor (K_y) was 0.62, whereas the values of the subsurface irrigation yield response factor (K_y) were 0.61 (0.05 m) and 0.79 (0.1 m), which indicates that onions from sets can be grown without irrigation in the temperate climate of Vojvodina. Regardless of the yield response factor, the lower yield of onions obtained under rainfed conditions emphasizes the necessity of irrigation. The highest yield of onions was obtained using a drip lateral placement depth of 0.1 m, which is recommended for high-yielding onion production.

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EFEKAT POVRŠINSKOG I POTPOVRŠINSKOG NAVODNJAVANJA KAPANJEM NA PRINOS, VEGETATIVNI PORAST I PRODUKTIVNOST UTROŠENE VODE CRNOG LUKA

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Izvod: Cilj istraživanja, obavljenog u Vojvodini, severnom delu Srbije, bio je da se analizira efekat površinskog i potpovršinskog navodnjavanja kapanjem (0,05 m i 0,1 m dubina postavljenih laterala) na prinos i produktivnost utrošene vode crnog luka (*Allium cepa* L., var. Holandski žuti). Vreme zalivanja je odredjivano vodnim bilansom. Dnevne vrednosti evapotranspiracije su računate korišćenjem referentne evapotranspiracije (ET_o) računate Hargreaves jednačinom i koeficijenata useva (kc). Zalivna norma iznosila je 30 mm, a norma navodnjavanja 150 mm. Na osnovu rezultata istraživanja može se zaključiti da je navodnjavanje signifikantno uticalo na visinu prinosa luka u poredjenju sa nenavodnjavanom, kontrolnom varijantom. Nisu utvrdjene signifikatne razlike izmedju površinskog i potpovršinskih varijanti navodnjavanja. Evapotranspiracija crnog luka u uslovima navodnjavanja bila je 363 mm, odnosno 220 mm na nenavodnjavanoj varijanti. Vrednosti K_y od 0,62, 0,61 (0,05 m) i 0,79 (0,1 m) ukazuju da je crni luk proizveden iz arpadžika umereno osetljiv na vodni stres u klimatskim uslovima regiona i da može biti uzgajan i bez navodnjavanja. Vrednosti koeficijenata I_{wue} i ET_{wue} bile su u intervalu od 3,55 do 4,97 kg m^{-3} i 3,72 do 5,22 kg m^{-3}. U cilju dobijanja visokih prinosa crnog luka preporučuje se potpovršinsko navodnjavanjem sa lateralima postavljenim na dubinu 0,1 m.

Ključne reči: crni luk, navodnjavanje, prinos, efikasnost korišćenja vode

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