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Research Article

Response of Potato to Water Stress in Southern Serbia

Pejić B[1]*, Aksić M[2], Mačkić K[1] and Šekularac G[3]

[1]Department of Field and Vegetable Crops, Faculty of Agriculture, University of Novi Sad, Serbia

[2]Faculty of Agriculture, Lešak, University of Kosovska Mitrovica, Serbia

[3]Faculty of Agriculture, Čačak, University of Kragujevac, Serbia

***Corresponding author:** Pejić B, Department of Field and Vegetable Crops, Faculty of Agriculture, University of Novi Sad, Dositej Obradovic Square 8, Serbia

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Abstract

An investigation was carried out on alluvium soil type in the river valley of Southern Morava, Southern Serbia during the seasons of 2008 and 2009, aiming to determine the response of potato to soil water deficit, using yield response factor. The values of yield response factor were derived from the linear relationship between relative seasonal evapotranspiration deficits and relative yield loss. Values of seasonal crop response factor of 1.14 indicate that potato is moderately sensitive to soil water stress in the climatic conditions of the Southern Serbia. Seasonal evapotranspiration was 495.0 mm and 291.2 mm in irrigated and rain-fed conditions respectively. A linear relationship was found between seasonal evapotranspiration and tuber yield. Potato yield in the variant with irrigation was 48.31 t ha^{-1} or 88.3% higher than in the variant without irrigation.

Keywords: Irrigation; Potato; Yield Response Factor

Introduction

Production of potato (Solanum tuberosum L.) takes a very important place in world agriculture, with a production potential of about 368 million t harvested and 19.3 million ha planted area with an average yield of 19.1 t ha^{-1} [1]. Potato production ranks fourth in the world after rice, wheat and maize [2]. In Serbia potato is grown at about 77,000 ha with an average yield of 10.2 t ha^{-1}, and total production of 786,000 tones. In southern Serbia potato crop land is 55,000 ha with an average yield of 9.2 t ha^{-1}, and total production of 55,000 tones [3]. The yield of potato in Serbia is fourth times lower than this achieved in the leading potato growing countries (Germany 45 t ha^{-1}, France 45 t ha^{-1}, Belgium 44 t ha^{-1} [1]). The low yields are the consequence of inadequate management practices, insufficient amount and unfavorable arrangement of precipitation in the growing season and inappropriate irrigation scheduling applied. In Serbia potato is cultivated under both irrigated and non-irrigated conditions. Portable sprinkler irrigation systems are commonly used. Due to the unpredicted amount and distribution of precipitation in the growing season, irrigation in Serbia is mainly supplemental. It is used primarily to supplement infrequent or irregular precipitation during drought periods [4].

Profitable management of irrigated potato requires skill and the best known management practices [5-9]. If shortage of readily available water in the soil, in the growing season, is eliminated by irrigation it is possible to achieve high and stable yields of potatoes, at the level of 40-50 t ha^{-1} or higher [9-11].

Several authors and research groups reported results of experiments aimed at determining optimum soil moisture under different environmental and technical conditions. Bošnjak and Pejić, Milić et al., Pejić et al. [8, 9, 12], found that the lower limit of optimum soil moisture for potatoes is 70% of field water capacity when this crop is grown in a soil with medium texture. Wright and Stark, King and Stark, Costa et al. [13-15] indicated that maximum yield of high quality potato tubers could only be achieved if the soil's available water in the maximum active root zone would not drop below the 50% limit.

A preliminary step to a more intensive exploitation of the available agro-ecological 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 potato 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 crop. These include plant, soil, cultural and environmental factors [16]. The applied irrigation system can also affect the ET of a crop under specific conditions [10, 17]. 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 [18]. Any estimation of ET requirements for growing crops must be accompanied by a description of the associated conditions. The duration of the total growing season and the time of the year during which crops are grown have an enormous influence on the seasonal crop water need. According to FAO [19] to get high yield of potato, with the total growing season of 120-150 days, 500-700 mm of water used on evapotranspiration is needed. Kiziloglu et al. [7] recorded seasonal evapotranspiration of potato 445.2 mm for the yield of 26.43 t ha^{-1} in semiarid climatic conditions of eastern Turkey. A seasonal ET of 470 mm for potato, irrigated with portable sprinklers, in the Vojvodina region, the northern part of Serbia was reported by [9].

Drought tolerance is defined as the ability of plants to live, grows, and yields satisfactorily with limited soil water supply or under periodic water deficiencies [20]. The actual evaluation of stress related to the yield due to soil water deficit during the potato 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–Ya/Ym) and a relative evaporation deficit (1–ETa/ETm) [21]. For $K_y \leq 1$ the plant is tolerant, for $K_y \geq 1$, the plant is sensitive to water stress. Doorenbos and Kassam [22] estimate that the average value of K_y is 0.7 during the potato growing season. Vaux and Pruitt [23]

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Table 1: Some water and physical properties of the soil at the experiment site.

Properties	Soil depth (cm)		
	0-20	20-40	40-60
Texture	Clay loam	Clay loam	Silty clay loam
Field water capacity (weight %)	27.32	25.94	24.44
Bulk density (g cm^{-1})	1.35	1.34	1.34
Specific weight (g cm^{-1})	2.65	2.58	2.56
Total porosity (vol %)	49.05	48.06	47.65
Capacity for water (vol %)	36.88	34.76	32.75
Capacity for air (vol %)	12.17	13.30	14.90

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 climatic 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, applied irrigation method. 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 [24] 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. Potato is very sensitive to water stress particularly in the stage of tuber formation. Even the decrease of 10% in the optimum water treatment in the growing period could have caused a decrease in the yield of potato [14]. Hassan et al. [25] reported that, potato is more sensitive to water stress at the stolonization and tuberization stages than the bulking and tuber enlargement stages. For the north-east of Portugal Ferreira and Goncalves [26] reported values of Ky for potato in the range of 0.71^{-1}.12 regardless of nitrogen dosage. Unlu et al. [10] also found out that there was no apparent effect of season or N fertilization rates on K_y values of potato (0.91-0.97) but the influence of different methods of irrigation were recorded (0.68 for trickle and 1.05 for sprinkler).

The objective of the study was to estimate the yield response factor and on the basis of it to analyze a seasonal potato response to water stress and in such a way to obtain additional information that can be useful in the improvement of potato growing practices under climate conditions of southern Serbia but also for the whole region around this areas well as neighboring countries.

Materials and Methods

The study was conducted on alluvium soil type (Table 1) in the river valley of Southern Morava (43° 19`N and 21°54`E, 194 m a.s.l.) during the seasons of 2008 and 2009.

During the growth period (April-September), the average seasonal temperature (°C), total seasonal precipitation (mm) and relative air humidity were 19.3°C, 222.7 mm and 65% in 2008 and 19.6°C, 231.2 mm and 65% in 2009, respectively. Total precipitation were measured from the standard pluviometer replenishment in experiment field while seasonal average air temperature and average relative air humidity values were taken from Niš meteorological station.

In the area, summers are hot and dry, and winters are cold and wet. Average temperature and rainfall values during the growth period (April-August) were 18.4°C and 22.0 mm in the first year of the research, and 20.4°C and 43.9 mm in the second year of the research respectively. During the growth period of the potato, minimum and maximum temperature values were 15.5°C in April and 22.3°C in August in the first year and 7.5°C in March and 24.3°C in August in the second year respectively.

The trial was set in random complete block design with four replications. The experiment included irrigated (well-watered) and non-irrigated (rain-fed) treatment. Tensiometers installed at the depth of 20 cm were used to determine the time of irrigation. Irrigation started when 30 kPa was read on the tensiometer`s vacuummeter. Tensiometers were controlled twice a day at 8 a.m. and 18 p.m. Irrigation was carried out by drip irrigation system.

Potato planting was done in the first half of April in both years, with the cultivar Kennebec. The row spacing between and within the rows were 0.7 and 0.3 m respectively. The size of the experimental unit was 10.5 m2. All plots received a seasonal total of 200 kg N, 120 kg P_2O_5, 300 kg K_2O and M_gO 95 kg per hectare. The potato were grown using commercial weed and pest management practices typical for the region. Potato was harvested at technological maturity and yield was calculated in t ha^{-1}.

Yield response factor (K_y), for the growing season, on potato yield was determined using the Stewart's model [21] as follows:

$$1-\frac{Ya}{Ym}=Ky\left(1-\frac{ETa}{ETm}\right)$$

where:

Y_a= the actual harvested yield (non-irrigated, t ha^{-1}), Y_m= the maximum harvested yield (under irrigation, non limiting 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, (1–ETa/ETm) = the relative evapotranspiration deficit and $(1–Y_a/Y_m)$ = the relative yield decrease.

Potato evapotranspiration (ET) was calculated using the water balance method [27]:

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

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

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

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.

Data reported for yield of potato 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. The relationship between crop yield and water used by evapotranspiration was evaluated using regression analysis. All the analyses were conducted using software package statistics 8.0 series 608c (StatSoft Inc. USA).

Table 2: Maximum and actual evapotranspiration, maximum and actual yield, relative evapotranspiration deficit, relative yield decrease, irrigation water applied, yield response factor.

Year	ET_m	ET_a	$1-ET_a/ET_m$	Y_m	Y_a	$1-Y_a/Y_m$	I	K_y
2008	491.3	288.1	0.416	47.64	24.52	0.485	236	1.17
2009	498.6	294.4	0.410	48.97	26.78	0.453	219	1.10
2008/09	495.0	291.2	0.54	48.31**	25.65	0.62	228	1.14

Means bearing ** were significantly different at the $p < 0.05$ level using the LSD test.

Results and Discussion

To maintain the optimum soil moisture it was added 236 mm and 219 mm of water by irrigation in 2008 and 2009 respectively (Table 2). Given data indicate that climatic patterns in Serbia are changeable and long-term predictions of precipitation are not possible. That confirm supplementary character of irrigation in the region, i.e. rainfall can affect the soil water regime and irrigation schedule of growing plants [4].

Evapotranspiration rate of potato in irrigated conditions (ET_m) ranged from 491.3 to 498.6 mm and from 288.1 to 294.4 mm in the non-irrigated conditions (ET_a) in 2008 and 2009 respectively (Table 2). Results are in agreement with those of Kiziloglu et al. [7] who reported seasonal evapotranspiration of potato of 445.2 mm for the yield of 26.43 t ha^{-1} in semiarid climatic conditions of eastern Turkey, Erdem et al. [28] reported that seasonal evapotranspiration of potato, drip irrigated, at the level of 50% of the available water, varied from 473 mm to 524 mm under semiarid conditions of Trakya region in Turkey, Pejić et al. [9] who found out seasonal evapotranspiration of potato of 469.6 mm for the yield of 43.16 t ha^{-1} for the Vojvodina region, the northern part of Serbia. Onder et al. [6] stressed that crop water requirements are a function of climatic factors, methods of irrigation and the length of the growing period.

The relationship between potato yield (t ha^{-1}) and seasonal crop water use (ET mm) for studied period was linear (R2 = 0.997, P < 0.05, Figure 1). Kiziloglu et al., Unlu et al., Ayas and Korukcu [7, 10, 29] also reported linear relationship between yield and seasonal evapotranspiration of potato in different climatic conditions of Turkey.

Several studies conducted for a wide range of environments have demonstrated that potato yield increases with irrigation [5, 9, 29, 30, 31]. In the study period, on average, the yield of potato was significantly higher in irrigated (48.31 t ha^{-1}) than in non-irrigated conditions (2.56 t ha^{-1}) (Table2).The average yield increase due to irrigation was 22.66 tha^{-1} or 88.3%. Results are in agreement with those of Kiziloglu et al. and Unlu et al. [7, 10] who reported that tuber yield of potato was higher for 70-74% in irrigation conditions compared with non-irrigated variant.

Irrigation scheduling methods are generally based on measurement of soil water content or meteorological parameters for modeling or computing evapotranspiration [31]. Pejić et al. [9] found out that the lower limit of optimum soil moisture for potatoes is 70% of field water capacity (FWC) when this crop is grown in a soil with medium texture. Several authors stressed that the most soil matric potential (SMP) for potato production is −30kPa [11, 32, 33]. Wang et al. [34] found that SMP of −25 kPa was the most favorable setting for potato production, while −15 kPa was too high and −45 kPa lead to severe water stress. High yields of potato in our study (48.31 t ha^{-1}) confirm that SMP of −30 kPa is the most suitable soil moisture for crop production in the region on alluvium soil type.

The crop yield response factor (Ky) gives an indication of whether the crop is tolerant to water stress. The values of Ky ranged from 1.17 to 1.10 for potato grown in 2008 and 2009 respectively. Average value of 1.14 (Figure 2) indicates that potato expresses some sensitivity to water stress in climate and soil conditions of Southern Serbia. Determined values of K_y of potato in our experiments are consistent with results reported by Kiziloglu et al. [7], who obtained K_y of 1.12 and Unlu et al. [10] who found out K_y of 1.05 for potato irrigated by sprinklers in climatic conditions of Turkey.

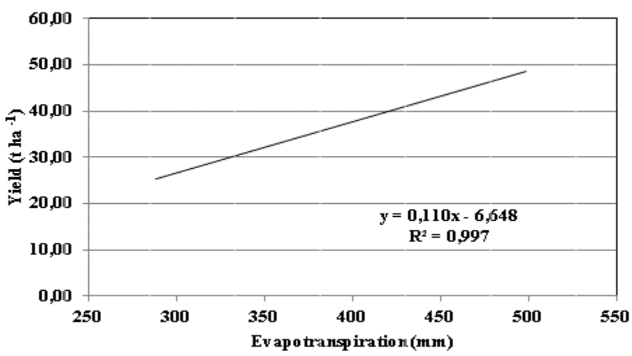

Figure 1: Relationship between seasonal evapotranspiration and tuber yield.

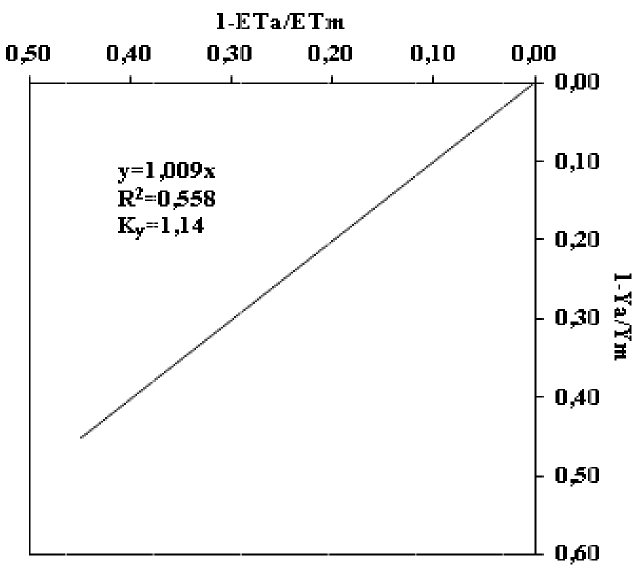

Figure 2: Relationship between relative yield decrease and relative crop evapotranspiration deficit for potato growing season.

Conclusion

Based on results gained on effects of water stress on water use and potato yields under climate conditions of Southern Serbia it can be concluded that the potato yield under non-irrigated conditions (25.65 t ha^{-1}) was significantly lower than the yield (48.31 t ha^{-1}) recorded under irrigated conditions. Evapotranspiration rate under irrigated conditions (ET_m) was 495.0 ranged from 491.3 to 498.6 mm, while they varied from 288.1 to 294.4 mm under non-irrigated (ET_a) conditions with an average value of 291.2 mm. Values of K_y (1.14) in the potato growing season point to the fact that potato expresses some sensitivity to water stress in climate and soil conditions of Southern Serbia. The determined values of K_y can be a good basis for potato growers in the region in relation to the optimum irrigation water use, planning, projecting and utilization of irrigation systems, and also for the improvement the production technology of the crop.

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