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# WATER–YIELD RELATIONS OF PROCESSING POTATO UNDER SURFACE AND SHALLOW SUBSURFACE DRIP IRRIGATION IN TEMPERATE CLIMATIC ENVIRONMENT


## SUMMARY

Field experiment was conducted to study the effects of surface (SDI) and shallow subsurface drip irrigation (SSDI) on potato (*Solanum tuberosum* L.) tuber yield, evapotranspiration, water use efficiency (WUE), and yield response factor ($K_y$). The experiment was carried out under semiarid climatic conditions in the Vojvodina region in 2020. The trial was established as a block design and adapted to technical specifications of drip irrigation system. In addition, the nonirrigated, control variant was also included in the trial. Irrigation was scheduled on the basis of water balance method. Daily water used on plants evapotranspiration ($ET_d$) was calculated by multiplying reference evapotranspiration ($ET_o$) with crop coefficients ($k_c$). $K_c$ values were 0.5, 0.7, 1.1, 0.9, 0.7 from planting to emergence, early vegetative development, tuber initiation, tuber enlargement and senescence, respectively. The potato processing variety 'Taurus' was used for the experiment. Obtained results indicate a significant effect of irrigation on potato yield compared to the nonirrigated variant (38.33 t ha$^{-1}$) but differences in the yield using the SDI (58.06 t ha$^{-1}$) and the SSDI (61.15 t ha$^{-1}$) were not significant. In the study period, seasonal evapotranspiration in irrigation conditions ($ET_m$) and in rainfed control variant ($ET_a$) was 478 mm and 319 mm respectively. IWUE values were 9.39, 10.85 kg m$^{-3}$ and 27.64, 29.09 kg m$^{-3}$ but ETWUE values were 12.40, 14.35 kg m$^{-3}$ and 12.14, 12.79 kg m$^{-3}$ for SDI and SSDI respectively. The seasonal yield response factor ($K_y$) of 1.03 and 1.12 for SDI and SSDI indicates that potato can be grown without irrigation in the temperate climate of Vojvodina.


**Keywords**: potato, drip irrigation, yield, evapotranspiration, water productivity

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## INTRODUCTION

Production of potato (*Solanum tuberosum* L.) takes a very important place in world agriculture, with a production potential of about 370 million tonnes harvested and 17.3 million hectares planted area with an average yield of 20.9 t ha$^{-1}$ (FAOSTAT, 2019). It rates fourth among the world's agricultural products in production volume, after wheat, rice, and corn (Fabeiro *et al.,* 2001). Over the last three years, a total of 36,000 hectares were devoted to potato in Serbia with an annual production of 597,000 tons and an average yield of 16.8 t ha$^{-1}$. In Vojvodina, the northern part of the Republic of Serbia potato is grown at about 5.700 hectares, with an annual production of 130,000 with an average yield of 23.0 t ha$^{-1}$ (Statistical Yearbook of the Republic of Serbia, 2021). In the region, the potato is mostly cultivated under rainfed conditions. Irrigation systems (portable sprinklers) cover only 12-15% of the potato growing area (Broćić and Stefanović, 2012). Lower average potato yields in Serbia, compared to those achieved in the leading potato growing countries (USA 49 t ha$^{-1}$, New Zealand 49 t ha$^{-1}$, Denmark 42 t ha$^{-1}$, Holland 42, Australia 40 t ha$^{-1}$, FAOSTAT, 2019), are primarily a consequence of inadequate management practices, insufficient amount and unfavorable distribution of precipitation in the growing season, production mostly under rainfed conditions as well as poor irrigation management.

In the variable climatic conditions of Vojvodina, in which summers are arid (Bošnjak, 2001), high and stable yields of potato can be reliably obtained only by supplementing crop water requirements through irrigation. Only optimum moisture conditions permit the plants to use water according to their needs, i.e., to the level of potential evapotranspiration (ETP). Bošnjak and Pejić (1995) found seasonal ETP of potato in the interval from 460 to 480 mm for the conditions of the Vojvodina region with the seasonal average and maximum daily values of 3.5 mm and 7 mm respectively.

Irrigation in Vojvodina is most commonly used to supplement infrequent or irregular precipitation during drought periods which regularly occur especially in July and August (Dragović *et al.,* 2012). Due to the unpredicted amount and distribution of precipitation in the growing season, irrigation in the Vojvodina region is mainly supplemental (Pejić *et al*., 2011a, Pejić *et al*., 2018).

Many irrigation experiments, conducted in a wide range of environments, have confirmed that potato yields increase with well-scheduled irrigation (Yuan *et al.,* 2003; Onder *et al*., 2005; Milić *et al.,* 2010; Badr *et al.*, 2012; Pejić *et al.,* 2014; Aksić *et al.,* 2014). Rational irrigation, in addition to providing plants with the necessary amounts of water during the growing season, especially in the critical stages of development, implies the correct choice of irrigation methods. Potatoes in the region are most often irrigated by sprinklers, but due to numerous advantages of drip irrigation, both surface (SDI) and shallow subsurface (SSDI) irrigation have recently been applied, especially in the cultivation of vegetables. The SSDI system is the latest method of irrigation. Camp (1998) reported that drip irrigation is superior to sprinkler irrigation due to efficient use of water resources, the possibility of placing water and other chemicals precisely directly to the root zone (Solomon, 1993; Bartolo, 2005), and significantly larger areas can be watered in one day, preventing crust formation which disturbs soil aeration and rainwater infiltration (Kalfountzos *et al.*, 2007). SSDI offers many advantages over SDI including reduced evaporation (Patel and Rajput, 2009), cut down surface runoff (Camp, 1998), water saving (Ayars *et al.*, 1999; Patel and Rajput, 2007), higher yields (Singh *et al.*, 2006; Pejić *et al.*, 2018), wind drift, vandalism and damage by animals. As well, SSDI has an advantage over SDI when using saline irrigation water in terms of yields and water use efficiency (Tingwu *et al.*, 2003), because SSDI can result in suitable root-zone salinity (Hanson *et al.*, 2009). The question of the depth at which laterals are posed has been the focus of researchers in recent years. Generally, it was suggested to place laterals in shallower layers of soil depending on cultivated plants and the physical properties of the soil (Al-Jamal *et al.* 2001; Patel and Rajput, 2009; Pejić *et al.*, 2018). There is almost no information in the literature regarding subsurface irrigation with laterals placed just below the soil surface (shallow subsurface drip irrigation) which are removed from the plot before harvest and used in the following years. Our knowledge indicates that the biggest advantage of SSDI compared to SDI is the possibility of placing the laterals together with the sowing or planting of plants, because it can be used for the uniform and timely emergence of plants, especially in arid and semi-arid regions. SDI can be placed only after the emergence of plants, at a certain stage of plant growth, i.e. plants must protect the laterals from wind movement (Pejić *et al.*, 2018).

The sensitivity of potato plants to water stress could be determined by using the yield response factor ($K_y$) which relates relative yield decrease to relative ET deficits (Doorenbos and Kassam, 1979). A greater $K_y$ value indicates an increased sensitivity of the cultivated plant to water stress. Doorenbos and Kassam (1979) estimate that the average value of $K_y$ is 0.7 for the potato growing season. The ultimate goal of irrigation is to utilize added water efficiently, i.e. that can give the greatest yield increase from added water (IWUE). If the irrigation regime is not harmonized with the plant water needs and water-physical properties of the soil, the effect of irrigation may be absent. IWUE generally tends to increase with a decline in irrigation but only in case that water deficit does not occur during a single growth period (Howell, 2001). The importance of analyzing evapotranspiration water use efficiency (ETWUE) is illustrated by the efforts of numerous researchers to direct total water use for evapotranspiration (ET) towards transpiration (T) as the productive part of water for plants (Allen *et al*., 1998; Howell, 2001). Wang *et al*. (1996) 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 ETWUE.

The objectives of this study were to determine the effects of surface and shallow subsurface drip irrigation on potato tuber yield, evapotranspiration, water use efficiency, and yield response factor. The obtained results will be used to provide the professionals with useful information about the practical possibilities of drip irrigation and to give recommendations for rational potato irrigation, which implies high and stable yields.

## MATERIAL AND METHODS

A trial with irrigated potato was conducted on a private farm in Čenej (45°22' N latitude, 19°47' E longitude, and 85 m.a.s.l.) near Novi Sad, the Republic of Serbia, in the Calcic Chernozem soil according to the the IUSS Working Group (WRB) (FAO, 2007), in 2020. In the period 2000-2018, the average seasonal air temperature and precipitation were 19.4°C, and 338 mm, respectively. According to the Hargreaves climate classification system, the study area is classified as arid in the summer period, from Jun to August (Bošnjak, 2001).

The previous crop was the carrot. The soil was ploughed at a depth of 0.3 m in the autumn. Rotary harrowing, fertilizing, planting and ridging were done simutaniously by Brand Grimme mashine („All-in one system"). The potato processing variety 'Taurus' was planted on 23 April. The crop spacing was 0.75 by 0.30 m. All recommended agronomic practices regarding cultivation and plant protection were applied at the experimental plot. The experiment was set up as a block design with three replicates and adapted to the technical specifications of drip irrigation. The trial also included the nonirrigated, control variant. The plants were irrigated with a lateral placed in every row (the distance between laterals was 0.75 m) on surface and subsurface variant (depth 0.1 m in the ridge, Petel and Rajput, 2007 reported that the maximum potato yield was recorded when drip tape was buried at 0.1 m) with drippers spaced every 0.2 m. Drippers had an average flow of 1.1 L $h^{-1}$ under a pressure of 70 kPa. Irrigation was scheduled on the basis of water balance method. Daily water used on plants evapotranspiration ($ET_d$) was calculated by multiplying reference evapotranspiration ($ET_o$) with crop coefficients ($k_c$). $K_c$ values were 0.5, 0.7, 1.1, 0.9, 0.7 from planting to emergence, early vegetative development, tuber initiation, tuber enlargement and senescence respectively (King and Stark, 1997, FAO, 2007, Table 2). $ET_o$ was calculated by Hargreaves equation (Hargreaves and Allen, 2003). Daily $ET_o$ values were taken from the website of the Hydrometeorological Service of the Republic of Serbia, (RHMZS). Irrigation started when readily available water (RAW) in the soil layer of 0.4 m (Wang *et al*. 2006 reported that most of the potato root is located at the depth of 0.4 m) was completely absorbed by plants. The irrigation rate was 30 mm at the beginning of the season and 40 mm in the middle season. The volume of irrigation water and the pressure in the system were controlled by the flow meter and the pressure gauge installed in the hose nozzle used for irrigation. Runoff and capillary rise were assumed negligible, but in the case of heavy precipitation, greater than the capacity of the soil for RAW in a layer of 0.4 m, percolated water into deeper soil layers was calculated. The size of the experimental unit was 10 $m^2$ (13.3 m x 0.75 m). The middle two rows in each plot were harvested by hand at physiological maturity on 31 August. The yield (t $ha^{-1}$) was computed based on the yield measured at the experimental unit. The number of tubers per plant, tuber yield per plant (g), and mean tuber weight (g) were determined from 10 randomly selected plants before harvest. After harvesting, tubers of each plot were graded into three size categories (>40, 35–40, and <35 mm) and weighed. This classification has also been used in Serbian companies that processed potato. Potato dry matter (%) was determined by the hydrometer (Zeal Manual Hydrometer). YSI 2700 Biochemistry analyzer Marshall Scientific apparatus was used for the determination of sugar concentration in potato tubers.

Yield response factor ($K_y$) during the growing season of potato was determined using Stewart's model (Stewart *et al.*, 1977) as follows:

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

$Y_a$ = the actual harvested yield (nonirrigated, t $ha^{-1}$),

$Y_m$ = the maximum harvested yield (under irrigation, nonlimiting conditions, t $ha^{-1}$),

$K_y$ = the yield response factor,

$ET_a$ = the actual evapotranspiration (mm), corresponding to $Y_a$

$ET_m$ = the maximum evapotranspiration (mm) corresponding to $Y_m$, and

$(1–ET_a/ET_m)$ = the relative evapotranspiration deficit and $(1–Y_a/Y_m)$ the relative yield decrease.

IWUE's and ETWUE's calculations were done in two ways:

IWUE = $Y_m – Y_a$ /I (Bos, 1985) **(2)**

IWUE = $Y_m$ /I (Viets, 1962) **(3)**

ETWUE = $Y_m – Y_a/ET_m$ - $ET_a$ (Bos, 1985) **(4)**

ETWUE = $Y_a/ET_m$ (Erdem *et al.*, 2006) **(5)**

Where I = the total seasonal irrigation water applied (mm)

Data reported for yield and yield components were subjected to analyses of variance (ANOVA). The significant differences for examined traits were calculated using the LSD test at the significance level of $p \leq 0.05$.

## RESULTS AND DISCUSSION

In the growing season of the experimental year (April-August), the mean air temperature and total precipitations were 19.3 °C and 319 mm, respectively (Tab. 2). Daily precipitation was measured on the experimental plot 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). As expected, seasonal precipitation of 319 mm (Tab. 1) was not sufficient for potato production, to allow plants to consume water in relation to their needs or evapotranspiration (478 mm, Tab. 2). For this reason, irrigation was needed to get acceptable yields of potato. The amount of water added by irrigation was 210 mm (Figure 1, Table 2). The examined year can be characterized as an average for potato production in comparison with long-term values of precipitation and air temperature (Table 2).

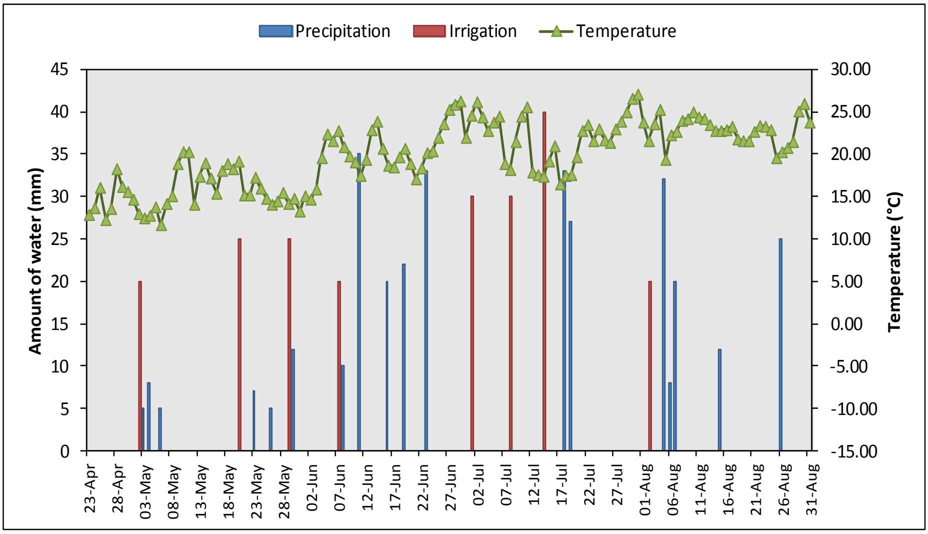


**Figure 1.** Irrigation schedules, irrigation water applied, and meteorological data for the experimental year (daily rainfall and daily average air temperature)

**Yield and yield components**

Unpredictable weather conditions in the region, first of all, amounts and distribution of precipitation, cause fluctuation in agricultural yields (Dragović, 2012; Vojnov *et al.*, 2020; Vojnov *et al.*, 2022). It is considered that generally, the potato is very sensitive to water stress (King and Stark, 1997; Pejić *et al.*, 2014; Pejić *et al.*, 2015), primarily due to its shallow roots (Singh, 1968; Opena and Porter, 1999; Onder *et al.*, 2005; Ahmadi *et al.*, 2011), even a short period of drought reduces tuber yield and quality (Vanloon, 1981; Miller and Martin, 1990; Kumar and Minhas, 1994). High yields of potatoes of excellent quality can be obtained only in conditions of optimal soil moisture (Bošnjak and Pejić, 1994; Ayas, 2013) when plants consume water for their needs or evapotranspiration. Pejić *et al* (2015) stressed that in the region of Vojvodina it is possible to achieve high and stable yields of potatoes, at the level of 50-60 t ha$^{-1}$ if a shortage of RAW in the soil, in the growing season, is eliminated by proper irrigation management.

According to the research results, irrigation, both SDI (58.06 t ha$^{-1}$) and SSDI (61.15 t ha$^{-1}$) had a significant effect ($p \leq 0.05$) on potato yield regarding the nonirrigated, control variant (38.33 t ha$^{-1}$), but differences in the yield obtained using SDI and SSDI were not significant (Table 1). Early studies conducted in different climate and soil conditions have also shown that irrigation significantly affects potato yield compared to rainfed production (Onder *et al.*, 2005; Ayas, 2013; Cantore *et al.*, 2014; Pejić *et al.*, 2015; Rolbiecki *et al.*, 2021). The obtained results are also consistent with researchers who reported that no statistical differences were found between surface and subsurface irrigation in potato yield (Phene, 1995; Weatherhead and Knox; 1998; Onder *et al.*, 2005; El Mokh *et al.*, 2014). Contrary to that, some studies indicated a significantly higher yield of potato resulting from subsurface compared to surface drip irrigation (Petel and Rajput, 2007; Badr *et al*., 2010; Badr *et al*., 2012). The better performance of subsurface drip irrigation is explained by favorable soil water status in the root zone as well as more efficient utilization of nutrients from the limited wetted area. Findings and conclusions related to potato yield are identical for yield components; irrigation significantly affects all tested yield components ($p \leq 0.05$), except the percentage of tuber sized 35-40 mm compared to the nonirrigated variant (Table 1). Differences in the yield components obtained using SDI and SSDI were not significant. The obtained results are completely consistent with the results of Phene (1995), Weatherhead and Knox (1998), and Onder *et al*. (2005) who also reported no significant differences between surface and subsurface irrigation methods on potato yield components. However, the irrigation significantly affected all yield components compared to the rainfed conditions.

**Table 1.** Yield and yield components of potato

| Variant | Rep. | Yield (t ha$^{-1}$) | Tub. size <35 mm (%) | Tub. size 35-40 mm (%) | Tub. size >40 mm (%) | Tuber number plants$^{-1}$ | Plant yield (g plant$^{-1}$) | Mean tuber weight (g) |
|---|---|---|---|---|---|---|---|---|
| SDI | 1 | 57.86 | 0.00 | 2.7 | 97.3 | 7.48 | 1300 | 174.0 |
| | 2 | 59.18 | 0.00 | 4.1 | 95.9 | 7.65 | 1330 | 174.0 |
| | 3 | 57.13 | 0.00 | 1.2 | 98.8 | 8.46 | 1290 | 152.0 |
| | Aver. | **58.06$^{a}$** | **0.00$^{a}$** | **2.7$^{a}$** | **97.3$^{a}$** | **7.86$^{a}$** | **1310$^{a}$** | **166.7$^{a}$** |
| SSDI | 1 | 66.90 | 0.00 | 1.2 | 98.81 | 8.55 | 1510 | 176.0 |
| | 2 | 56.54 | 0.00 | 1.5 | 98.51 | 7.19 | 1270 | 177.0 |
| | 3 | 60.00 | 0.00 | 2.3 | 97.75 | 7.63 | 1350 | 177.0 |
| | Aver. | **61.15$^{a}$** | **0.00$^{a}$** | **1.7$^{a}$** | **98.4$^{a}$** | **7.79$^{a}$** | **1380$^{a}$** | **176.7$^{a}$** |
| Nonirrigated | 1 | 37.22 | 1.7 | 4.2 | 94.1 | 5.66 | 840 | 148.0 |
| | 2 | 38.32 | 3.3 | 2.6 | 94.1 | 5.67 | 860 | 152.0 |
| | 3 | 39.46 | 2.2 | 3.7 | 94.1 | 7.40 | 890 | 120.0 |
| | Aver. | **38.33$^{b}$** | **2.4$^{b}$** | **3.5$^{a}$** | **94.1$^{b}$** | **6.24$^{b}$** | **860$^{b}$** | **140.0$^{b}$** |

*Different letters in the same column denote statistically significant difference at $p \leq 0.05$

### Evapotranspiration, yield response factor, and water use efficiency

Evapotranspiration (ET) represents the sum of water used by plants for transpiration (T) and water loss due to evaporation from plant and soil surfaces (E). Water used for plant evapotranspiration is influenced by a number of factors including the amount of water in the soil; it is the highest at the moisture of field capacity and it decreases with the decrease of water content in the soil (Vučić, 1976; Ferreira and Carr, 2002), the irrigation methods (Al-Jamal *et al*., 2001; Erdem *et al*., 2006), irrigation regimes (Onder *et al*., 2005; Pejić *et al*., 2014), variety and length of growing season (Sharma *et al.*, 1993), management practices (Fandika *et al.*, 2016), environmental factors-atmospheric demand (Jones *et al.*, 1984; Allen *et al.*, 1998) and amount of crop cover (LAI) (Wright and Stark, 1990). Potato water demand for high tuber yield varied from 500 to 700 mm (Doorenbos and Kassam, 1979). Sharma *et al.* (1993) reported that potato plants need 500-600 mm of water throughout their life cycle. Bošnjak and Pejić (1995) reported seasonal ET of potato in the interval from 460 to 480 mm for the temperate climate conditions of the Vojvodina region. Aksić *et al* (2014) found that high and stable potato yield, in the conditions of south Serbia, could be reached if water consumption on evapotranspiration varied between 491 and 499 mm.

**Table 2.** Water balance of potato

| Elements | Planting to emergence | Early vegetative development | Tuber initiation | Tuber enlargement | Senescence | Total/ Average |
|---|---|---|---|---|---|---|
| | 23.04 13.05 | 14.05 4.06 | 5.06 3.07 | 4.07 31.07 | 1.08 31.08 | |
| $ET_o$ | 81 | 86 | 136 | 140 | 143 | **586** |
| $k_c$ | 0.5 | 0.7 | 1.1 | 0.9 | 0.7 | **0.8** |
| $ET_m$ | 41 | 61 | 150 | 126 | 100 | **478** |
| $ET_m$ (%) | 9 | 13 | 31 | 24 | 21 | **100** |
| Duration (days) | 21 | 22 | 29 | 28 | 31 | **131** |
| $ET_d$ | 2.0 | 2.8 | 5.2 | 4.5 | 3.2 | **3.4** |
| P | 18 | 24 | 120 | 60 | 97 | **319** |
| T | 15.1 | 16.2 | 20.9 | 21.6 | 22.9 | **19.3** |
| Δ | 0 | 0 | 0 | 0 | 0 | **0** |
| r | 0 | 0 | 0 | 0 | 0 | **0** |
| $ET_a$ | 18 | 24 | 120 | 60 | 97 | **319** |
| d | 23 | 37 | 30 | 66 | 3 | **159** |
| s | 0 | 0 | 0 | 0 | 0 | **0** |
| I | 20 (1) | 50 (2) | 50 (2) | 70 (2) | 20 (1) | **210** |

$ET_o$ – the reference evapotranspiration (mm), $ET_m$ – the maximum evapotranspiration – irrigated (mm), $ET_a$ – the actual evapotranspiration – rainfed (mm), $ET_d$ – daily evapotranspiration –irrigated (mm), P – rainfall (mm), Δ ± – inflow and outflow of water into the soil reserve (r), d – deficit of readily available water and s – surplus, percolated water

In the study period, the evapotranspiration rate in irrigation conditions ($ET_m$) and in rainfed, control variant ($ET_a$) was 478 mm and 319 mm respectively (Table 2). The highest evapotranspiration rate ($ET_m$) was recorded in the tuber initiation and the tuber enlargement part of the season amounted to 150 mm

(31%), and 126 mm (24%) respectively (Table 2). The highest value of average daily water use on evapotranspiration ($ET_d$) was detected in the tuber initiation at 5,2 mm, but the average value for the entire growing season was 3,4 mm (Table 2). A maximum $ET_d$ value of 7.2 mm was detected on 29 June, 68 days after planting by the end of the tuber initiation stage (Figure 2).

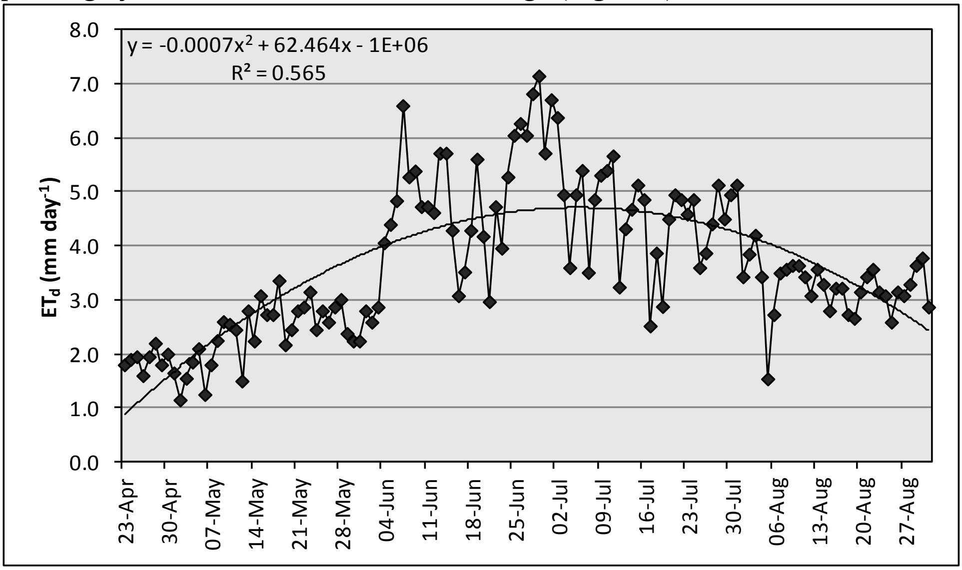


**Figure 2.** Daily water used on potato evapotranspiration

Obtained results are in agreement with Sharma *et al*. (1993) who reported that the water requirement of potato varies from 350-550 mm depending upon the length of the growing season, atmospheric demand, soil type, and crop variety. Onder *et al*. (2005) found, in the East Mediterranean Region of Turkey, that seasonal evapotranspiration of potato varied from 457 mm to 473 mm for potato irrigated by surface and subsurface drip irrigation respectively. The highest evapotranspiration rate ($ET_m$) recorded in the tuber initiation and the tuber enlargement part of the season clearly indicates that this period of potato vegetation is the most sensitive to water stress. Several studies have also confirmed that mentioned stages of potato development are the most sensitive to water stress (Doorenbos and Kassam, 1979; Kumar and Minhas, 1994; Yuan *et al*., 2003; Ashok, 2008; Begum *et al*., 2018). Shock *et al*. (1992) reported that adequate irrigation supply before and during tuber initiation increases the number of tubers per plant, but irrigation after tuber initiation stimulates tuber size (Eldredge *et al*., 1996). Karam *et al*. (2014) found out that treatment with deficit irrigation at the tuber bulking stage achieved a marketable yield 12% lower than that obtained in the well irrigated treatment. Obtained results are not in line with the findings of Faberio *et al*. (2001) who reported that tuber ripening is the growth stage that is most sensitive to water stress.

The maximum $ET_d$ value of 7.2 mm, recorded by the end of the tuber initiation stage is correlated with the fact that in that period the potato plants are maximally developed and environmental factors, first of all, air temperature reaches the maximum values. These results are consistent with the information in the literature data. The same value of maximum $ET_d$ (7.2 mm) was recorded by Kumar *et al*. (2020) in the sub-humid sub-tropical region of India, 78 days after planting, during the mid-stage of the growing season. Bošnjak and Pejić (1995) have determined the average seasonal evapotranspiration of 3.5 mm and maximum daily evapotranspiration of 7-8 mm in soil and climate conditions of Vojvodina. Wright and Stark (1990) observed, in irrigated areas in Oregon and Washington, that potato reached a maximum $ET_d$ level of 8.5 mm just before effective full cover.

To compare results with other authors two different ways were used to compute WUE values. Howell (2001), Pejić *et al*. (2011a) indicated that care should be taken when comparing WUE values as many researchers have evaluated WUE in different ways (Viets, 1962; Bos, 1985; Stanhill, 1986; Payero *et al*., 2006; Molden, *et al*., 2010). It means that in climatic conditions where irrigation is supplementary WUE's calculation takes into account yields and plants evapotranspiration with and without irrigation (Bos, 1985; Erdem *et al*., 2006, Bajić *et al*., 2022), compared to arid regions where crop production cannot be realized in conditions of natural water supply. Thus in arid climate WUE's values are calculated as the ratio of yield and water added by irrigation or water used for plant seasonal evapotranspiration (Viets, 1962; Ati *et al*., 2012). As well Djaman *et al*. (2021) stressed that potato WUE strongly depends on the genetic material, management practices, irrigation regime, fertilizer rate, and other environmental conditions and all those should be taken into account when comparing results.

Regardless of the method of WUE calculation, no statistical differences were found between SDI and SSDI. IWUE values were 9.39 and 10.85 kg $m^{-3}$ ($Y_m$-$Y_a$/I) and 27.64 and 29.09 kg $m^{-3}$ (Y/I) for SDI and SSDI respectively. ETWUE values were 12.40 and 14.35 kg $m^{-3}$ ($Y_m$ - $Y_a$/$ET_m$ - $ET_a$) and 12.14 and 12.79 kg $m^{-3}$ ($Y_m$/$ET_m$) for SDI and SSDI respectively (Tab. 3). Onder *et al*. (2005) also reported that SSDI irrigation method did not offer a significant advantage for both yield and WUE compared to the SDI irrigation in early potato production under Mediterranean conditions. They determined IWUE values of 11.16 and 9.91 kg $m^{-3}$ for SDI and SSDI irrigation respectively. Based on the mentioned conclusions, they do not recommend the SSDI irrigation method due to its technical application difficulties.

Our results are in accordance with values reported by Aksić *et al*. (2014) who found out WUE values of potato (Y/ET) in the interval between 9.70 and 9.82 kg $m^{-3}$ on the variant of 30 kPa before irrigation in the conditions of south Serbia. IWUE values of potato reported in our study from 27.64 to 29.09 kg $m^{-3}$ for SDI and SSDI respectively were similar to 26.0 kg $m^{-3}$ reported by Rolbiecki *et al*. (2021) for drip irrigated potato in the temperate climate in the central part of Poland.

**Table 3.** Irrigation water use efficiency of potato

| Drip Irrigation | IWUE $Y_m$-$Y_a$/I (kg m$^{-3}$) | IWUE Y/I (kg m$^{-3}$) | ETWUE $Y_m$ - $Y_a$/$ET_m$ - $ET_a$ (kg m$^{-3}$) | ETWUE $Y_m$/$ET_m$ (kg m$^{-3}$) |
|---|---|---|---|---|
| SDI | 9.83 | 27.55 | 12.98 | 12.10 |
| | 9.93 | 28.18 | 13.12 | 12.38 |
| | 8.41 | 27.20 | 11.11 | 11.95 |
| | **9.39**[a] | **27.64** [a] | **12.40** [a] | **12.14**[a] |
| SSDI | 14.09 | 31.85 | 18.67 | 14.00 |
| | 8.68 | 26.92 | 11.46 | 11.83 |
| | 9.78 | 28.51 | 12.92 | 12.55 |
| | **10.85** [a] | **29.09** [a] | **14.35** [a] | **12.79**[a] |

*Different letters in the same column denote statistically significant difference at $p \leq 0.05$

The yield response factor ($K_y$), for the total crop growing period, was 1,03 and 1.12 for SDI and SSDI respectively (Tab. 4). The value of $K_y$ in this study reveals that the relative yield decrease was nearly equal to the rate of ET deficit. Pejić *et al*. (2011a) reported that the accuracy of $K_y$ depends on having a sufficient range and number of values for Y and ET, and assumes that the relationships between Y and ET are linear over this range (Pejić *et al*., 2011b, Pejić *et al*., 2011c).

The obtained results agreed with the findings of Doorenbos and Kassam (1979), Ayas and Korukçu (2010), Mandal *et al*. (2018), Ayas (2013), and Kiziloglu *et al*. (2006) who found similar values of $K_y$ values for the total potato growing season. Darwish *et al*. (2006) found the $K_y$ value of 0.80 for processing potato for an entire growing period in the dry Mediterranean conditions of Lebanon.

**Table 4.** Evapotranspiration and yield response factor of potato

| Variant | $ET_m$ | $ET_a$ | $Y_m$ | $Y_a$ | 1-$ET_a$/$ET_m$ | 1-$Y_a$/$Y_m$ | $K_y$ |
|---|---|---|---|---|---|---|---|
| SDI | 478 | 319 | 58.06 | 38.33 | 0.33 | 0.34 | 1.03 |
| SSDI | 478 | 319 | 61.15 | 38.33 | 0.33 | 0.37 | 1.12 |

**Quality of processing potato**

No significant differences in the tested parameters of potato quality were found either between the irrigated variants in relation to the nonirrigated one, as well as between the SDI and SSDI irrigation treatment (Tab. 5).

The obtained results on the absence of statistical difference in dry matter content in potato between irrigated and nonirrigated variants are not in accordance with the results of many other authors who stated higher dry matter content on nonirrigated or deficit irrigated variants compared to irrigated variant (Kashyap and Panda, 2003; Karam *et al*., 2014).

**Table 5.** Quality of processing potato

| Variant | Replicates | Specific gravity ($g\ cm^{-3}$) | Dry matter content (%) | Sucrose ($mg\ g^{-1}$) | Glucose ($mg\ g^{-1}$) |
|---|---|---|---|---|---|
| SDI | 1 | 1.079 | 21.05 | 0.26 | 0.02 |
| | 2 | 1.086 | 22.25 | 0.64 | 0.05 |
| | 3 | 1.080 | 21.15 | 0.58 | 0.05 |
| | Average | **1.081**[a] | **21.48**[a] | **0.49**[a] | **0.04**[a] |
| SSDI | 1 | 1.085 | 21.98 | 0.68 | 0.07 |
| | 2 | 1.080 | 21.25 | 0.52 | 0.06 |
| | 3 | 1.077 | 20.55 | 0.35 | 0.04 |
| | Average | **1.080**[a] | **21.26**[a] | **0.52**[a] | **0.06**[a] |
| Nonirrigated | 1 | 1.077 | 20.6 | 0.48 | 0.03 |
| | 2 | 1.076 | 20.5 | 0.62 | 0.08 |
| | 3 | 1.076 | 20.46 | 1.08 | 0.11 |
| | Average | **1.076**[a] | **20.52**[a] | **0.73**[a] | **0.07**[a] |

*Different letters in the same column denote statistically significant difference at $p \leq 0.05$

## CONCLUSIONS

Based on the obtained results, it can be concluded that irrigation had a significant effect on potato yield compared to the nonirrigated variant the (38.33 t $ha^{-1}$) but differences in the yield obtained using the SDI (58.06 t $ha^{-1}$) and the SSDI (61.15 t $ha^{-1}$) were not significant.

Preference should be given to the SSSD irrigation as placing laterals can be done together with the sowing or planting of plants which can affect the uniform and timely emergence of plants. In the study period, seasonal evapotranspiration in irrigation conditions ($ET_m$) and in rainfed control variant ($ET_a$) was 478 mm and 319 mm respectively. IWUE values were 9.39 and 10.85 kg $m^{-3}$ ($Y_m$-$Y_a$/I) and 27.64 and 29.09 kg $m^{-3}$ (Y/I) but ETWUE values were 12.40 and 14.35 kg $m^{-3}$ ($Y_m$ - $Y_a$/$ET_m$ - $ET_a$) and 12.14 and 12.79 kg $m^{-3}$ ($Y_m$/$ET_m$) for SDI and SSDI respectively.

The yield response factor ($K_y$) for the total crop growing period, was 1.03 and 1.12 for SDI and SSDI respectively which indicates that potato can be grown without irrigation in the temperate climate of Vojvodina. These results will improve precise planing and efficient management of irrigation for potato in the region.

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