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THE RESPONSES OF MAIZE GENOTYPES TO GROWTH CONDITIONS

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Studies on the effects of sowing densities on maize grain yields under irrigation were performed with the aim of creating favourable conditions for plant growth and development, under which the genetic yield potential would be maximally exploited. A two-factorial trial was performed in the period 2006–2009 on chernozem, according to the split-plot method with four replicates. Four maize hybrids of different FAO maturity groups (ZP 341, ZP 434, ZP 684 and ZP 704) were observed in combination with seven sowing densities (G1 – 40,816 plants ha–1, G2 – 50,125 plants ha–1, G3 – 59,524 plants ha–1, G4 – 69,686 plants ha–1, G5 – 79,365 plants ha–1, G6 – 86,286 plants ha–1 and G7 – 98,522 plants ha–1). The obtained results showed statistically very significant differences in maize grain yields between the studied hybrids and the sowing densities. The lowest yields were recorded for all studied hybrids at the lowest sowing density (40,816 plants ha–1). The regression analysis indicated that, depending on a maize hybrid, the following maximum yields could be

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expected: ZP 341 - 13.25 t ha–1 at a sowing density of 81,000 plants ha–1, ZP 434 - 13.00 t ha–1 at a sowing density of 75,000 plants ha–1 , ZP 684 - 13.83 t ha–1 at a sowing density of 82,000 plants ha–1 and ZP 704 - 12,83 t ha–1 at the sowing density of 77,000 plants ha–1. In accordance with the rational use of seeds, high yields are obtained by sowing that provides 50,000 plants of ZP 434 ha–1, 60,000 plants of ZP 341 ha–1 and ZP 704 ha–1 and 70,000 plants of ZP 684 ha–1.

Key words: genotype, plant densities, maize, yield, irrigation

INTRODUCTION

The development of new maize hybrids has permanently moved the limits towards higher yields. However, statistics has been recording significantly lower average values, as well as, their variation in dependence on the meteorological conditions during the crop growth season. During the five-year period (2005–2009), the year 2007 was the most unfavourable year for maize production in Europe, with the average yields of 4,965 kg ha–1 (FAOSTAT, 2009). On the other hand, favourable conditions in 2005 resulted in higher yields with an average of approximately 6,236 kg ha–1. During these two years, the maize yields in Serbia showed the same trend with average values of 3,905 kg ha–1 and 7,085 kg ha–1, respectively.

The problem of yield instability due to precipitation deficit during the growth season of maize was the subject of many studies (MARKOVIĆ *et al.,* 2011; VIDENOVIĆ *et al*., 2011). Moreover, it was confirmed that irrigation partially neutralised climate as a limiting factor for realising high yields (DRAGOVIĆ, 2000; DRAGOVIĆ *et al*., 2006; MAKSIMOVIĆ *et al*., 2008, TURRAL *et al*., 2010). In addition, studies indicate that irrigation during cultivation in relation to rainfed conditions changes the prerequisites for the maximum utilisation of the yield potential of hybrid genetics. When sowing, with its crucial role for obtaining high yields, is considered, special requirements refer to the necessary number of plants per area unit.

It is well known that sowing of all crops, including maize, is performed in such a way to provide the crop with sufficient space for its free growth and development (VIDENOVIĆ *et al*., 2007, SIMIĆ and STEFANOVIĆ, 2008). Literature data show that the optimum density, which ensures with certainty high yields, is that which provides for the maximum utilisation of sunlight, nutrients and soil moisture (XUE *et al*., 2002; GONZALO *et al.,* 2006; RAOUF *et al*., 2009). The maize grain yield per plant usually decreases with increasing sowing density per area unit. However, a general ascertainment of previous studies is that there is no universal formula for the optimum sowing density, because it depends on a great number of factors, especially on genotype, soil conditions and water availability during the growth season. LIEBMAN *et al*. (2001) stated that the optimum sowing density is the density at which a further increase of seed costs has no economic justification from the aspect of yield increase.

The aim of this study was to determine the effects of sowing density on maize grain yields on irrigated chernozem in order to establish densities that would provide the maximal utilisation of genetic yield potential. Bearing in mind that cost-effectiveness is an imperative of contemporary production, the objective of this study were sowing densities ranging from 40,816 to 100,000 plants per hectare, in order to determine those that would be the most favourable from the aspect of the rational usage of seed. The importance of these studies for both science and practice is reflected by the fact that the trials were performed on chernozem, which covers approximately 30 % of the total arable area of Vojvodina. Furthermore, equations of the regression analysis indicate the yields that could be expected at different sowing densities under the agroecological conditions of south-eastern Srem. Moreover, the question of different fertiliser rates in combination with density is raised, with the aim of determining a rational solution for the growth of the observed hybrids under conditions of different amounts of available water during the maize growth period.

MATERIALS AND METHODS

The trials were performed on calcareous silty loam chernozem, formed on loess (Zemun loess terrace) in the period 2006–2009. A two-factorial trial was set up according to the split-plot method with four replicates. Four maize hybrids (ZP 341, ZP 434, ZP 684 and ZP 704) were observed at seven sowing densities (Table 1). The elementary plot size was 19.6 m2 (7 m x 2.8 m), while the plot size for yield calculation (two rows) depended on the sowing density.

Table 1 Basic elements of the trial

Densities	Number of plants per ha	Sowing distance (cm)	Number of plants per row	Trial plot (m^2)
G1	40816	35.0	20	1020.41
G2	50125	28.5	24	1044.28
G3	59524	24.0	29	1026.27
G4	69686	20.5	34	1024.80
G5	79365	18.0	39	1017.50
G6	89286	16.0	44	1014.61
G7	98522	14.5	48	1026.27

Wheat was the preceding crop and standard cropping practices were applied. Mineral fertilisers were applied at the rate of 150 kg N ha–1, 60 kg P2O5 ha–1 and 60 kg K2O ha–1. The sowing and harvesting of the maize were realised manually during the optimum cultural periods. Irrigation was performed when the soil moisture amounted to approximately 70 % of the saturated water capacity (SWC). The time and irrigation norms were determined based on the soil moisture at a depth of 0–60 cm. The soil moisture content was determined thermo gravimetrically by sampling the soil every seven to ten days.

The mean air temperature (2006: 18.7 °C; 2007: 20.0 °C; 2008: 19.3 °C, 2009: 21.1 °C) in the April–September period in the years of investigation (Table 2) was higher than the long-term mean (1980–2005: 18.5 °C). The precipitation sum, in comparison with the long-term mean (383 mm), was lower in all years of investigation, except in 2006. The lowest mean air temperature (18.7 °C) and the highest precipitation sum (438 mm) during the maize growth period were recorded in 2006. The succeeding year, 2007, was characterized by a total precipitation sum of 275 mm and a high mean air temperature (20.0 °C) during the growth season, with extremely high temperatures during July. In 2008, the precipitation sum during the maize growth period was the lowest (247 mm), while the mean air temperature amounted to 19.3 °C. The year 2009 was the warmest (21.1 °C), with high average air temperatures in July (24.0 °C) and August (24.5 °C) and a precipitation sum of 321 mm during the growth period.

Table 2 Average air temperatures and precipitation sums during the maize growing period

Year	Months of the growing period						Mean/ Sum
	IV	V	VI	VII	VIII	IX	
			Mean air temperatures (^{0} C)				
2006	13.1	16.7	19.7	23.8	20.2	18.6	18.7
2007	13.8	18.9	23.1	25.0	23.8	15.7	20.0
2008	13.4	18.3	22.3	22.6	22.8	16.6	19.3
2009	16.2	19.8	21.1	24.0	24.5	21.0	21.1
1980-2005	11.8	17.2	20.3	21.9	22.1	17.8	18.5
			Precipitation sum (mm)				
2006	85	35	134	22	137	26	438
2007	1	55	73	15	66	65	275
2008	33	34	50	50	23	57	247
2009	6	34	153	79	45	4	321
1980-2005	58	56	92	61	62	54	383

*Republic Hydrometeorological Service of Serbia

The irrigation regime of the trial, both over time and the number of waterings, and over amount of water added by watering, were in accordance with the precipitation distribution during the maize growth season (Table 3). In 2006, the plot was not irrigated, as the sum and the distribution of the precipitation were sufficient for maintenance of the soil moisture above the required level. The total amount of water (precipitation + irrigation) that reached the soil surface during the maize growth period depended on the year and ranged from 361 mm to 438 mm.

Table 3 Irrigation regime of maize crop (mm)

Year	Watering		April – September	
	Date	Norm	Irrigation norm	Total sum (precipitation +irrigation)
2006	-	-	-	438
2007	20.07. 03.08.	50 40	90	365
2008	26.06. 16.07. 10.08.	30 60 50	140	387
2009	27.07.	40	40	361

The results of the maize grain yields (calculated at 14 % moisture) were processed by the statistical method of the analysis of variance with the application of the LSD test. The sowing densities for maximal yields were estimated by regression analysis.

RESULTS AND DISCUSSION

The obtained results indicate that the sowing density very significantly affected the grain yield in all the observed maize hybrids. Depending on a maize hybrid and environmental conditions during the growth period, the differences of the yields over the years of the investigations were very significant or significant.

The highest average grain yield of 13.21 t ha^{-1} was recorded for the hybrid ZP 341 at a sowing density of 69,686 plants ha^{-1} (Table 4). High yields, without a statistically significant difference in relation to the highest yield, were obtained in variants with greater sowing densities and with a density of 59,524 plants ha^{-1}. Sowing at densities lower than 59,524 plants ha^{-1} resulted in very significantly lower average yields and the lowest value (10.78 t ha^{-1}) was recorded at a density of 40,816 plants ha^{-1}. The environmental conditions very significantly affected the differences in yields over the years of the investigations. However, their interaction with the sowing density was not significant. The best results (13.43 t ha^{-1}) were obtained in the extremely dry year (2008), but the differences in relation to the average yields in 2006 (12.88 t ha^{-1}) were not significant. Statistically significantly lower yields, without mutual differences, were achieved in 2009 (11.99 t ha^{-1}) and 2007 (11.68 t ha^{-1}).

The highest grain yield (12.94 t ha $^{-1}$) for the hybrid ZP 434 was also achieved at a sowing density of 69,686 plants ha^{-1} (Table 5). The difference in relation to the yields of the other hybrids was statistically not very significant, except in relation to the grain yield obtained at a sowing density of 40,816 plants ha^{-1} (10.69 t ha^{-1}). Differences in grain yields of the ZP 434 hybrid obtained over the years of the investigations were significant, while the interaction of the years with the densities was not significant. Similarly to the hybrid ZP 341, the lowest average value (11.13 t ha^{-1}) was achieved in 2007, while the highest grain yield (13.29 t ha^{-1})

was recorded in 2008. The average yields in 2008 did not significantly differ from those obtained in 2009 (12.35 t ha^{-1}) and 2006 (12.32 t ha^{-1}).

Table 4 Average yields (t ha^{-1}) of ZP 341 at different sowing densities

Density	2006	2007	2008	2009	Average
G1	11.34	10.26	11.14	10.39	10.78
G2	12.03	11.03	12.98	11.05	11.77
G3	12.64	12.69	14.01	11.94	12.82
G4	13.08	12.33	14.45	12.99	13.21
G5	13.97	11.94	14.39	12.36	13.17
G6	13.48	11.45	13.67	12.52	12.78
G7	13.63	12.06	13.39	12.65	12.93
Mean	12.88	11.68	13.43	11.99	12.50

Analysis of variance – Yields of ZP 341

Source of variation (C_v- 6.61)	F value	Prob.	0.05	0.01
Years	8.7804	0.0024**	0.8380	1.175
Densities	18.7467	0.0000 **	0.5820	0.7725
Years x Densities	1.1015	0.3688 ns	-	-

Table 5 Average yields (t ha^{-1}) of ZP 434 at different sowing densities

Year	2006	2007	2008	2009	Average
G1	10.95	9.48	11.75	10.58	10.69
G2	12.36	10.99	12.79	12.73	12.22
G3	12.72	12.54	12.79	12.49	12.64
G4	12.88	11.31	14.16	13.42	12.94
G5	13.12	11.37	14.68	12.29	12.86
G6	12.09	11.22	13.77	12.66	12.44
G7	12.13	11.01	13.09	12.30	12.13
Mean	12.32	11.13	13.29	12.35	12.27

Analysis of variance – Yields of ZP 434

Source of variation (C_v- 7,54)	F value	Prob.	0.05	0.01
Years	5.6316	0.0121 *	1.148	1.610
Densities	10.8544	0.0000 **	0.6521	0.8655
Years x Densities	1.1334	0.3400 ns	-	-

An analysis of the variance of the yield of the hybrid ZP 684 showed that the observed factors and their interaction significantly affected the registered differences (Table 6). The highest average grain yield (13.74 t ha $^{-1}$) was achieved at a sowing density of 79,365 plants ha^{-1}, but there were no statistically significant differences in relation to the yields in the variants with greater densities and a density of 59,524 plants ha^{-1}. Significantly lower yields were achieved at sowing densities lower than 59,524 plants ha^{-1}: 12.72 t ha^{-1} (50,125 plants ha $^{-1}$) and 11.49 t ha^{-1} (40,816 plants ha^{-1}). Regardless of the sowing density, the highest yields over the years of the investigations were achieved in 2008 (14.75 t ha^{-1}), but without significant differences in relation to 2006 (13.70 t ha^{-1}) but with a significant difference in relation to the averages obtained in 2009 (12.08 t ha^{-1}) and 2007 (11.94 t ha^{-1}). There were no statistically significant differences between the average yields obtained in 2009 and 2007. The years x densities interaction indicates that the best results were obtained in 2008 at sowing densities of over 69,686 plants ha^{-1}.

Table 6 Average yields (t ha^{-1}) of ZP 684 at different sowing densities

Density	2006	2007	2008	2009	Average
G1	11.88	11.91	11.36	10.80	11.49
G2	12.83	12.37	13.64	12.02	12.72
G3	14.57	12.24	14.57	12.19	13.39
G4	14.24	11.12	15.85	12.71	13.48
G5	14.63	11.87	15.87	12.6	13.74
G6	13.75	12.35	16.17	12.62	13.72
G7	13.99	11.70	15.81	12.61	13.53
Mean	13.70	11.94	14.75	12.22	13.15

Analysis of variance – Yields of ZP 684

Source of variation (C_V- 5.88)	F value	Prob.	0.05	0.01
Years	10.4297	0.0012**	1.2900	1.8080
Densities	16.6234	0.0000**	0.5950	0.7216
Years x Densities	5.0670	0.0000**	1.0870	1.4430

Not only did the sowing density and conditions during the growth period individually affect the yield formation in the hybrid ZP 704, but also their interaction significantly (Table 7). However, the highest average grain yield of 12.94 t ha^{-1} was recorded at the lower sowing density (69,686 plants ha^{-1}), but with the same tendency in relation to yields registered with the other sowing densities. Namely, there were no statistically significant differences in relation to the yields in these variants with sowing densities of 79,365 plants ha^{-1}, 89,286 plants ha^{-1} or 59,524 plants ha^{-1} (12.77 t ha $^{-1}$, 12.34 t ha^{-1} and 12.44 t ha^{-1}, respectively). Comparing yields over the years of investigation, the highest values were recorded in 2008

(13.35 t ha^{-1}), while a lowest average value with a very significant difference in relation to all other years was recorded in 2007 (10.53 t ha^{-1}). The years x densities interaction indicates that the best results were achieved in 2008 with sowing densities of 79,365 plants ha^{-1} (15.49 t ha^{-1}), 69,686 plants ha^{-1} (14.48 t ha^{-1}) and 89,286 plants ha^{-1} (14.35 t ha^{-1}).

Table 7 Average yield (t ha^{-1}) of ZP 704 at different sowing densities

Density	2006	2007	2008	2009	Average
G1	10.54	9.90	10.97	12.31	10.93
G2	11.92	10.93	12.19	12.48	11.88
G3	12.84	11.48	12.72	12.70	12.44
G4	13.70	10.76	14.48	12.82	12.94
G5	13.11	9.99	15.50	12.49	12.77
G6	12.02	9.67	14.34	13.33	12.34
G7	12.24	10.94	13.24	12.47	12.22
Mean	12.34	10.53	13.35	12.66	12.22

Analysis of variance –Yields of ZP 704

Source of variation (C_v- 7.99)	F value	Prob.	0,05	0,01
Years	16,7176	0,0001**	0,9072	1,272
Densities	7,4541	0,0000**	0,6880	0,9132
Years x Densities	3,0980	0,0003**	1,376	1,826

Studies indicate that yield variations over the years in all the studied maize hybrids were significant, which is, among other things, a result of the non-adjustment of the irrigation regime to the meteorological conditions during the maize growth period. The irrigation regime applied in these studies, formed by watering at a pre-irrigation soil moisture of approximately 70 % SWC, best suited the conditions in 2008, which resulted in the highest yields from all hybrids. Contrary to this year, the irrigation regime was not appropriate for the conditions during the growth period in 2007, when the lowest yields were achieved. In July of 2007, especially in the second half of the month, the mean daily air temperatures were extremely high (over 30 °C), during the time when plants completely developed their root system, hence the applied irrigation system could not provide easily accessible water to the soil in accordance to the requirements of the plants. According to many authors (PANDEY *et al.*, 2000; CHICATUN *et al.*, 2007; KARA and BIBER, 2008), the phenomenon of difficult to access water in the effective rhizosphere zone significantly reduces yields. Hybrids of a shorter vegetation were least affected by the environmental conditions, which is logical as their flowering stage occurred earlier, which coincided with the "critical period" for water requirements and the highest danger for yield reduction. The most unfavourable conditions during the growing period in

2007 in relation to 2008 reduced the average yields of maize hybrids ZP 341, ZP 341, ZP 684 and ZP 704 by 13.1 %, 16.3 %, 18.7 % and 21.1 %, respectively.

The long-term results indicate that a functional dependence of the sowing density and the grain yield was in the form of a parabola (Figure 1). Increasing the number of plants per hectare up to a certain limit increased the grain yield of maize, but after that limit, the yield decreased. Previous studies of recently developed ZP maize hybrids of different FAO maturity groups indicated the same trend in the dependence between yield and the sowing density (VIDENOVIĆ *et al*., 2003; KRESOVIĆ *et al*., 2004, 2004a; SIMIĆ and STEFANOVIĆ, 2007).

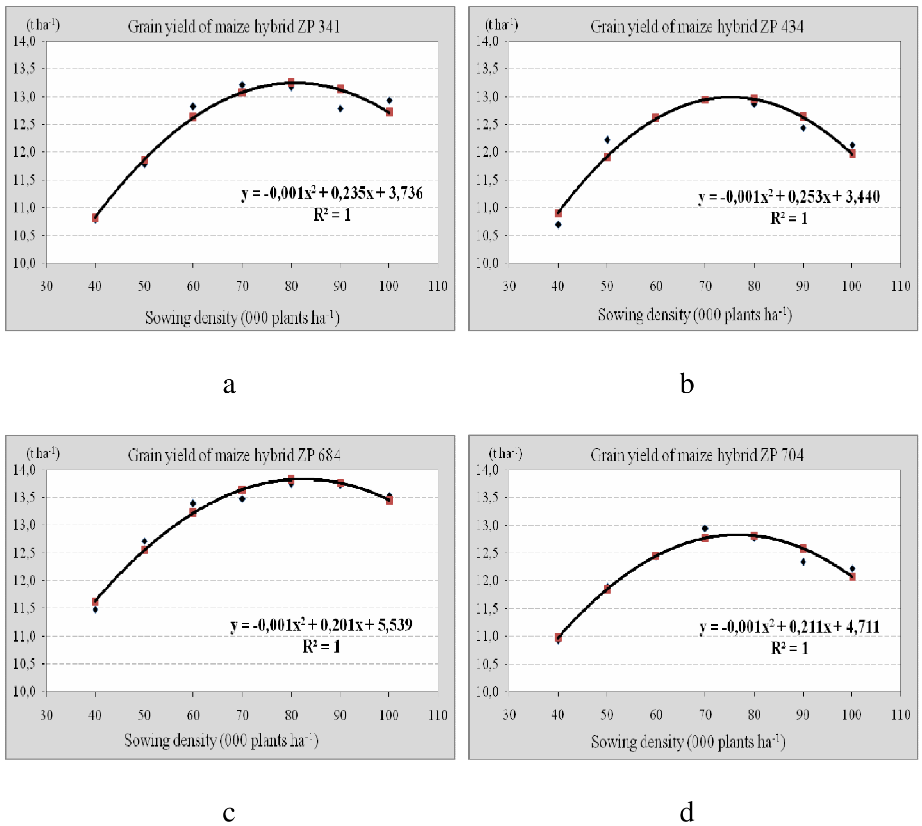

Figure 1 Dependence of the graina yield (y-t ha^{-1}) of maize hybrids (a-ZP 341; b-ZP 434; c-ZP 684; d-ZP 704) on the sowing density (x-000 plants ha^{-1})

The lowest yields of all the studied hybrids were obtained at the lowest sowing density (40,816 plant ha^{-1}) under the irrigation conditions of Zemun loess terrace chernozem. The maximum grain yield of the maize hybrid ZP 341 of 13.25 t ha^{-1} can be expected at a sowing density of 81,000 plants ha^{-1} (Figure 1-a). A sowing density of 75,000 plants ha^{-1} can result in the maximum grain yield of the hybrid ZP 434 (13.00 t ha^{-1}) (Figure 1-b). The maximum yield of 13.83 t ha^{-1} of the hybrid ZP 684 is to be expected at a sowing density of 82,000 plants ha^{-1} (Figure 1-c), while a yield of 12.83 t ha^{-1} of the hybrid ZP 704 can be expected at a sowing density of 77,000 plants ha^{-1} (Figure 1-d).

However, the obtained results indicate that high maize yields, without mutual significantly statistical differences, were achieved on irrigated chernozem within a wide interval of sowing densities. High yields of hybrids ZP 341, ZP 434, ZP 684 and ZP 704 were achieved at sowing density in the intervals of 60,000 to 100,000 plants ha^{-1}, 50,000 to 100,000 plants ha^{-1}, 70,000 to 100,000 plants ha^{-1} and from 60,000 to 90,000 plants ha^{-1}, respectively. This means that a high yield will be achieved with a rational use of seeds, high yields are obtained by sowing that provides 50,000 plants of ZP 434 ha^{-1}, 60,000 plants of ZP 341 and ZP 704 ha^{-1} and 70,000 plants of ZP 684 ha^{-1}. In addition, it should be born in mind that a very high correlation between achieved yields and the rates of applied fertilisers exists; hence, it is very important to apply an adequate rate of NPK fertilisers (MAHMOOD *et al*., 2001; TRINH *et al*., 2008; MUHAMMAD *et al*., 2010), which opens new issues for further studies.

CONCLUSION

Long-term studies (2006–2009) on sowing densities in maize hybrids of different FAO maturity groups were performed under irrigation cultivation conditions on chernozem. The obtained results indicate that yield variations over the years were significant in all maize hybrids, which is, among other factors, a consequence of the non-adjustment of the irrigation regimes to the plant requirements under the meteorological conditions during the growth period in 2007. The unfavourable conditions resulted in reductions of the average yields of the hybrids ZP 341, ZP 434, ZP 684 and ZP 704 by 13.1 %, 16.3 %, 18.7 % and by 21.1 %, respectively.

The sowing density in all the studied maize hybrids very significantly affected the maize grain yield formation. The lowest yields for all the studied hybrids were achieved at the lowest sowing density (40,816 plants ha^{-1}). Regression analysis indicated that, depending on a maize hybrid, the following maximum grain yields could be expected: ZP 341 - 13.25 t ha^{-1} at a sowing density of 81,000 plants ha^{-1}, ZP 434 - 13.00 t ha^{-1} at a sowing density of 75,000 plants ha^{-1}, ZP 684 - 13.83 t ha^{-1} at a sowing density of 82,000 plants ha^{-1} and ZP 704 - 12.83 t ha^{-1} at a sowing density of 77,000 plants ha^{-1}. However, the results indicated that high yields of maize, without mutual significant statistical differences, were obtained on irrigated chernozem over a wide range of sowing densities. This means that high yields were achieved with ZP 434 at 50,000 plants ha^{-1}, ZP 341 and ZP 704 at 60,000 plants ha^{-1} and ZP 684 at 70.000 plants ha^{-1}.

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REAKCIJA GENOTIPOVA KUKURUZA NA USLOVE GAJENJA

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I z v o d

U cilju stvaranja povoljnih uslova za rast i razviće biljaka, pri kojima se maksimalno koristi genetički potencijal rodnosti, obavljena su proučavanja uticaja gustine setve na visinu prinosa zrna kukuruza gajenog u navodnjavanju. Dvofaktorijalni ogled izveden je u periodu 2006-2009 na černozemu, po metodi razdeljenih parcela u četiri ponavljanja. Isptitivano je četiri hibrida kukuruza različite FAO grupe zrenja (ZP 341, ZP 434, ZP 684 i ZP 704) u kombinaciji setve sa sedam gustina (G_1 – 40000 bilj.ha^{-1}, G_2 – 50000 bilj.ha^{-1}, G_3 – 60000 bilj.ha^{-1}, G_4 – 70000 bilj.ha^{-1}, G_5 – 80000 bilj.ha^{-1}, G_6 – 90000 bilj.ha^{-1}, G_7 – 100000 bilj.ha^{-1}). Dobijeni rezultati pokazuju da su izmedju ispitivanih hibrida i gustina setve ostvarene statistički veoma značajne razlike prinosa zrna kukuruza. Svi ispitivani hibridi najniže prinose su ostvarili pri najmanjoj gustini setve, sa 40.000 bilj.ha^{-1}. Regresiona analiza pokazuje da se zavisno od hibrida kukuruza mogu očekivati sledeći maksimalani prinosi zrna: ZP 341 - 13,25 tha^{-1} pri gustini setve 81.000 bilj.ha^{-1}, ZP 434 - 13,00 tha^{-1} pri gustini 75.000 bilj.ha^{-1} , ZP 684 - 13,83 tha^{-1} pri gustini 82.000 bilj.ha^{-1} i ZP 704 - 12,83 tha^{-1} pri 77.000 bilj.ha^{-1}. U skladu sa racionalnom upotrebom semena, visoki prinosi se dobijaju setvom koja obezbeđuje po hektaru 50.000 biljaka hibrida ZP 434, zatim 60.000 biljaka hibrida ZP 341 i ZP 704 i 70.000 biljaka ZP 684.

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