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EFFECTS OF WATER STRESS ON WATER USE AND YIELD OF MAIZE

BORIVOJ PEJIĆ[1], BRANKA KRESOVIĆ [2], ANGELINA TAPANAROVA[3], BOŠKO GAJIĆ[3], KSENIJA MAČKIĆ[1]

SUMMARY: The study of effects of water stress on yield and water use by maize plants was carried out in the experimental field of the Maize Research Institute at Zemun Polje in the period 2006-2008. Maize sensitivity to water stress was determined using a yield response factor (K_y). The values of K_y were derived from the linear relationship between relative evapotranspiration deficits ($1-ET_a/ET_m$) and relative yield decrease ($1-Y_a/Y_m$). To assess the irrigation effect on maize yield, irrigation water use efficiency (I_{wue}) and evapotranspiration water use efficiency (ET_{wue}) were determined. Values of K_y in the growing season (K_y 0.94) indicate that maize is moderately sensitive to water stress under the climate conditions of Serbia. The amounts of water used on evapotranspiration under irrigation (ET_m) and non-irrigation (ET_a) conditions ranged from 453 to 501 mm, and 257 to 363 mm, respectively. The values of I_{wue} and ET_{wue} varied from 0.020 to 0.036 t ha^{-1}/mm and 0.024 to 0.038 t ha^{-1}/mm, respectively, mostly depending on the favourableness of the year for the maize production and irrigation water applied. K_y, I_{wue} and ET_{wue} can be used as a good basis for maize growers in the region in terms of optimum irrigation water use, for the planning, design and operation of irrigation projects in the region, and also for the improvement the production technology of the crop.

***Key words**: maize, water stress, yield, water use efficiency*

INTRODUCTION

Maize (*Zea mays*, L.) is one of the most important field crops in the world. It is grown on approximately 24% of areas cultivated with cereals (about 155 million ha). Furthermore, the participation of maize in grain production amounted to approximately 30% (i.e. about 609 million tonnes), while the average yield was 4.97 t ha^{-1} in the period

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[1]Borivoj Pejić PhD, associate professor and mr Ksenija Mačkić, teaching assistant, University of Novi Sad, Faculty of Agriculture, Boško Gajić PhD, full professor and Angelina Tapanarova PhD, senior expert associate, University of Belgrade, Faculty of Agriculture, Kresović Branka, PhD, scientific associate, Maize Research Institute Zemun Polje.
Corresponding author: Borivoj Pejić, e-mail: pejic@polj.uns.ac.rs, phone.: +381 21 485-3229.

2006-2008 (FAO Statistical Yearbook, 2008). Maize is even more significant for Serbia. During the same period, maize was cultivated on the 38% of plough field areas, i.e. on 1.23 million ha. The average yield recorded in the period 2006-2008 amounted to 4.4 t ha^{-1}, varying from 3.2 to 5.1 t ha^{-1} (Statistical Yearbook of Serbia, 2008), and correlated, first of all, with the sum and distribution of precipitation.

It is generally considered that maize is resistant to drought and that maize plants use water economically. Nevertheless, maize consumes great amounts of water due to its large vegetative mass, high yields and a long growing season. In the case of water deficiency, maize successfully overcomes drought, but yields less, because plants consume less readily available categories and forms of water from the soil (Bošnjak et al., 2005).

Based on long-term experiments carried out under the conditions of Vojvodina, Bošnjak et al. (2005) point out to maize yields lower by 28.7% as a result of a deficit of readily available soil water with a remark that yield can be lower by 147-159% in extremely arid years in relation to yields recorded under irrigation conditions. Cakir (2004) emphasises that yields amount to 15 t ha^{-1} under irrigation conditions in north-western parts of Turkey, while they amount to 5 t ha^{-1} under rainfed conditions. A striking example of low yields of maize (ranging from 1.22 to 4.63 t ha^{-1}) under rainfed conditions is provided by studies carried out by Vasić et al. (1997) in the arid region of eastern Serbia.

The effect on irrigation on the increase of maize yields depends on weather conditions of the year, primarily on the sum and distribution of precipitation. In dry years, it can be great (Bošnjak and Dobrenov, 1993; Bošnjak and Pejić, 1994), while in wet years, it can be very modest or even it can be omitted (Bošnjak, 1993; Bošnjak and Pejić, 1998; Pejić et al., 2011, Kresović et al., 2012).

The actual evaluation of stress related to the yield due to soil water deficit during the maize growing season can be obtained by the estimation of the yield response factor (K_y) that represents the relationship between a relative yield decrease ($1–Y_a/Y_m$) and a relative evaporation deficit ($1–ET_a/ET_m$). Doorenbos and Kassam (1979) estimate that the average values of K_y is 1.25 during the maize growing season. 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 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.

In order to approach the implementation of any idea on the intensive utilisation of agroecological conditions or the development of new procedures for the irrigation regimes of crops, it is necessary to know precise water needs of plants, i.e. potential evapotranspiration (ETP). Water requirements of maize under agroecological conditions of Serbia vary from 450 to 540 mm (Jeremić and Spasojević, 1968; Bošnjak, 1982; Vasić, 1984; Pejić, 2000).

The estimation of water use efficiency in relation to evapotranspiration (ET_{wue}) can show a more realistic evaluation of irrigation effects, i.e. of the irrigation regime applied in maize crops. Also, the importance of analyizing 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., 1997). The parameter ET_{wue} mostly depends on precipitation amount and distribution and establishes whether the growing period is favorable for plant production or not. 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.

An even clearer estimation of irrigation effects and the applied irrigation regime can be obtained by the evaluation of irrigation water use efficiency (I_{wue}). If the irrigation regime is not synchronised with water needs of crops, water and physical properties of soil and weather conditions, the effect of irrigation can fail, that is the I_{wue} values can be bellow the optimum. 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 objective of the study was to estimate the yield response factor (K_y) and on the basis of this factor to analyse a seasonal maize response to water stress and in such a way to obtain additional information that can be useful in the improvement of maize growing practices under climate conditions of Serbia. The established values of ET_{wue} and I_{wue} will be used in analyses of the applied irrigation regime and effects of irrigation on maize yields with the aim to use water more efficiently in irrigation practice. Estimated values of water use on maize evapotranspiration will be compared with previously established water requirements by maize under agroecological conditions of Serbia.

MATERIAL AND METHODS

The trial was carried out on calcareous chernozem in the experimental field of the Maize Research Institute at Zemun Polje during the period 2006-2008. Furthermore, the trial was set up according to the block design and was adapted to sprinkler irrigation. There were two variants in the trial: irrigation with the pre-irrigation soil moisture of 80-85% of field water capacity (FWC) and control (non-irrigated variant). Irrigation was scheduled by monitoring soil moisture levels at 10-20 cm intervals down to 60 cm depth. This was estimated by using a gravimetric method at about 10 day intervals depending upon the weather conditions (Tapanarova, 2011).

Maximum evapotranspiration (under irrigation, non limiting conditions) (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 (1) the actual evapotranspiration (non-irrigated conditions) (ET_a) was calculated on the basis of precipitation data and pre-vegetation soil water reserve using the water balance method (Bošnjak et al., 2012). These values were then used to calculate the soil water deficit in the maize growing season.

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

Where:
ET_m = monthly maximum evapotranspiration for maize (mm)
K = hydrophytothermic index for maize
T = sum of mean daily air temperatures in a given month (^oC)

The yield response factor (K_y), as a parameter of effects of water stress on maize yield decrease during the growing season is calculated using the formula given by Vaux and Pruitt, 1983 (2).

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

Where:

Y_a = the actual harvested yield (non-irrigated conditions, 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

$(1–ET_a/ET_m)$ = the relative evapotranspiration deficit

$(1–Y_a/Y_m)$ = the relative yield decrease.

Irrigation water use efficiency (I_{wue}, t ha^{-1}/mm) and evapotranspiration water use efficiency (ET_{wue}, t ha^{-1}/mm) were estimated by expressions given by Bos (1980, 1985), (3, 4):

$$I_{wue}=\frac{Y_m - Y_a}{I} \qquad (3)$$

$$ET_{wue}=\frac{Y_m - Y_a}{ET_m - ET_a} \qquad (4)$$

Where:

I = the amount of irrigation water applied (mm)

The elementary plot size amounted to 20 m^2 (7.14 m x 2.8 m). The hybrid ZPSC-684 of FAO maturity group 600 with the sowing density of 55,000 plants ha^{-1} was used in the trial. Harvest was done by hand at harvest maturity, while yield (Y) was calculated in t ha^{-1} at 14% moisture. The experimental maize plots received conventional growing technology adjusted to the conditions of irrigation. 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 were evaluated using regression analysis.

Data on precipitation and air temperatures were recorded in the meteorological station of the Maize Research Institute, Zemun Polje. During the three-year trial period, the average air temperature for the period May-September (20.1°C) was higher, while the precipitation sum (249.9 mm) was lower than a long-term average (1980-2005) (Table 1). From the aspect of a water supply of maize, 2006 was favourable, 2007 was moderately favourable, while 2008 was unfavourable for the maize production. Amounts of water added by irrigation were correlated with the amount and distribution of precipitations. The irrigation water applied was 100 mm, 155 mm and 280 mm in the irrigation period of 2006, 2007 and 2008, respectively (Table 2).

Table 1. Mean monthly air temperatures (°C) and monthly precipitation sum (mm) during maize growing season

Year	Month										Seasonal average	
	May		June		July		August		September			
	°C	mm	°C	mm	°C	mm	°C	mm	°C	mm	°C	mm
2006	15.8	33.3	18.8	143.6	22.8	27.3	19.6	109.0	18.5	10.8	19.1	324.0
2007	18.8	42.0	22.5	63.0	23.9	18.7	23.7	51.6	15.1	73.0	20.8	248.3
2008	18.3	39.7	22.3	36.3	22.6	46.2	22.8	19.7	16.6	55.4	20.5	177.3
Average 2006/2008	17.6	38.3	21.2	81.0	23.1	30.7	22.0	60.1	16.7	46.4	20.1	249.9
Average 1980/2005	17.2	56.4	20.3	92.3	21.9	61.0	22.1	62.2	17.8	53.8	19.9	325.7

RESULTS AND DISCUSSION

The calculated values of water use on maize in irrigated conditions (ET_m) varying from 453 to 501 mm (Table 2) are in accordance with values previously recorded for the agroecological conditions of Serbia. Jeremić and Spasojević (1968) have determined that water requirements of maize in the Morava region ranged from 418 to 475 mm. Bošnjak (1982) has determined in field plots that water requirements of maize for the conditions of Vojvodina varied from 460 to 520 mm. Škorić and Berić (1994) have determined for the same climate conditions by the calculation over reference evapotranspiration (ETo) and crop coefficients (K_c) that water requirements for normal growth and development of maize amounted to 523 mm. Vasić (1984) has established that water requirements of maize under the Zemun Polje conditions and different methods of irrigation ranged from 451 to 526 mm. The determined values of water use on maize in non-irrigated conditions (ET_a) varied form 257 to 363 mm (Table 2). The calculated values of the deficit in readily available soil water (ET_m - ET_a) ranging from 90 to 233 mm point to the fact that the genetic potential for yield of otherwise very high-yielding maize hybrids will not be fully realized, since the amount of precipitation determines the potential yield levels. Agriculture in Serbia indubitably lacks water as one of the cornerstones of crop production (Vučić**,** 1976).

Effects of irrigation on the maize yield increase in the investigation period amounted to 47.8%, i.e. 4.88 t ha^{-1} (Table 2). Obtained results are in accordance with results gained by Bošnjak and Dobrenov (1993), who have established the average maize yield increase of 45.8% under weather conditions of Vojvodina. Bošnjak and Pejić (1994) have indicated that the average yield increase of maize was 40-44%, with variations over years from modest 6-8% to very high 147-159%.

The relationship between maize yields (t ha^{-1}) and seasonal water crop use (ET, mm) of maize was linear ($r = 0.92$, $P < 0.05$, Fig. 1). This linearity has also been established by other researchers (Steele et al., 1994, Howell et al., 1995; Istanbulluoglu et al., 2002; Dagdelen et al., 2006; Payero et al,; 2006; Pejić et al., 2011).

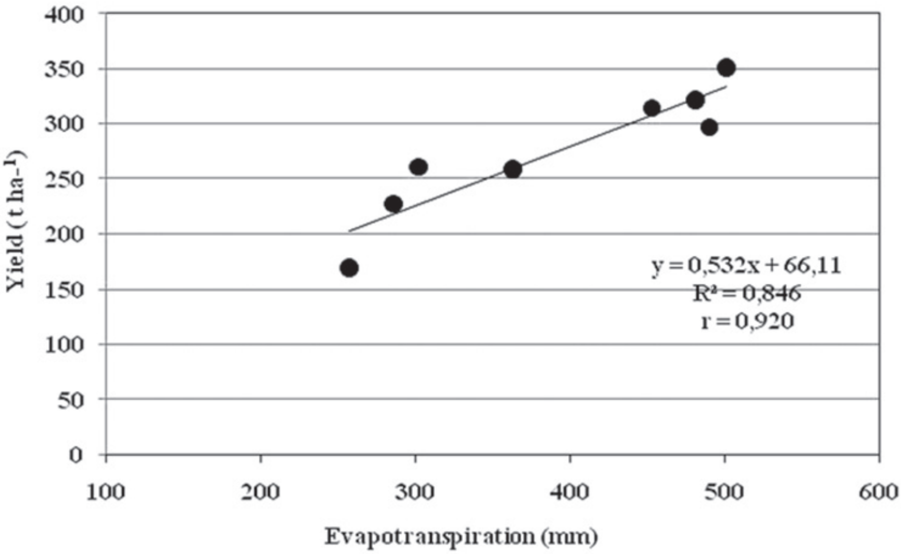

Fig. 1 Relationship between grain yield (Y) and seasonal crop water use (ET) of maize

The value of K_y of 0.94 recorded for the maize growing season (Fig. 2) is lower than values established by other researchers based on results obtained under arid climatic conditions (1.25 - Doorenbos and Kassam, 1979 - FAO publication; 1.47 - Howell et al., 1997 for Bushland in Texas; 1.36 - Cakir, 2004 for arid conditions of Turkey). Calculated values of K_y are in accordance with results obtained under moderate climate. Craciun and Craciun (1999) point out to values for temperate conditions of Romania ranging form 0.66 to 0.86 for hybrids of various maturity groups. Furthermore, Kanber et al. (1990) and Istanbulluoglu et al. (2002) have established values of 0.93 and 0.76 for coastal areas of Turkey. Pejić et al. (2009) point out that the K_y values of 0.65 determined for climate conditions of Vojvodina are the result of weather conditions, first of all, because of precipitation amount and their distribution. They stressed that only three out of 11 investigation years were extremely dry, while remaining eight were without or with an insignificant water deficit. Values of 0.65 in the growing season indicate that maize is moderately sensitive to the soil water deficit under climatic conditions of Vojvodina.

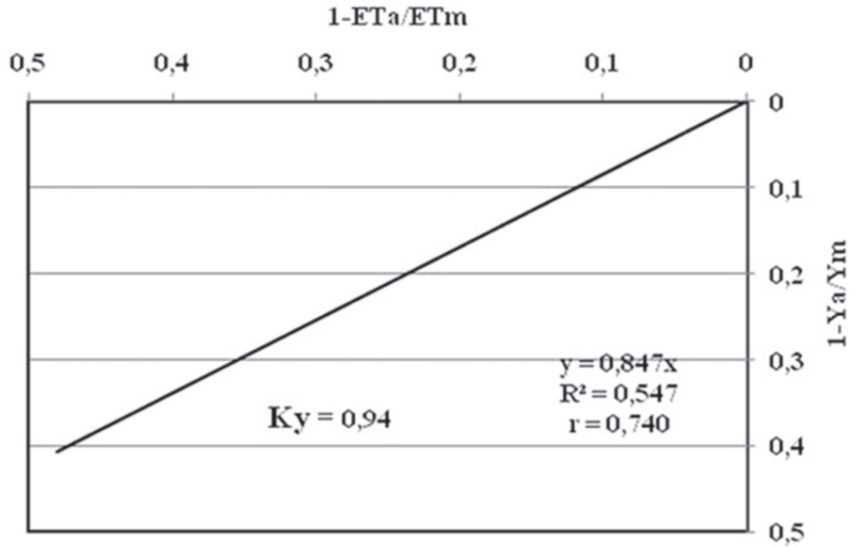

Fig. 2. Maize response to water stress for the total growing season

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; Bos, 1980, 1985; Howell, 2001; Pejić, 2010, Pejić, 2011). Consequently, care should be taken when comparing WUE values. Gained results under given agroecological conditions can be compared only in the approximately same temporal distance, because not only genetic potential of yielding was smaller more than 30 years ago (Pejić, 2000), but also growing practices have been significantly modified (Videnović et al., 2007).

Table 2. Water used on maximum (ET_m) and actual (ET_a) evapotranspiration of maize (mm), yield in irrigated (Y_m) and non-irrigated (Y_a) conditions (t ha^{-1}), irrigation water applied (I, mm), yield response factor (K_y), evapotranspiration (ET_{wue}) and irrigation water use efficiency (I_{wue}) (t ha^{-1}/mm)

Year	ET_m	ET_a	$1-ET_a/ET_m$	Y_m	Y_a	I	$1-Y_a/Y_m$	K_y	ET_{wue}	I_{wue}
2006	453	363	0.20	14.59	11.14	100	0.24	1.20	0.038	0.034
2007	501	286	0.43	16.33	10.74	155	0.35	0.81	0.026	0.036
2008	490	257	0.48	14.33	8.73	280	0.39	0..81	0.024	0.020
2006/8	481	302	0.37	15.08*	10.20	178	0.32	0.94	0.029	0.030

Numbers followed by * indicate statistical significance (LSD test $P \leq 0.05$)

Values of the water use efficiency in relation to evapotranspiration (ET_{wue}) ranged from 0.024 to 0.038 t ha^{-1}/mm (Table 2). The determined values are in accordance with the results gained by Hook (1985) who pointed to the ET_{wue} value of 0,030 t ha^{-1}/mm under humid conditions of south-eastern regions of the USA and by Pejić (2000) who determined ET_{wue} value of 0.026 t ha^{-1}/mm under conditions of sprinkler irrigation under climatic conditions of Vojvodina. The greatest values of ET_{wue} (0.038 t ha^{-1}/mm) were recorded in 2006, which was favourable for the maize production, during which the lowest amount of water was added by irrigation (100 mm, Table 2). Results are consistent with the statement of Howell (2001) who pointed out that the greater values of ET_{wue} were obtained if smaller amounts of irrigation water was used, because water was then used more efficiently, including precipitation water during the growing season and water reserves from deeper soil layers.

Irrigation water use efficiency (I_{wue}) determined in the period of investigation ranged from 0.020 to 0.036 t ha^{-1}/mm (Table 2). Obtained values are congruent with results of Cassel and Edwards (1985) gained for the conditions of North Caroline (0.003 - 0.036 t ha^{-1}/mm) and Pejić (2000) gained for the conditions of Vojvodina (0.029 - 0.031 t ha^{-1}/mm). Robertson et al. (1980) recorded maximum values of I_{wue} (0.045 t ha^{-1}/mm) for the conditions of Florida noting that the highest maize yields were recorded when I_{wue} ranged from 0.020 to 0.030 t ha^{-1}/mm.

CONCLUSION

Based on results gained on effects of water stress on water use and maize yields under climate conditions of Serbia it can be concluded that the maize yield under rainfed conditions (10.20 t ha^{-1}) was significantly lower than the yield (15.08 t ha^{-1}) recorded under irrigation conditions. Evapotranspiration rate under irrigation conditions (ET_m) ranged from 453 to 501 mm, while they varied from 257 to 363 mm under non-irrigation conditions (ET_a). Irrigation water use efficiency (I_{wue}) ranging from 0.020 to 0.036 t ha^{-1}/mm and evapotranspiration (ET_{wue}) varying from 0.024 to 0.038 t ha^{-1}/mm indicate that the applied irrigation regime in the maize crop was optimal in relation to water and physical properties of soil and biological traits of maize plants. Values of K_y (0.94) in the maize growing season point to the fact that maize is moderately sensitive to water stress under climate conditions of Serbia. The determined values of K_y, I_{wue} and ET_{wue} can be a good basis for maize growers in the region in relation to the optimum irrigation water use, planning, projecting and utilisation of irrigation systems, and also for the improvement the production technology of the crop.

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UTICAJ VODNOG STRESA NA POTROŠNJUVODE I PRINOS KUKURUZA

BORIVOJ PEJIĆ, BRANKA KRESOVIĆ, ANGELINA TAPANAROVA,
BOŠKO GAJIĆ, KSENIJA MAČKIĆ

Izvod

Eksperimentalna istraživanja uticaja vodnog stresa na potrošnju vode i prinos kukuruza su obavljena na oglednom polju Instituta za kukuruz Zemun Polje iz Zemuna u periodu od 2006-2008 godine. Osetljivost kukuruza na vodni stres u periodu vegetacije utvrdjena je na osnovu vrednosti koeficijenta opadanja prinosa - K_y. Vrednosti K_y su obračunate iz odnosa relativnog opadanja prinosa ($1–Y_a/Y_m$) i relativnog deficita evapotranspiracije ($1–ET_a/ET_m$). Za ocenu efikasnosti navodnjavanja, odnosno realizovanog zalivnog režima utvrdjen je koeficijent iskorišćenosti vode dodate navodnjavanjem (I_{wue}) i koeficijent iskorišćenosti vode u odnosu na evapotranspiraciju (ET_{wue}). Vrednosti K_y u vegetacionom periodu (K_y 0,94) ukazuju da je kukuruz umereno osetljiv na vodni stres u klimatskim uslovima Srbije. Utrošak vode na evapotranspiraciju u uslovima navodnjavanja (ET_m) kretao se u intervalu od 453-501 mm, a u uslovima bez navodnjavanja (ET_a) u intevalu od 257-363 mm. Vrednosti koeficijenta iskorišćenosti vode dodate navodnjavanjem (I_{wue}) su bile u intervalu 0,020 do 0,036 t ha^{-1}/mm, a koeficijenta iskorišćenosti vode u odnosu na evapotranspiraciju (ET_{wue}) u intervalu 0,024 do 0,038 t ha^{-1}/mm u zavisnosti od povoljnosti godine za proizvodnju kukuruza, odnosno količune vode dodate navodnjavanjem. Utvrdjene vrednosti K_y, I_{wue} and ET_{wue} mogu biti dobra osnova za proizvodjače kukuruza u regionu u pogledu optimalnog korišćenja vode za navodnjavanje, za planiranje, projektovanje i korišćenje zalivnih sistema, a takodje i za unapredjenje tehnologije proizvodnje kukuruza.

Ključne reči: kukuruz, vodni stres, prinos, efikasnost korišćenja vode.

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