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Water-yield relations of maize (*Zea mays* L) in temperate climatic conditions

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Abstract

A field study was carried out from 2001 to 2007 in order to determine the water-yield relationship of maize in the Vojvodina region, a northern part of the Serbia Republic. The yield response factor (K_y) was calculated to express the response of maize to water stress both for the growing season and specific growth stages. To assess the effectiveness of irrigation on maize yield, an irrigation water use efficiency (I_{WUE}) and evapotranspiration water use efficiency (ET_{WUE}) were determined. The study indicated that in the climatic conditions of Vojvodina maize is most sensitive to water stress in the flowering and pollination stage (K_y = 0.52), but less sensitive in the stages of vegetative gowth (K_y = 0.37), grain filling and maturity (K_y 0.41). Values of yield response factor in the growing period (K_y = 0.54) indicated that maize is moderately sensitive to soil water stress in the temperate climatic conditions of Vojvodina. The I_{WUE} and ET_{WUE} were in intervals of 0.47 to 3.00 kg m^{-3} and 0.67 to 2.34 kg m^{-3} respectively, mostly depending on the extent of favorable conditions of the season for maize production and irrigation water applied. The parameters K_y, I_{WUE} and ET_{WUE} could be used by maize growers as a guide in the study region in terms of optimum utilization of irrigation water for the planning, design and operation of irrigation projects and for improving the production technology of the crop.

Keywords: maize (*Zea mays* L), yield response factor (K_y), water use efficiency (WUE)

Introduction

In Vojvodina, a northern part of the Serbia Republic, maize is the dominant field crop, grown on average in 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 significant variation from 2.94 to 6.44 t ha^{-1} (Statistical Year Book of Serbia, 2007). Most maize crops in Vojvodina are produced under rainfed conditions, however, some areas with this crop are produced under irrigation to stabilize production from year to year. In the variable climatic conditions of Vojvodina, in which summers are semi-arid to semi-humid (Bošnjak, 2001), high and stable yields of maize can be reliably obtained only by supplementing crop water requirement through irrigation. Only optimum conditions permit the plants to use water according to their needs, i.e., to the level of potential evapotranspiration (460 to 540 mm, Bošnjak, 1982; Pejić, 2000). The critical periods in maize growth and development in relation to water use in Vojvodina often coincide with intensive droughts, (July and August), and for this reason the yield performance is significantly correlated with the amount and distribution of precipitation in this period (Bošnjak and Pejić, 1999; Šeremešić and Milošev, 2006). If the natural water deficit occurs in maize during the growing season, in dry years in Vojvodina, the risk of crop failure can be reduced by the use of irrigation supplies (Pejić, 2000).

Many researchers have evaluated the effect of stress timing on maize yield (Hall et al, 1981; Frey, 1982; Frederick et al, 1989; Nesmith and Ritchie, 1992; Zinselmeier et al, 1999). Others have developed models to quantify the effect of stress timing on yield (Stewart et al, 1977; Doorenbos and Kassam, 1979; Yazar et al, 2002; Dagdelen et al, 2006). Doorenbos and Kassam (1979) proposed that the effect of water stress on yield could be quantified by a linear function in which the slope of the line (K_y) was an empirical yield response factor that varied depending on the stage of growth at the time of water stress. For maize, they reported K_y values of 0.4, 1.5, 0.5 and 0.2 for vegetative, flowering, yield formation and ripening stages respectively, indicating that yield was more affected by water stress during the flowering stage than at any other stage of crop growth. The model suggests that if water is limited, irrigators should time water application to coincide with the most sensitive stage. Vaux and Pruitt (1983) suggest that it is highly important to know not only the K_y values from the literature but also those determined for a particular

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Table 1 - Physical and water properties of the soil at the experimental site.

Depth (mm)	Textural status (%) Sand	Silt	Clay	Bulk density (kg m^{-3})	Total porosity (vol%)	Air porosity (vol%)	Field capacity (weight %)	Wilting point (weight %)	Total available soil water (mm)
0-300	34	48	18	1270	54.9	21.9	26.0	10.9	57.5
300-600	29	44	27	1310	48.8	14.1	26.5	11.2	60.0

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. The accuracy of K_y depends on having a sufficient range and number of values for yield (Y) and evapotranspiration (ET) and assumes that the relationships between Y and ET are linear over this range. Several studies have confirmed the diferences in K_y values of maize in different climatic conditions. Stan and Naescu (1997) determined K_y of maize for Romania for differnt maize hybrids in ranges from 0.66 to 0.86, Dagdelen et al (2006) 1.04 for a maize as a second crop in western Turkey and Oktem (2008) 0.82 to 1.43 for drip irrigated sweet corn in south-eastern Turkey.

The importance of analyizing evapotranspiration water use efficiency (ET_{WUE}) is ilustrated by the efforts of numerous studies that consider the total water use for evapotranspiration towards transpiration use as to the productive part of water to plants (Wallace and Batchelor 1977; Howell et al, 1990). The parameter ET_{WUE} mostly depends on precipitation amount and distribution and establishes whether the growing period is favorable for plant production or not. Irrigation schedules and applied management practices in relation to obtained yields of growing plants substantially influences this coefficient. Wang et al (1996) pointed out that crop yield depends on the rate of water use and that the factors that increase yield and decrease water used for ET favorably affect the water use efficiency. Howell (2001) indicated that ET_{WUE} generally is highest with less irrigation, implying full use of the applied water and perhaps a tendency to promote deeper soil water extraction to make better use of both the stored soil water and the growing-season precipitation. The irrigation water use efficiency (I_{WUE}) provides a more realistic assessment of the irrigation effeciveness as many management factors such as fertility, variety, pest management, sowing date, soil water content at planting, planting density and row spacing could affect yield substantially between irrigated and dryland agriculture. The parameter, I_{WUE}, generally tends to increase with a decline in irrigation if that water deficit does not occur at a single growth period (Howell, 2001).

The main objectives of this study were to: (1) quantify maize yield response to water stress both for growing season and at specific growth stages in temperate region and (2) compare the determined values of ET_{WUE} and I_{WUE} with those obtained from past studies of different climatic conditions, particularly to assist in developing strategies for improved production technology of maize in the Vojvodina and similar regions in other parts of the world.

Materials and Methods

The experiments were conducted at Rimski Šančevi, an experimental station of the Institute of Field and Vegetable Crops in Novi Sad (45°19`N, 19°50`E, elev. 84 m) on the chernozem soil on the loess terrace during 2000-2007. The soil of the experimental site is calcareous loamy (Table 1). Structural stability of the soil up to 600 mm is satisfactory with 60-71% of soil aggregates larger than 0.25 mm persistent in water (Pejić et al, 2005). As regards to the physical and hydraulic properties of soil at the study site (Table 1), the soil is quite suitable for most crops and methods of irrigation application.

Table 2 - Mean monthly air temperatures (°C) and monthly precipitation sum (mm) during maize growing season (Rimski Šančevi).

Year	Month May °C	mm	June °C	mm	July °C	mm	August °C	mm	September °C	mm	Seasonal Average °C	mm
2000	18.5	39	21.4	28	22.1	29	24.0	5	17.8	13	20.8	114
2001	17.8	79	18.3	219	22.3	80	22.7	30	16.1	162	19.4	570
2002	19.1	19	21.1	28	23.6	35	21.5	50	16.3	45	20.3	177
2003	20.6	23	24.0	31	22.6	60	24.6	30	17.2	84	21.8	228
2004	15.2	89	19.8	97	21.9	63	21.7	39	16.2	42	19.0	330
2005	17.0	38	19.3	135	21.3	122	18.3	134	17.3	67	18.6	496
2006	16.6	70	19.7	104	23.5	31	19.7	125	17.9	24	19.5	354
2007	18.4	99	22.0	71	23.2	39	21.2	80	14.6	79	19.9	368
Average	17.9	57	20.7	89	22.6	57	21.7	62	16.7	64	19.9	330
Long-term average (1964-1999)	16.8	60	19.9	86	21.4	68	21.0	57	17.1	35	19.2	306

The experiment was established in a system of random blocks and adapted to technical specifications of the sprinkler irrigation. The criteria used for irrigation in the field experiment included application of water when soil moisture was at 60-65% of field capacity (FC) i.e., irrigation was applied when about two-thirds of available water in the soil layer to 600 mm was depleted (Bošnjak, 1987). The non-irrigated plot was used as control. Irrigation was scheduled by monitoring soil moisture levels at 100 mm intervals down to 600 mm depth. This was estimated by using a gravimetric method at about 10 day intervals depending upon the weather conditions. Maximum evapotranspiration (ET_m) of maize during growing season was calculated using the bioclimatic method that employs hydrophytothermic index (K) with its values 0.11 for May, 0.18 for June, 0.18 for July, 0.18 for August, and 0.11 for September taken from Bošnjak (1982). After determining the ET_m value the actual evapotranspiration (ET_a) was calculated on the basis of precipitation data and pre-vegetation soil water reserve. These values were then used to calculate the soil water deficit for the growing season and for specific maize growth stages:

$$ET_m = \sum_{i=1}^{n} \left(K \cdot T_i \right) \qquad (1)$$

where

ET_m = monthly maximum evapotranspiration for maize (mm); K = hydrophytothermic index for maize T_i = sum of mean daily air temperatures in a given month (°C).

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

$$\left(1 - \frac{Y_a}{Y_m} \right) = K_y \left(1 - \frac{ET_a}{ET_m} \right) \qquad (2)$$

where

Y_a = the actual harvested yield (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); 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.

Evapotranspiration water use efficiency (ET_{WUE}, kg m^{-3}) and Irrigation water use efficiency (I_{WUE}, kg m^{-3}) were estimated as Bos (1980; 1985):

$$ET_{WUE} = Y_i - Y_d / ET_m - ET_a \qquad (3)$$

$$I_{WUE} = Y_i - Y_d / I_i \qquad (4)$$

where

Y_i = the yield and ET_m is the ET for irrigation level "i"; Y_d = the yield and ET_a is the ET for an "equivalent" dryland or rainfed only plots, and I_i = the amount of irrigation applied for irrigation level "i".

Duration of different maize growth stages (hybrid NS-640) were determined by maize breeders from the Institute of Field and Vegetable Crops, from Novi Sad: emergence 1 May, vegetative growth 1 May to 15 July, flowering and pollination 15 July to 5 August, grain filling and maturity 5 August to 30 September.

Precipitation (P) and temperature (T) data were obtained from Rimski Šančevi Meteorological Station (Table 2).

The period under study had varying weather conditions from year to year. This was especially true of the amount and distribution of precipitation, which varied from one year to the next. The growing seasons of 2001, 2004, 2005, 2006 and 2007 seasonal precipitation were 570, 330, 496, 354 and 368 mm respectively and therefore the study period had precipitation higher than the long-term seasonal average

Table 3 - Irrigation schedules and irrigation water applied (mm).

	Irrigation rate						
	Month						
	VI		VII		VIII		Irrigation water applied in the season (mm)
Year	mm	Date	mm	Date	mm	Date	
2000	60	23 June	60	24 July	60	08 August	180
2001	-		60	11 July	-		60
2002	60	24 June	60	05 July	-		120
2003*	60	05 June	30	05 July	-		200*
	60	20 June	-		-		
2004	-		45	02 July	60	17 August	105
2005	60	05 June	0		-		60
2006	-		60	06 July	-		180
	-		60	17 July	-		
	-		60	28 July	-		
2007	45	22 June	60	19 July	60	09 August	165

*2003 Two irrigations were performed after sowing (03 April – 20 mm and 05 May – 30 mm) to ensure uniform sprouting of plants

Table 4 - Maximum (ET_m) and actual (ET_a) evapotranspiration, maximum (Y_m) and actual (Y_a) yield, yield response factor (K_y) of maize, evapotranspiration (ET_{WUE}) and irrigation water use eficiency (I_{WUE}).

Year	ET_m	ET_a	$1\text{-}ET_a/ET_m$	Y_m	Y_a	$1\text{-}Y_a/Y_m$	K_y	ET_{WUE}	I_{WUE}
2000	495	174	0.65	13.457	8.037	0.40	0.61	1.69	3.00
2001	464	383	0.18	10.766	9.606	0.11	0.61	1.43	1.93
2002	481	237	0.51	13.604	10.210	0.25	0.49	1.39	2.83
2003	520	261	0.50	13.530	9.650	0.29	0.58	1.50	1.94
2004	458	353	0.23	12.960	10.500	0.19	0.82	2.34	2.34
2005	442	442	none	14.220	13.760	none	none	none	0.77
2006	461	399	0.13	14.820	13.920	0.06	0.46	1.45	0.50
2007	477	361	0.24	14.780	14.000	0.05	0.21	0.67	0.47
2000/7	471	356	0.35	13.517*	11.210	0.19	0.54	1.50	1.72

*numbers are significant by the LSD test at P≤ 0.05

(1964/1999 – 306 mm) (Table 2). However, despite its abundance, the precipitation was not favourably distributed, so additional water had to be supplied by irrigation of 60, 105, 60, 180 and 165 mm during 2001, 2004, 2005, 2006 and 2007 respectively (Table 3). Given data indicate that climatic patterns in Vojvodina are changeable and longer-term predictions of precipitation are not possible. That confirms the supplementary character of irrigation in Vojvodina, (Pejić et al, 2011a; 2011b), i.e. that precipitation can affect the soil water regime and irrigation schedule of maize. The other three years 2000, 2002 and 2003 had precipitation in the maize growing seasons in ranges from 114 and 177 mm in extreme drought conditions for 2000 and 2002 and 228 mm in 2003 which was moderate for maize prodution. High air temperatures and small amounts and uneven distribution of precipitation in those years led to a larger number of irrigations and overall irrigation rates, 180, 120 and 200 mm, respectively (Table 3).

The experimental maize plots received conventional growing technology adjusted to the conditions of irrigation. Maize was harvested at technological maturity and grain yield (Y) was calculated by t ha^{-1} adjusted to 14% moisture content. Statistical processing of data was done by the analysis of variance (ANOVA) and testing the obtained results by the Fisher's LSD test (P< 0.05 levels between the means). The relationship between crop yield and, water used by evapotranspiration, relative yield decrease and relative crop evapotranspiration deficit for maize growing season and specific growth stages were evaluated using regression analysis.

Results and Discussion

In Vojvodina, a typical temperate region, maize is considered to be an irrigation dependant crop because it rarely meets its water requirements from precipitation received during the growing season. In the study period, evapotranspiration rate in irrigation conditions (ET_m) ranged from 442-520 mm and in the rainfed conditions (ET_a) in the range from 174-442 mm (Table 4). The results observed in this research were in agreement with Bošnjak, 1982 who stated that for the Vojvodina region maize water requirements are 460-520 mm, Stegman (1986) who also reported similar values of seasonal water use of maize without water deficit for Nort Dakota of 432-514 mm.

The relationship between maize yield (t ha^{-1}) and seasonal crop water use (ET mm) for studied period was linear (r = 0.77, P < 0.05) (Figure 1). A linear relationship between crop water use and yield for maize has been reported by other researchers (Steele et al, 1994; Howell et al, 1995; Istanbulluoglu et al, 2002; Dagdelen et al, 2006; Payero et al, 2006). The average yield increase of maize due to irrigation was on average 2.31 t ha^{-1}, ranging from 5.42 t ha^{-1} in a year with limited precipitation and higher than average seasonal temperatures (2000) to 0 t ha^{-1} in the heavy rain year 2005 (Table 4). In the study period, on average, the yield of maize was significantly higher in irrigated areas (13.52 t ha^{-1}) than in rainfed conditions (11.21 t ha^{-1}). Various studies conducted in a wide range of environments have demonstrated that maize yield increases with irrigation (Cara and Biber 2008; Mengu and Ozgurel, 2008).

The obtained K_y of 0.54 for whole maize growing season (Table 4, Figure 2) is lower than the 1.25 reported by Doorenbos and Kassam (1979), 1.47 for Texas found by Howell et al (1997) and 1.36 estimated by Cakir (2004) in the arid climate of Turkey. Values are consistent with those of 0.66-0.86 determined by Stan and Naescu (1997) for temperate conditions of

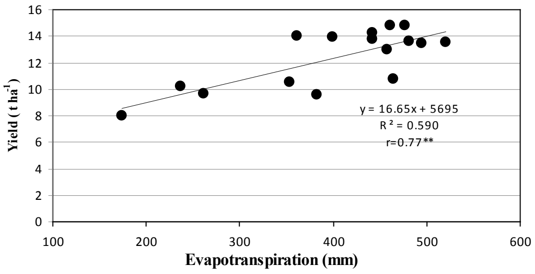

Figure 1 - Relationship between grain yield (Y) and seasonal crop water use (ET) of maize.

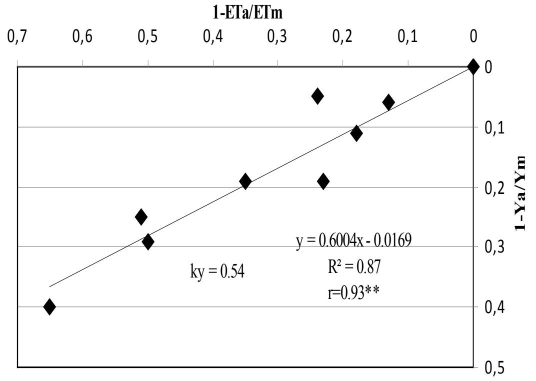

Figure 2 - Yield response of maize to water for the total growing season.

Romania 0.93 and the 0.76 estimated by Kamber et al (1990) and Istambulluoglu et al (2002), for the coastal area of Turkey. The lower values of K_y obtained in the study period which compared with those from other regions are related to the weather conditions during the study period in the Vojvodina region. In particular, K_y was affected by the amounts and distribution of precipitation and small evapotranspiration reduction in some years. On average the relative evapotranspiration decrease was 35% resulting in yield reduction of 19% (Table 4).

The effect of drought stress on the yield of maize depends on genotype, intensity and duration of stress and the growth stage exposed to water stress (Classen and Shaw, 1970). The obtained results indicated that in the climatic conditions of the Vojvodina Province maize is the most sensitive to water stress in the stage of flowering and pollination (K_y = 0.52) but less sensitive in the stage of vegetative growth (K_y = 0.37) and grain filling and maturity (K_y = 0.41) (Figure 3). The results are in agreement with those of Doorenbos and Kassam (1979) when they emphasized that maize appears to be relatively tolerant to water deficits during the vegetative and ripening periods and that the greatest decrease in grain yields is caused by moisture deficit in the soil profile during the flowering period; Frey (1982) proposed that the most critical period for yield formation in the life cycle of maize begins approximately 2 weeks before silking and continues until 2 to 3 weeks after silking; Cakir (2004) who stressed that much higher grain losses of 66-93% should be expected as a result of prolonged water stress due to irrigation ommision during both the tasseling and ear formation stages.

The best method to describe the role that irrigation has in water use efficiency (WUE) in irrigated agriculture is by expressions given by Bos (1980, 1985). Many researchers have evaluated water use efficiency in different ways (Viets, 1962; Begg and Turner, 1976; Howell, 2001). Consequently, care should be taken when comparing WUE values. Evapotranspiration water use efficiency (ET_{WUE}) of maize ranged from 0.67 to 2.34 kg m^{-3} with an average value of 1.50 kg m^{-3}, while irrigation water use efficiency (I_{WUE}) varied from 0.47 to 3.00 kg m^{-3} with an average value of 1.72 kg m^{-3}. The highest ET_{WUE} of 2.34 kg m^{-3} was recorded in 2004 with an evapotranspiration deficit of 23% (Table 4) and irrigation water applied of 105 mm (Table 3). The results are in agreement with those given by Howell (2001) who also stated that generally ET_{WUE} is highest with less irrigation. The highest I_{WUE} of 3.00, 2.83 and 2.34 kg m^{-3} were recorded respectively in the droughty years of 2000, 2002 and 2003 which was moderate for maize prodution. Similar results of I_{WUE} were also reported by Musick and Dusek (1980), Howell et al (1995) and Howell et al (1997) for Bushland Texas which ranged from 1.73 to 2.41 kg m^{-3}. Higher values of both ET_{WUE} and I_{WUE} in Texas compared with values obtained in the Vojvodina region could be explained by different evapotranspiration demand of maize plants i.e. the growing season in Texas (22°C) is warmer than in Vojvodina (19.2°C). Mengu and Ozgurel (2008) estimated similar I_{WUE} values of maize for western Turkey (1.78 to 2.13 kg m^{-3}) for full irrigation treatments using the close and furrow irrigation method. Results of both ET_{WUE} and I_{WUE} which were similar with those obtained from the literature indicate that irrigation schedule of maize, in the study period, was properly adapted to plant water requirements and water-physical soil properties.

Conclusions

It was concluded from this study that maize grain yields were significantly affected by irrigation as high and stable yields of maize in this region can be reliably obtained only by supplementing crop water requirement through irrigation. Evapotranspiration rate in irrigation conditions (ET_m) ranged from 442 to 520 mm, and in rainfed conditions (ET_a) in the interval from 174 to 442 mm.

Based on the analysis of maize response to soil water deficit in the growing season and specific

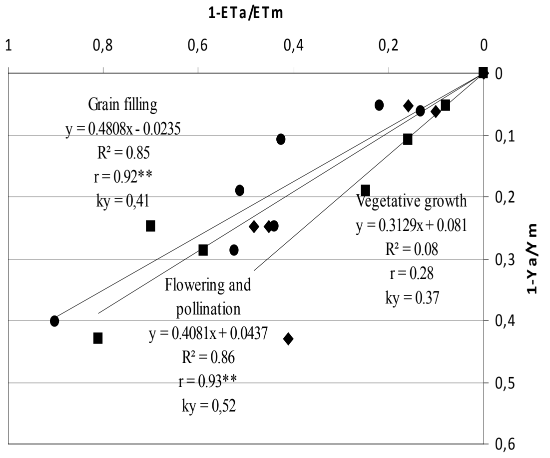

Figure 3 - Yield response of maize to water at specific growth stages.

growth stages, using a crop response factor (K_y), it could be concluded that maize is moderately sensitive to soil water stress (K_y = 0.54) in the temperate climatic conditions of Vojvodina. Flowering and pollination stages (K_y = 0.52) are the most sensitive, then the grain filling and maturity (K_y = 0.41) with the least susceptible stage being vegetative (K_y = 0.37). Evapotranspiration water use efficiency values varied from 0.67 to 2.34 kg m^{-3} with an average value of 1.50 kg m^{-3}, while irrigation water use efficiency varied from 0.47 to 3.00 kg m^{-3} with an average value of 1.72 kg m^{-3}. The seasonal value of yield response factor (K_y = 0.54) could be used as a good basis for irrigation strategy development in the region. The K_y of 0.52 in the most sensitive flowering and pollination stage suggests that if water is limited the irrigator should plan irrigation to coincide with that stage of maize growth in climate conditions of Vojvodina.

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