UDC 575.827; 633.13
Original scientific paper

GENOTYPE AND ENVIRONMENTAL INTERACTION EFFECT ON HETEROSIS EXPRESSION IN MAIZE

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Kresović B.J., Ž.V. Videnović, and M.M. Tolimir (2004): *Genotype and environmental interaction effect on heterosis expression in maize*. – Genetika, Vol. 36, No. 2, 171-180.

The three-year studies on effects of irrigation and sowing densities were carried out on chernozem at Zemun Polje in the period 1998-2000. The four-replicate trial was set up according to the split-plot design. Six ZP maize hybrids (ZP 360, ZP 539, ZP 580, ZP 633, ZP 677, and ZP 704) were sown in seven densities (40,816, 50,125, 59,523, 69,686, 79,365, 89,286 and 98,522 plants ha^{-1}) under both, irrigation and rainfed conditions. Obtained results indicate that yields of hybrids under irrigation conditions were lower at sowing densities up to 50,000 plants ha^{-1} (40,816 and 50,125). The hybrid ZP 539 had similar yields (13.44-13.93 t ha^{-1}) at densities ranging from 60,000 to 100,000 plants ha^{-1}. The highest yields of hybrids ZP 360 and ZO 580 were achieved with the densities of 80,000, 90,000 and 100,000 plants ha^{-1}. The hybrid ZP 633 had the highest yields at the densities of 60,000-90,000 plants ha^{-1}, while the highest yields of the hybrids ZP 677 and ZP 704 were achieved with densities of 60,000-100,000 plants ha^{-1}. The curvilinear regression was determined by the analysis of dependence of achieved yields of maize hybrids on sowing densities. The following maximum yields could be expected under irrigation conditions: ZP 360 - 14.19 t ha^{-1} with the sowing density of 93,500 plants ha^{-1}; ZP 539 - 14.03 t ha^{-1} with the sowing density of 78,500 plants ha^{-1}; ZP 580 - 14.41 t ha^{-1} with the sowing density of 95,700 plants ha^{-1};

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ZP 633 - 13.64 t ha^{-1} with the sowing density of 80,000 plants ha^{-1}; ZP 677 - 13.31 t ha^{-1} with the sowing density of 92,250 plants ha^{-1} and ZP 704 - 14.33 t ha^{-1} with the sowing density of 84,111 plants ha^{-1}.

Key words: densities, yields, maize, irrigation

INTRODUCTION

No more than a few percents of the total arable lands cultivated with maize in Serbia are irrigated. However, maize is an essential row crop in crop rotations under irrigation conditions (BOŠNJAK and DOBRENOV, 1993). Many authors consider maize the best cereal crop under irrigation condtions as it shows the highest increase of yield (VASIĆ, 1991). Beside a proper choice of a hybrid, high and quality yields are a result of the application of appropriate cropping practices that differ from practices used under rainfed conditions. Differences occur in crop rotation (MOLNAR, 1993), fertilisation (KRŽIĆ, 1989), tillage (VIDENOVIĆ and VASIĆ, 1982), sowing density (BOŽIĆ, 1992), plant protection (STEFANOVIĆ, 1988), and positive effects are obtained only if all cropping practices are correctly applied (KRESOVIĆ, 2003). Sowing within these complex practices usually has a decisive role in achievements of high yields. According to the literature, a number of plants per area units should be increased by 10-15% under irrigation conditions in relation to rainfed conditions (NEDIĆ, 1986). Today, however, recently developed maize hybrids require a greater sowing density than other hybrids within their maturity group; hence, the question of the most favourable densities for maximum yields under irrigation conditions has arisen. The objective of the present study was to observe effects of irrigation and sowing density on yields achieved on chernozem with the aim to determine a sowing density at which the utilisation of the genetic potential of the yield of a new generation of ZP maize hybrids is the highest.

MATERIAL AND METHODS

The three-year experiments (1998-2000) were performed at Zemun Polje on slightly calcareous chernozem, whose structure points to a high potential fertility of the trial area. Up to the depth of 90 cm, the average bulk density, specific gravity and total porosity amount to 1.30 g cm^{-3}, 2.60 g cm^{-3} and 49.78%, respectively. Chernozem is moderately aerated and permeable in the direction of the depth. As the carbonate content in the humus accumulative horizon is below 5%, this soil is grouped into the category of slightly calcareous chernozem (Table 1). A soil reaction in the plough-field area is neutral to slightly alkaline. Up to the depth of 50 cm, soil is fairly supplied with humus and easy available phosphorus, and rich in total nitrogen and potassium.

A four-replicate trail was set up according to a split-plot design. Six ZP maize hybrids were observed at seven sowing densities under conditions of both, irrigation and rainfed (Table 2). The elementary plot size amounted to 28 m^2 (10 m x 2.8 m), and the experimental plot size depended on the sowing density. Yields

ha^{-1} in t at 14% moisture were processed by the analysis of variance with the use of the LST test.

Table 1. Some soil properties

Horrizons	Depth	$CaCo_3$	pH		Humus	Total N	Easy available	
							P_2O_5	K_2O
	cm	%	H_2O	NKcl	%	%	$mg \cdot 100^{-1}g$	
A_h	00-10	3.16	7.70	6.90	3.35	0.219	14.5	31.6
	10-20	3.46	7.75	6.85	3.33	0.209	14.8	32.4
	20-30	3.12	7.90	6.95	3.25	0.206	12.5	30.1
	30-50	4.88	8.25	7.30	3.06	0.173	10.2	28.6
A_hC	50-70	5.96	8.20	7.35	2.11	-	-	-
	70-90	18.12	8.25	7.30	1.78	-	-	-

Wheat was used as a preceding crop and the common cropping practices were applied. Mineral fertilisers were applied in the amounts of 15 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1}. Sowing and harvest were done manually on the optimum dates. The intervention by irrigation was done at 75% field water capacity. The determination of dates of watering and the calculation of watering norms were based on the water content of soil to the 0-90 cm depth. Soil samples were taken on each seventh day and the water content of soil was estimated by a thermogravimetric method.

Table 2. Basic elements of the trial

ZP hybrids	Density ($plants \cdot ha^{-1}$)	Plant spacing in a row (m)	Plants number per row	Elementary plot size (m^2)
H_1- ZP 360	G_1- 40,816	0.350	28	13.720
H_2- ZP 539	G_2- 50,125	0.285	35	13.965
H_3- ZP 580	G_3- 59,523	0.240	41	13.776
H_4- ZP 633	G_4- 69,686	0.205	48	13.776
H_5- ZP 677	G_5- 79,365	0.180	55	13.860
H_6- ZP 704	G_6- 89,286	0.160	62	13.888
	G_7- 98,522	0.145	68	13.804

Average air temperatures of the maize growing season in the investigation period did not significantly differ from one another (1998: 20.3 ^oC, 1999: 19.7 ^oC and 2000: 20.0 ^oC) but precipitation sums did. The precipitation sums in the April-September period amounted to 317.0 mm, 664.0 mm and 202.6 mm in 1998, 1999 and 2000, respectively. Considering the water requirement of maize, the year of 1999 had a sufficient precipitation sum and the irrigation was not applied. The remaining two years were characterised by a precipitation deficit; soil moisture dropped bellow a lower limit of capillary bond breakage and irrigation was done several times. As a rule, the irrigation regime for the trial area by dates and numbers of watering, as well as, by watering norm, was in accordance with the precipitation distribution during the growing season of maize (Table 3).

Table 3. Irrigation regime of maize

Year	Number of watering	Date of watering	Watering norm	Irrigation norm
1998	I	05.06.	30 mm	190.0 mm
	II	26.06.	30 mm	
	III	03.07.	30 mm	
	IV	17.07.	30 mm	
	V	31.07.	30 mm	
	VI	14.08.	40 mm	
1999	-	-	-	-
2000	I	23.05.	40 mm	260,0 mm
	II	06.06.	40 mm	
	II	14.06.	40 mm	
	IV	22.06.	70 mm	
	V	19.07.	70 mm	

RESULTS AND DISCUSSION

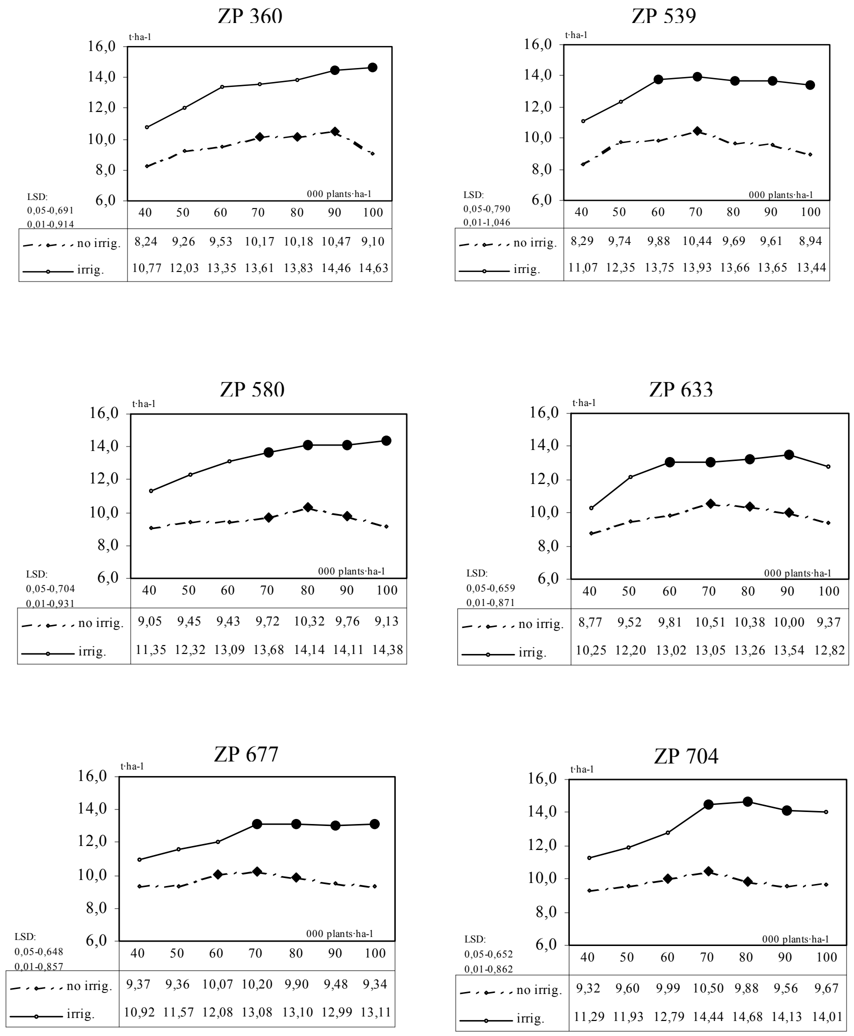
The analysis of the three-year results shows that irrigation very significantly affected the level of maize hybrid yields. Effects achieved by irrigation varied over years (Table 4).

Table 4. Average grain yields (t ha^{-1}) of maize hybrids under irrigation and rainfed conditions

Hybrid	1998		1999		2000		Mean	
	rainfed	irrigat.	rainfed	irrigat.	rainfed	irrigat.	rainfed	irrigat.
ZP 360	10.86	14.63	11.76	12.13	6.06	12.97	9.56	13,24
ZP 539	11.01	14.56	10.59	11.00	6.93	13.81	9.51	13,12
ZP 580	11.37	14.83	11.85	12.18	5.41	12.88	9.54	13,30
ZP 633	11.79	13.78	11.62	11.37	5.90	12.62	9.77	12,59
ZP 677	12.03	13.50	11.30	11.49	5.69	12.23	9.67	12,41
ZP 704	12.05	14.48	10.99	12.00	6.32	13.49	9.79	13,32
Average	11.52	14.30	11.35	11.69	6.05	13.00	9.64	13,00

Factor		rainfed			irrigation	
	LSD:	0.05	0.01	LSD:	0.05	0.01
Year		0.167	0.220		0.182	0.240
Hybrid		-	-		0.258	0.339
Year x Hybrid		0.409	0.539		0.446	0.588

Irrigation was not applied during the rainy year of 1999, and therefore there were no differences in yields (11.35 and 11.69 t ha^{-1}). On the other hand, in 1998, the yield averagely increased by 2.78 t ha^{-1} (24.1%), while the corresponding increase in the extremely dry year of 2000 was by 6.95 t ha^{-1} (46.5%). Our results showing that irrigation effects were much greater in the year with less precipitation are in accordance with results obtained by many other authors (BOŠNJAK, 1994; DRAGOVIĆ, 1994; MILIVOJEVIĆ *et al*., 1997; VASIĆ *et al*., 1997). The three-year average yield of all hybrids under rainfed, i.e. irrigation conditions amounted to 9.64 t ha^{-1}, i.e. 13.0 t ha^{-1}, respectively, indicating an average yield increase under irrigation by 3.36 t ha^{-1} (25.8%).



ZP 360

	40	50	60	70	80	90	100
no irrig.	8,24	9,26	9,53	10,17	10,18	10,47	9,10
irrig.	10,77	12,03	13,35	13,61	13,83	14,46	14,63

ZP 539

	40	50	60	70	80	90	100
no irrig.	8,29	9,74	9,88	10,44	9,69	9,61	8,94
irrig.	11,07	12,35	13,75	13,93	13,66	13,65	13,44

ZP 580

	40	50	60	70	80	90	100
no irrig.	9,05	9,45	9,43	9,72	10,32	9,76	9,13
irrig.	11,35	12,32	13,09	13,68	14,14	14,11	14,38

ZP 633

	40	50	60	70	80	90	100
no irrig.	8,77	9,52	9,81	10,51	10,38	10,00	9,37
irrig.	10,25	12,20	13,02	13,05	13,26	13,54	12,82

ZP 677

	40	50	60	70	80	90	100
no irrig.	9,37	9,36	10,07	10,20	9,90	9,48	9,34
irrig.	10,92	11,57	12,08	13,08	13,10	12,99	13,11

ZP 704

	40	50	60	70	80	90	100
no irrig.	9,32	9,60	9,99	10,50	9,88	9,56	9,67
irrig.	11,29	11,93	12,79	14,44	14,68	14,13	14,01

Fig. 1. Grain yields (t ha^{-1}) of maize hybrids under different conditions in dependence on sowing densities

Statistically significant differences in yields were obtained over investigation years under conditions of irrigation. The highest yields of all ZP hybrids were obtained in 1998 (14.30 t ha^{-1}), then in 2000 (13.00 t ha^{-1}) and the lowest ones in 1999 (11.69 t ha^{-1}). The sum of precipitation and added water by irrigation under conditions of approximate average temperatures during the growing season amounted to 507.0 mm, 664.0 mm and 464.6 mm in 1998, 1999 and 2000, respectively. The temperature sum x water amount sum interaction in 1998 resulted in the highest utilisation of the genetic potential of the yield of maize hybrids, while both, higher and lower amounts of water resulted in the yield reductions. Obtained results are in agreement with previously gained results on effects of different amounts of water on maize yields in the same location (VASIĆ *et al.*, 1997).

Furthermore, the level of yields depended largely on the maize hybrids. The following hybrids had similar yields over the three-year investigation period: ZP 704 (13.33 t ha^{-1}), ZP580 (13.30 ha^{-1}), ZP 360 (13.24 t ha^{-1}) and ZP 539 (13.12 t ha^{-1}). Hybrids ZP 633 (12.59 t ha^{-1}) and ZP 677 (12.41 t ha^{-1}) had statistically significantly lower yields.

The sowing density also had very significant effects on the use of the genetic potential of the maize hybrids yields under conditions of irrigation. The highest yields of observed hybrids were obtained in different sowing densities (Fig. 1).

The curvilinear regression was determined by the analysis of dependence of achieved yields of maize hybrids on sowing densities (Fig. 2). The higher sowing densities of all hybrids were the higher yields up to a certain level were, after which yields declined. The differences among densities at which the genetic yielding potential is maximally used were also obtained.

The hybrid ZP 360 had the highest yields under irrigation conditions (14.46 and 14.63 t ha^{-1}) at the densities of 90,000-100,000 plants ha^{-1}, while the corresponding yields (10.17, 10.18 and 10.47 t ha^{-1}) under rainfed conditions were obtained at the densities of 70,000-90,000 plants ha^{-1} (Fig. 1a). Obtained results point out that under irrigation conditions this hybrid requires a significantly higher sowing density. In relation to the most favourable plant spacing under rainfed conditions (70,000 plants ha^{-1}), a yield higher by 28.6% was obtained under irrigation conditions at the highest sowing density. The top yields of the hybrid ZP 360 under irrigation conditions can be expected at the level of 14.19 t ha^{-1} at the sowing density of 93,500 plants ha^{-1} (Fig. 2a).

Under irrigation conditions, the hybrid ZP 539 (Fig. 1b) in comparison to other observed hybrids had the greatest scope of sowing densities (60,000-100,000) at which high yields (13.75, 13.93, 13.66, 13.65, 13.44 t ha^{-1}) were obtained. However, under rainfed conditions, the highest yield (10.44 t ha^{-1}), statistically significantly higher than others, was obtained at the density of 70,000 plants ha^{-1}. Results point to the fact that high yields were obtained under both, rainfed and irrigation conditions, with the sowing density ranging from 60,000 to 70,000 plants ha^{-1}. The top yields of this hybrid (14.03 t ha^{-1}) can be expected at the sowing density of 78,500 plants ha^{-1} (Fig. 2b).

The lowest sowing density of the hybrid ZP 580 at which the high yield will be achieved is 70,000 plants ha^{-1} (Fig. 1c). High average yields (13.68, 14.14, 14.11 and 14.38 t ha^{-1}), but with no statistically significant differences, were obtained with the sowing densities up to 100,000 plants ha^{-1} under irrigation conditions, i.e. up to 90,000 plants ha^{-1} (9.72, 10.23 and 9.76 t ha^{-1}) under rainfed conditions. Obtained results show that high yields were obtained with the sowing density of 70,000 plants ha^{-1} regardless of growing conditions. Under irrigation conditions, however, the maximum yields (14.41 t ha^{-1}) of this hybrid can be expected at the density of 97,500 plants ha^{-1} (Fig. 2c).

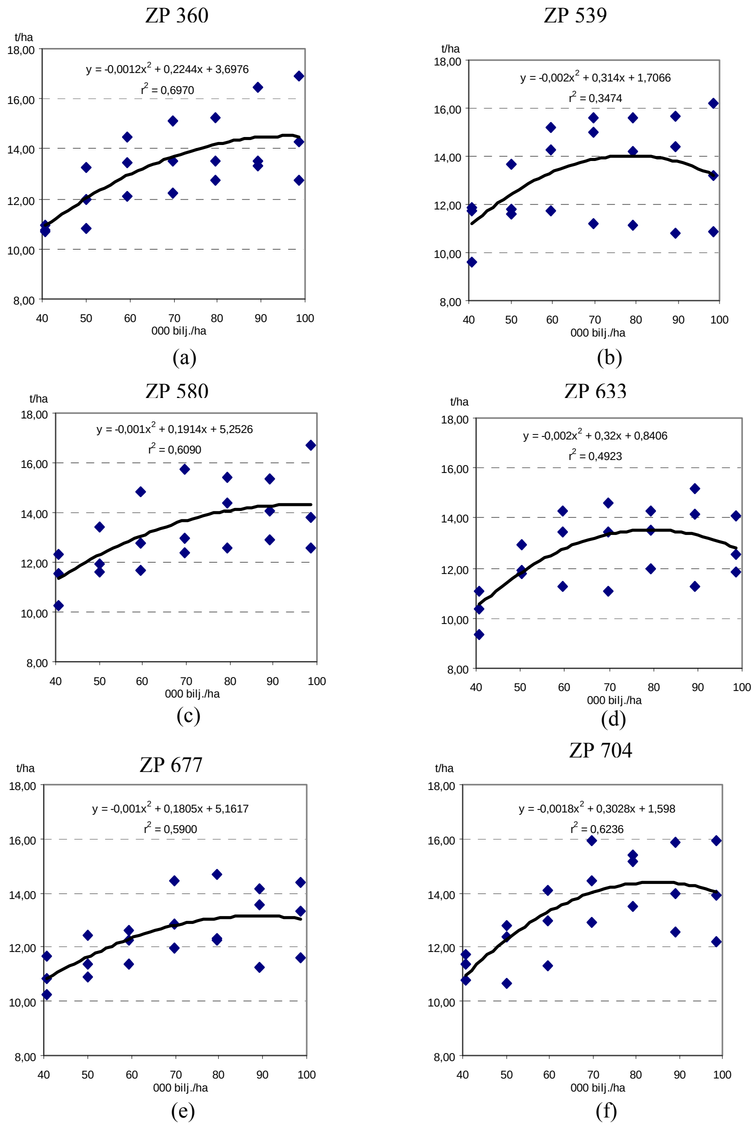


Fig. 2. Dependence of grain yield of ZP hybrids on sowing density

The hybrid ZP 633 had the top yields (13.02, 13.05, 13.26 and 13.54 t ha^{-1}) under irrigation conditions at the densities of 60,000-90,000 plants ha^{-1}, while the highest yields (10.51, 10.38 and 10.00 t ha^{-1}) under rainfed conditions were obtained at the densities of 70,000-90,000 plants ha^{-1} (Fig. 1d). Obtained results point out that high yields were obtained at densities 70,000-90,000 regardless of growing conditions. The maximum yields of the hybrid ZP 633 (13.64 t ha^{-1}) under irrigation conditions could be expected at the sowing density of 80,000 plants ha^{-1} (Fig. 2d).

High yields of the hybrid ZP 677 (13.08, 13.10, 12.99 and 13.11 t ha^{-1}) under irrigation conditions were obtained by sowing of 70,000-100,000 plants ha^{-1}, while the corresponding values (10.07, 10.20 and 9.90 t ha^{-1}) under rainfed conditions were obtained with the sowing densities of 60,000-80,000 plants ha^{-1} (Fig. 1e). Obtained results point out that high yields were obtained at densities 70,000-80,000 plants ha^{-1} regardless of the growing conditions. The maximum yields of the hybrid ZP 677 (13.64 t ha^{-1}) under irrigation conditions could be expected at the sowing density of 92,500 plants ha^{-1} (Fig. 2e).

The highest yields of the hybrid ZP 677 (14.44, 14.68 and 14.13 t ha^{-1}) under irrigation conditions were obtained by sowing of 70,000-90,000 plants ha^{-1}, while the corresponding values (10.50 and 9.88 t ha^{-1}) under rainfed conditions were obtained with the sowing densities of 60,000-80,000 plants ha^{-1} (Fig. 1f). Obtained results point out that high yields were obtained at densities 70,000-80,000 regardless of the growing conditions. The maximum yields of this hybrid (14.33 t ha^{-1}) under irrigation conditions could be expected at the sowing density of 84,111 plants ha^{-1} (Fig. 2f).

At last, once again it should be emphasised that the present study dealt with the three-year average values. Statistically very significant differences between observed hybrids and densities were obtained over years under rainfed conditions. Namely, hybrids had the same trend of the yield increase with the sowing density increase under irrigation conditions in the years favouring the maize production (1998 and 1999), while the highest yields in the extremely dry year (2000) were obtained with lower sowing densities (VIDENOVIĆ *et al*., 2003).

CONCLUSIONS

Obtained results on effects of the sowing density on the grain yields of ZP maize hybrids recently developed for irrigation growing conditions on chernozem point out to the fact that the higher sowing density was the higher yields up to a certain level were, after which yields reduced. In dependence on a maize hybrid, sowing densities at which the use of the genetic yielding potential was maximum varied. The following maximum yields could be expected under irrigation conditions: ZP 360 - 14.90 t ha^{-1} with the sowing density of 93,500 plants ha^{-1}; ZP 539 - 14.03 t ha^{-1} with the sowing density of 78,500 plants ha^{-1}; ZP 580 - 14.41 t ha^{-1} with the sowing density of 95,700 plants ha^{-1}; ZP 633 - 13.64 t ha^{-1} with the sowing density of 80,000 plants ha^{-1}; ZP 677 - 13.31 t ha^{-1} with the sowing density of

92,250 plants ha^{-1} and ZP 704 - 14.33 t ha^{-1} with the sowing density of 84,111 plants ha^{-1}.

Received August 3rd, 2004
Accepted August 30th, 2004

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INTERAKCIJA GENOTIPA I FAKTORA SPOLJNE SREDINE NA EKSPRESIJU HETEROZISA KOD KUKURUZA

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Izvod

Trogodišnjia proučavanja uticaja navodnjavanja i gustine setve obavljena su u periodu 1998-2000 u Zemun Polju na černozemu. Ogled je postavljen po split-plot metodi, u četiri ponavljanja. U uslovima sa i bez navodnjavanja, u sedam gustina setve (40816, 50125, 59523, 69686, 79365, 89286 i 98522 plants·ha^{-1}) sejano je šest ZP hibrida kukurza (ZP 360, ZP 539, ZP 580, ZP 633, ZP 677, ZP 704). Rezultati proučavanja pokazuju da su u navodnjavanju svi hibridi statistički veoma značajno niže prinose ostvarili u gustinama setve sa oko 50.000 bilj.·ha^{-1} (40.816 i 50.125 bilj.·ha^{-1}). Hibrid ZP 539 u svim ostalim gustinama (60-100.000 bilj.·ha^{-1}) imao je približne vrednosti prinosa (13,44 t·ha^{-1}- 13,93 t·ha^{-1}). Najbolje rezultate prinosa hibridi ZP 360 i ZP 580 ostvarili su u gustinama 80, 90 i 100.000 bilj.·ha^{-1}, hibrid ZP 633 u gustinama 60, 70, 80 i 90.000 bilj.·ha^{-1}, a hibridi ZP 677 i ZP 704 u gustinama 70, 80, 90 i 100.000 bilj.·ha^{-1}. Analizom zavisnosti ostvarenih prinosa hibrida kukuruza od gustine setve utvrdjena je krivolinijska regresija. U navodnjavanju mogu se očekivati sledeće vrednosti maksimalanih prinosa: ZP 360 - 14,19 t·ha^{-1} setvom u gustini 93.500 bilj.·ha^{-1}, ZP 539 - 14,03 t·ha^{-1} u gustini 78.500 bilj.·ha^{-1}, ZP 580 - 14,41 t·ha^{-1} u gustini 95.700 bilj.·ha^{-1}, ZP 633 - 13,64 t·ha^{-1} u gustini 80.000 bilj.·ha^{-1}, ZP 677 - 13,31 t·ha^{-1} u gustini 92.250 bilj.·ha^{-1} i ZP 704 - 14,33 t·ha^{-1} u gustini 84.111 bilj.·ha^{-1}.

Primljeno 3. VIII 2004.
Odobreno 30. VIII 2004.