Originalni naučni rad
Original research article

Effect of readily available water deficit in soil on maize yield and evapotranspiration

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Summary: An investigation was carried out at Rimski Šančevi experiment field of Institute of Field and Vegetable Crops, Novi Sad on calcareous chernozem soil on the loess terrace, in the period 2000-2007, and included irrigated variant (T_1) and non-irrigated i.e. control variant (T_0). NS-640, maize hybrid from the FAO maturity group 600, was analyzed. Readily available soil water deficit (RASWD) in the layer of 60 cm in the course of growing season and actual evapotranspiration (ETa) were calculated by the water balance method. Water consumption for potential evapotranspiration (ETm) in individual months and the growing season were calculated by the bioclimatic procedure, using hydrophytothermic indexes. The correlation analysis revealed highly significant dependences of maize yield (Y) on RASWD (r = -0.941) and the amount of precipitation (P) in August (r = 0.931). Statistically significant dependence was also found between Y and RASWD (r = -0.765) and P (r = 0.768) in July and August. The obtained results indicate that maize production in Vojvodina under the rainfed conditions is unreliable, and that it is correlated with weather conditions, especially with the amount and distribution of precipitation. The statistically significant correlation obtained between Y and ETa (r = 0.755) confirms that water supply is the basic prerequisite which allows the other production factors to be realized. Significantly higher maize yields in the T_1 variant (13.517 t ha^{-1}) in relation to the T_0 variant (11.210 t ha^{-1}) indicate clearly that under the climatic conditions of Vojvodina high and stable yields of maize can be achieved only in irrigation.

Key words: evapotranspiration, maize, readily available soil water deficit, yield

Introduction

In Vojvodina, maize is a primary row crop in irrigated crop rotations and cropping systems, and it is also the dominant field crop grown on average at about 640,000 ha, or about 42 % of the total arable land. The average yield in the period 2000-2007 was 5.0 t ha^{-1}, with a wide range of variation from 2.94 to 6.44 t ha^{-1} (Statistical Yearbook of Serbia, 2007).

The climatic region of Vojvodina is characterized by unstable meteorological conditions in some years. This is particularly true for precipitation, which changes from year to year not only in the amount but also in distribution. If drought is defined as insufficient supply of water to plants, when potential evapotranspiration exceeds the actual one, regardless of the causes of this phenomenon, it is obvious that drought is a regular phenomenon in Vojvodina that occurs each year and extends more or less serious impact on yields of agricultural crops (Bošnjak et al. 2005).

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In Vojvodina, high and stable yields of maize are achieved when natural deficit of readily available soil water (RASWD) that occurs during maize growing season is eliminated by irrigation.

The effect of irrigation on maize yield depends on weather conditions, primarily the amount and distribution of precipitation. It may be high in dry years (Bošnjak & Pejić 1997, Pejić 2000, Cakir 2004, Panda et al. 2004, Pejić et al. 2007) and low or altogether absent in humid years (Bošnjak 1993, Bošnjak & Pejić 1998). Under the agro-ecological conditions of Vojvodina, the potential evapotranspiration (ETm) of maize is 470 to 540 mm (Bošnjak 1982, Pejić 2000). However, the probability of such precipitation level is only 4 % to 5 %. It means that full realization of genetic yield potentials of the hybrids cannot be expected, because the amount of precipitation limits yield performance to the provided phytoclimatic level. It is obvious that water shortage is the major instigator of negative factors that limit the maize production in Vojvodina (Vučić 1976).

The objective of this research was to analyze long-term data for readily available water deficit in soil and precipitation shortage during growing season and their effects on maize yield and evapotranspiration, in order to assess possibilities for irrigated maize production in Vojvodina.

Materials and methods

The study was carried out at Rimski Šančevi experiment field of Institute of Field and Vegetable Crops, Novi Sad on the calcareous chernozem on the loess terrace, in the period 2000-2007. Experiments were set in the system of random blocks and adapted to the conditions of sprinkling irrigation. The study included a variant with irrigation (T1 - 60 % to 65 % of FWC- field water capacity) and the non-irrigated control variant (T_0). Irrigation was scheduled by monitoring the dynamics of soil moisture at 10-day intervals. When necessary, measurements were made at shorter intervals, in soil layers from 10-20 cm to 60 cm in depth. Soil moisture was determined by the gravimetric method, by oven-drying samples at 105-110 ^{o}C. Deficit of readily available water (RASWD) in the soil layer of 60 cm during growing season and the actual evapotranspiration (ETa) were calculated by the water balance method (Vučić 1973). Water consumption for the potential evapotranspiration (ETm) in individual months and the growing season was calculated by the bioclimatic procedure, using hydrophytothermic indexes (0.11 for May, 0.18 for June, 0.18 for July, 0.18 for August and 0.11 for September) (Bošnjak 1982). Data on precipitation (P) and air temperature (T) were taken from Rimski Šančevi meteorological station located at the experiment field of Institute of Field and Vegetable Crops, Novi Sad (Tab. 1).

The experiment included maize hybrid NS-640 from FAO maturity group 600. The size of experimental unit was 35 m^2. Harvest was performed by hand at the stage of technological maturity. Grain yield (Y) was calculated in t ha^{-1} on the 14 % moisture basis. Up-to-date production technology was employed. Cultivation practices were performed at optimum dates.

Statistical data were processed by the analysis of variance and results were tested by the LSD test. Regression and significance of correlation coefficients was calculated among the tested parameters.

Results and discussion

The climatic region of Vojvodina is characterized by variable climatic conditions. The average amount of precipitation for the period 1964-2007 in Vojvodina was 598.7 mm and the average yearly temperature was 11.2 ^{o}C. In the course of the growing season (April-September), the rainfall is 328 mm, or 55 % of the total precipitation, while the average air temperature is 17.8 ^{o}C.

Maize is typically considered to be drought resistant and an economical water consumer. However, because of a large vegetative matter, high yield and a long growing season maize has high total water consumption. Maize successfully overcomes dry spells because maize plants are capable of taking up less available forms of soil water, but its yield is low. Most intensive droughts in Vojvodina occur in July and August when natural pre-

cipitation provides only 12 % of the minimum needed for general potential evapotranspiration, which amounts to 100 mm (Bošnjak 1999). Using the model of Hergreaves, authors Bošnjak (1993) and Dragović (1995) found that these months border on semiarid to arid climate, with the natural water supply which is not sufficient for successful crop production. The critical periods in maize growth and development in relation to water use coincide in Vojvodina with most intensive droughts, and yield performance is highly correlated with the amount and schedule of rainfall in this period (Bošnjak & Pejić 1997).

Tab. 1. Mean monthly air temperatures (T) and monthly precipitation (P) during maize growing season (Rimski Šančevi)

Tab. 1. Srednje mesečne temperature vazduha (T) i mesečne količine padavina (P) u periodu vegetacije kukuruza (Rimski Šančevi)

Year / *Godina*	Mesec / *Month*									
	May / *Maj*		June / *Jun*		July / *Jul*		August / *Avgust*		September / *Septembar*	
	°C	mm	°C	mm	°C	mm	°C	mm	°C	mm
2000	18.5	39	21.4	28	22.1	29	24.0	5	17.8	13
2001	17.8	79	18.3	219	22.3	80	22.7	30	16.1	162
2002	19.1	19	21.1	28	23.6	35	21.5	50	16.3	45
2003	20.6	23	24.0	31	22.6	60	24.6	30	17.2	84
2004	15.2	89	19.8	97	21.9	63	21.7	39	16.2	42
2005	17.0	38	19.3	135	21.3	122	18.3	134	17.3	67
2006	16.6	70	19.7	104	23.5	31	19.7	125	17.9	24
2007	18.4	99	22.0	71	23.2	39	21.2	80	14.6	79
Average / *Prosek*	17.9	57	20.7	89	22.6	57	21.7	62	16.7	64

Tab. 2. Maize yields in irrigated and non-irrigated conditions

Table 2. Prinos kukuruza u uslovima sa navodnjavanjem i bez navodnjavanja

Year / *Godina*	Yield / *Prinos* (t ha^{-1})		Effect of irrigation / *Efekat navodnjavanja* (%)	Actual evapotranspiration ETa / *Realna evapotranspiracija ETa* (mm)
	Irrigated / *Navodnjavano*	Non-irrigated / *Nenavodnjavano*		
2000	13.457	8.037	67.4	174
2001	10.766	9.606	12.1	383
2002	13.604	10.210	33.2	237
2003	13.530	9.650	32.5	261
2004	12.960	10.500	23.4	353
2005	14.220	13.760	3.3	442
2006	14.820	13.920	6.5	399
2007	14.780	14.000	5.6	361
Prosek / *Average*	13.517	11.210	21.0	362
LSD	0.05	2.024		
	0.01	2.810		

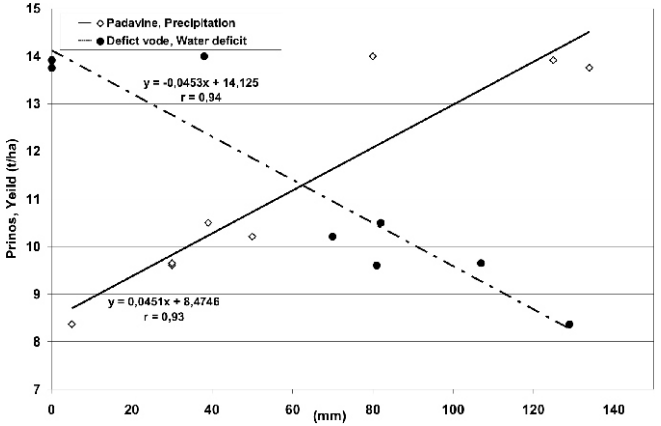
In the studied period, the largest maize yield (14.820 t ha^{-1}) was achieved under irrigation and the lowest (8.037 t ha^{-1}) under rainfed conditions (Tab. 2). The average yield increase was 21 % with actual values in the interval from 3.3 % to 67.4 %. Several domestic authors, based of their experimental results, reported that irrigation tended to increase the yield of maize up to 30 % (Kresović et al. 1993, Pejić 2000, Bošnjak et al. 2005). Results were

also obtained, in both experiments and production conditions, which indicated even greater irrigation effects. Authors Bošnjak & Pejić (1994) obtained average yield increases of 40 % to 44 %, the actual yields varying in some years from mere 6 % to 8 % to as much as 147 % to 159 %. Bošnjak & Dobrenov (1993) reported an average yield increase of irrigated maize amounting to 45.8 % Variations in individual years ranged from 6.4 % to 73.6 %, depending on quantity and distribution of precipitation, although the precipitation was 20 % to 50 % below the average value in some parts of Vojvodina. Irrigation increased the yield of maize about three times in 1990, which was extremely dry. Such an increase had never been obtained before under the variable climatic conditions of Vojvodina.

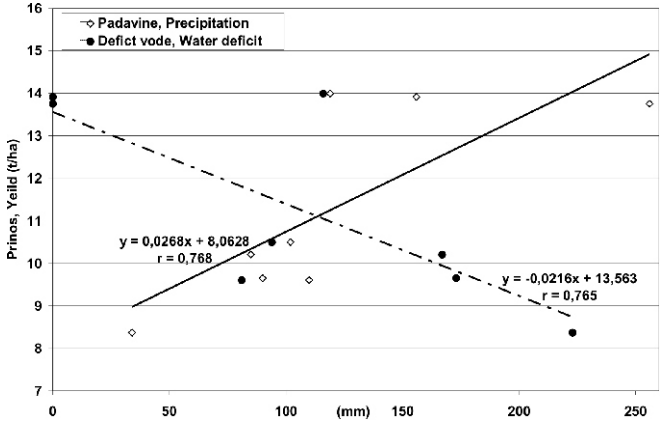
Under the rainfed conditions, maize yield (Y) was in correlation with the amount and distribution of precipitation (P) during the growing season, i.e. with readily available soil water deficit (RASWD) in the zone of active rhizosphere (Tab. 3, Graph. 1, 2).

Tab. 3. Readily available soil water deficit (RAWD) and monthly precipitation sums (P)
Tab. 3. Deficit lakopristupačne vode u zemljištu (RAWD) i mesečne sume padavina (P)

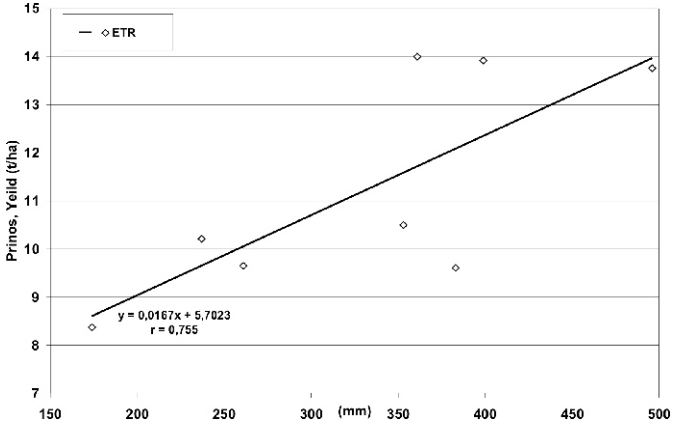
Year / *Godina*	Readily available soil water deficit (r.a.s.w.d. - mm) - Monthly precipitation sum (m.s.p. - mm) / *Deficit lakopristupačne vode (d.l.p.v.z. - mm) - Mesečna suma padavina (m.p.s. - mm)*					
	July / *Jul*		August / *Avgust*		July-August / *Jul-August*	
	d. l.v.z. *r.a.s. w.d.*	m.s.p. *m.p.s.*	d. l.v.z. *r.a.s. w.d.*	m.s.p. *m.p.s.*	d. l.v.z. *r.a.s. w.d.*	m.s.p. *m.p.s.*
2000	94	29	129	5	223	34
2001	0	80	81	30	81	110
2002	97	35	70	50	167	85
2003	66	60	107	30	173	90
2004	12	63	82	39	94	102
2005	0	122	0	134	0	256
2006	42	31	0	125	0	156
2007	78	39	38	80	116	119
Average / *Prosek*	49	57	63	62	107	119



Graph. 1. The relationship between maize yield (Y), precipitation (P) and deficit of readily available soil water (RAWD) in August (R. Šančevi, 2000-2007)
Graf. 1. Odnos između prinosa kukuruza (Y), padavina (P) i deficita lakopristupačne vode u zemljištu (DLPVZ) u avgustu (R. Šančevi, 2000-2007)



Graph. 2. The relationship between maize yield (Y), precipitation (P) and deficit of readily available soil water (RAW) in July-August (R. Šančevi, 2000-2007)
Graf. 2. Odnos između prinosa kukuruza (Y), padavina (P) i deficita lakopristupačne vode u zemljištu (DLPVZ) u julu i avgustu (R. Šančevi, 2000-2007)



Graph. 3. The relationship between maize yield (Y) and actual evapotranspiration (ETa) (R. Šančevi, 2000-2007)
Graf. 3. Odnos između prinosa kukuruza (Y) i realne evapotranspiracije (ETa) (R. Šančevi, 2000-2007)

The correlation analysis (Graph. 1) indicated a highly significant correlation between Y on one side and RASWD (r = -0.941) and P (r = 0.931) in August on the other. Significant correlations were also found between Y and RASWD (r = -0.765) and P (r = 0.768) in July and August (Graph. 2). Authors Pejić (1996) and Bošnjak & Pejić (1997) pointed out that maize yield decreases linearly with readily available soil water deficit in July and August, when maize is in the stages of flowering, fertilization and grain fill, which confirms that maize production without irrigation is quite risky under the variable climatic conditions of Vojvodina.

When growing under natural conditions, plants take up water from pre-vegetation soil reserves, precipitation during growing season and from ground water, their water requirement depending on the evapotranspira-

tion requirements of the environment. Therefore, plants do not meet their water requirements invariably. In other words, the values of actual evapotranspiration (ETa) vary from year to year and depend primarily of the quantity and distribution of precipitation in the growing season. The statistically significant correlation (Graph. 3, r = 0.755) between Y and water spent for actual evapotranspiration (ETa) confirms that the crop production in Vojvodina misses water as a trigger for the other production factors (Vučić 1976).

Conclusion

The obtained results indicate that, under the natural conditions of water supply to plants, maize production in Vojvodina is risky and correlated with weather conditions, especially with the amount and distribution of precipitation, and the status of readily available soil water.

The significantly higher maize yields in the irrigated variant as compared with the non-irrigated one indicate that under the climatic conditions of Vojvodina high and stable yields of maize can be achieved only in irrigation.

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Uticaj deficita lakopristupačne vode u zemljištu na prinos i evapotranspiraciju kukuruza

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Izvod: Eksperimentalna istraživanja su obavljena na oglednom polju Instituta za ratarstvo i povrtarstvo, Novi Sad na Rimskim Šančevima, na zemljištu tipa karbonatni černozem lesne terase u periodu 2000-2007. U ogledu su bile zastupljene varijanta sa navodnjavanjem (T_1) i kontrolna varijanta bez navodnjavanja (T_0). Analiziran je hibrid kukuruza NS-640 grupe zrenja FAO 600. Deficit lakopristupačne vode u zemljištu (DLPVZ) u sloju do 60 cm u periodu vegetacije, kao i utrošak vode na stvarnu evapotranspiraciju (ETa) obračunate su vodnim bilansom. Utrošak vode na potencijalnu evapotranspiraciju (ETm) u pojedinim mesecima i vegetacionom periodu obračunate su bioklimatskim postupkom primenom hidrofitotermičkih indeksa. Korelacionom analizom utvrđena je visokosignifikantna zavisnost prinosa kukuruza (Y) od DLPVZ (r = -0,941) i količine padavina (P) u avgustu (r = 0,931). Takođe je utvrđena statistički signifikantna zavisnost Y od DLPVZ (r = -0,765) i P u julu i avgustu (r = 0,768). Dobijeni rezultati potvrđuju činjenicu da je proizvodnja kukuruza u Vojvodini, u uslovima prirodne obezbeđenosti biljaka vodom, nesigurna i da je u korelaciji sa vremenskim uslovima pre svega sa količinom i rasporedom padavina. Ostvarena statistički signifikantna korelacija (r = 0,755) između prinosa kukuruza i utrošene vode na stvarnu evapotranspiraciju (ETa) potvrđuje da poljoprivredi Vojvodine nedostaje voda kao pokretač ostalih faktora proizvodnje. Signifikantno veći prinosi kukuruza na varijanti T_1 (13,517 t ha^{-1}) u odnosu na T_0 varijantu (11,210 t ha^{-1}) jasno ukazuju da se u klimatskim uslovima Vojvodine mogu postići visoki i stabilni prinosi kukuruza samo u uslovima navodnjavanja.

Ključne reči: deficit lakopristupačne vode u zemljištu, evapotranspiracija, kukuruz, prinos

Primljeno / Received: 15.09.2009.
Prihvaćeno / Accepted: 15.10.2009.