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THE DEPENDENCE OF MAIZE (*Zea mays*) HYBRIDS YIELDING POTENTIAL ON THE WATER AMOUNTS REACHING THE SOIL SURFACE

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The aim of the present study was to observe the response of maize hybrids under rainfed and irrigation conditions of the soil in order to establish the dependence of yielding potential on the water amounts reaching the soil surface during the growing season. The four-replicate trail was set up according to the randomised complete-block design on chernozem. Pre-watering soil moisture was approximately 70% of field water capacity, and soil moisture was established thermogravimetrically.

During the five-year studies, the following differences in yields could be as follows: 12.68 t ha^{-1} (ZP 341); 12.76 t ha^{-1} (ZP 434); 13.17 t ha^{-1} (ZP 578); 14.03 t ha^{-1} (ZP 684) and 13.75 t ha^{-1} (ZP 704) under conditions of 440 mm, 440 mm, 424 mm, 457 mm and 466 mm of water, respectively. The hybrid ZP 341, i.e. ZP 578 expressed the highest, i.e. the lowest tolerance in dry relative seasons, respectively. The reduction of the water amount for every 10 mm decreased the yield by 119.4 kg ha^{-1} (ZP 341), 156.7 kg ha^{-1} (ZP 434), 172.3 kg ha^{-1} (ZP 578), 148.9 kg ha^{-1} (ZP 684) and 151.1 kg ha^{-1} (ZP 704).

Key words: genotype, maize, yield, rainfed conditions, irrigation

INTRODUCTION

New hybrids, with high genetic potential and stability of the yield also have good adaptability to diverse agroecological conditions, tolerance to drought, plant diseases, etc.

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However, there is no a single hybrid encompassing all these positive traits, because high genetic yielding potential is primarily determined by the selection in accordance with agroecological conditions and the complex of applied measures in the maize growing practices (DRINIĆ and MLADENOVIĆ-DRINIĆ, 2006; JOCKOVIĆ *et al*., 2010).

Distinctly different agro-ecological conditions of maize cultivation have had initiated the development of a large number of high-yielding hybrids, intended for growing at different altitudes, on different soil types of , as well as in areas with different thermal and pluviometric regimes. There are significant differences among hybrids in relation to plant architecture, resistance to lodging and diseases, competitive ability against weeds, the duration of the period from pollination, flowering, grain filling, etc., but they are all, more or less susceptible to water deficiency during the growing season. In the case of soil water deficiency, the plant thermal regimes are changed, physical and biological processes are delaying, and plants are depleting because their root system is not capable to supply plants with water and mineral nutrients (IBRAHIM and KANDIL, 2007). All previous studies confirm that water deficiency affects almost all processes due to physiological stress, so plants respond through reduced yields. The plant's response to water deficiency depends on a phenophase and on stress duration: 10-15 days prior and after pollination of maize are the most critical periods (KARAM *et al*., 2003; CAKIR, 2004; HUSSAIN *et al*., 2004; DRAGOVIĆ *et al*., 2005; BOŽIĆ *et al*., 2007; PEJIĆ *et al*., 2010).

Studies related to the water requirement of maize show that crops vary over agro-ecological conditions. According to PEJIĆ *et al.,* 2011, the values of evapotranspiration potential of maize amounts to: 375 mm (Minnesota, USA), 890 mm (central Asian parts of the former USSR) and 470-540 mm (in Serbia). Authors indicate that under the rainfed condition maize production in Vojvodina is risky. It is obvious that rainfed conditions have not been favourable and that the problem of reduced yielding potential would be present unless a sufficient water amount, necessary for crops supplied, mainly by irrigation. Therefore, besides applied cropping practices (VIDENOVIĆ *et al.,* 2007; DRAGIČEVIĆ *et al.,* 2011, 2012; SIMIĆ *et al.,* 2012, etc.), the selection of hybrids routed by the pluviometric regime of the location is one of the measures to mitigate losses arising from water deficiency.

The starting points for this study were results obtained in previous studies on the genotype x growing conditions interaction (KRESOVIĆ *et al*., 2011). The potential losses in yields due to water deficiency were determined for growing conditions under which yielding was high with optimal sowing density (60,000 plants ha^{-1}). It is important to state that minimum fertiliser rates, suitable for high yields on chernozem were applied (rational fertilisation). ELVIO and RINALDI (2008) emphasise that maize can be cultivated with high yields, as well as savings in irrigation and reduced nitrogen supply, what also exploit the positive interaction between these factors, so maximising resource-use efficiency. In such a way, obtained results present output quantification, as a base for establishing the feasibility of cultivation of genotypes in areas with different pluviometeric regimes. The objective of this study was to observe the response of maize genotypes under rainfed and irrigation conditions in order to establish the dependence of yielding potential and the water amounts used during the growing season.

MATERIALS AND METHODS

The five-year experimental studies (2004-2008) were carried out on calcareous chernozem soil type at Zemun Polje. The four-replicate trail was set up according to the randomised complete-block design. The elementary plot size was 19.6 m^2 (7 m x 2.8 m). Hybrids of different FAO maturity groups (ZP 341, ZP 434, ZP 578, ZP 684 and ZP 704) were observed under rainfed and irrigation conditions. Common cropping practices were applied during vegetation. The sowing density amounted 60,000 plants ha^{-1}. The following amounts of mineral fertilisers were used: 150 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1}. Pre-watering soil moisture was approximately 70% of field water capacity, and soil moisture was established thermogravimetrically. Grain yield in t ha^{-1} at 14% moisture was processed by the statistical method of the analysis of variances, while differences among individual treatments were analysed by the Fisher's test (LSD) at the probability levels of 5% and 1%. The regression analysis was used to determine the dependence of grain yield on the water amount that reached the soil surface during the maize growing season (through rainfall or irrigation).

The experiment encompassed years with different temperatures and precipitation sums during the maize growing season (Republic Hydrometeorological Service of Serbia - Chart 1). The years of 2004 and 2005 were the coldest with the average temperatures of 18.2 °C and precipitation sums of over 400 mm (426 mm and 433 mm, respectively). The similar precipitation sum was established in 2006 (438 mm), but average temperatures were somewhat higher (18.7 °C). The precipitation sums of 300 mm were determined in 2007 and 2008. A total of 275 mm were measured in the growing season of 2007, while the average air temperature was high (20.0 °C), with very hot July (25.0 °C). The lowest precipitation sum (247 mm) was determined in 2008, while air temperatures (19.3 °C) were somewhat lower in comparison with 2007. During the 2004-2008 period, the average temperature and precipitation sum in the maize growing season amounted to 18.9 ^{o}C and 364 mm, respectively,

The irrigation rates depended on meteorological conditions during the investigation period. Irrigation was not applied in 2005, since the precipitation sum was sufficient to maintain the soil moisture above or at the level of predicted pre-watering soil moisture. In remaining years, according to soil moisture monitoring, the correction of precipitation deficit was done with the following irrigation rates: 20 mm (2004), 30 mm (2006), 135 mm (2007) and 160 mm (2008).

RESULTS AND DISCUSSION

The analysis of variance for maize grain yields for the period 2004-2008 indicates that the relationship between water and yields generally have increasing trend. High values of the coefficient of correlation in all observed hybrids (0.806-0.875) point out that grain yield significantly depended on the amount of water reaching the soil surface during the growing season (Tables 1-5), but only to a certain level and after that yields decreased.

The average grain yield of the hybrid ZP 341 under rainfed conditions amounted to 11.57 t ha^{-1}, which was reduced by 1.33 t ha^{-1} (reduction yield coefficient k=0.103) due to water deficiency during the growing season (Table 1). The highest yield (13.75 t ha^{-1}) was recorded in 2004, when 446 mm of water reached the soil surface (rainfall 426 mm + irrigation 20 mm). Yields in years with rainfall less than 300 mm were reduced by 2.67 t ha^{-1} (2008, k=0.205) and 1.93 t ha^{-1} (2007, k=0.152). In comparison with other hybrids, this hybrid had the lowest susceptibility to water deficiency under conditions of high temperatures. The regression analysis of the five-year results indicates that with the water amount increase up to 440 mm (x) the hybrid ZP 341 tended to increase the yield up to 12.68 t ha^{-1} (Y), while higher water amounts resulted in the yield decrease ($Y=0.074+0.057x-0.000065x^2$). Under the same thermal conditions (x_1) during the growing season, the reduction of the water amount for every 10 mm decreased the yield of the hybrid ZP 341 by 119.4 kg ha^{-1} ($Y=6.2994+0.062x_1+0.01194x$).

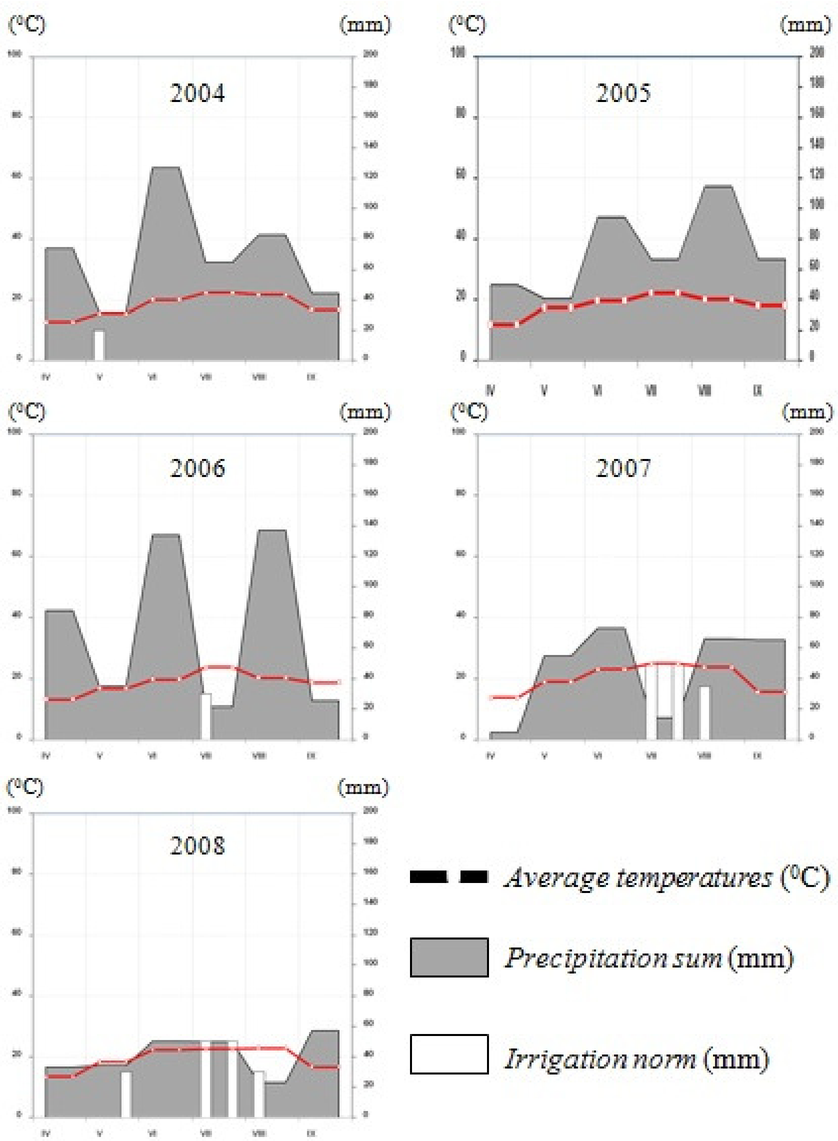
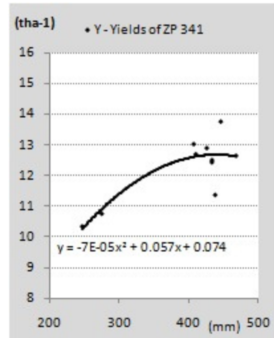


Chart1. Climate diagram for months of growing season and irrigation norms, 2004-2008

Table 1. Grain yield (t ha^{-1}) of the hybrid ZP 341 under different conditions and dependence of grain yield on the water amount (mm) during the growing season

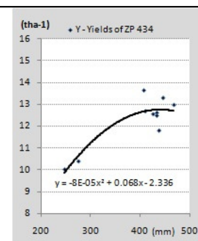
Year	Rainfed conditions	Irrigation
2004	12.89	13.75
2005	12.50	12.43
2006	11.37	12.64
2007	10.76	12.69
2008	10.35	13.02
Average	11.57	12.91



Analysis of variance – Yields of ZP 341				
Source of variation (Cv- 3,84)	F value	Prob.	0.05	0.01
Years	6.5965	0.0029**	0.7982	1.104
Condition	80.2107	0.0000**	-	-
Years x Condition	9.8858	0.0004**	0.7085	0.9795

Table 2 Grain yield (t ha^{-1}) of the hybrid ZP 434 under different conditions and dependence of grain yield on the water amount (mm) during the growing season

Year	Rainfed conditions	Irrigation
2004	12.54	13.28
2005	12.6	12.47
2006	11.79	12.96
2007	10.39	12.67
2008	10.02	13.62
Average	11.47	13.00

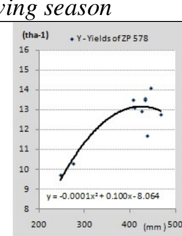


Analysis of variance – Yields of ZP 434				
Source of variation (Cv- 4,88)	F value	Prob.	0.05	0.01
Years	7.1008	0.0020**	0.6287	0.8692
Condition	65.5485	0.0000**	-	-
Years x Condition	11.6899	0.0002**	0.9005	1.2450

The average grain yield (11.47 t ha^{-1}) of ZP 434 was lower by 1.53 t ha^{-1} under rainfed conditions (reduction yield coefficient k=0.118) than yields obtained under irrigation conditions (Table 2). The highest yield (13.62 t ha^{-1}) of this hybrid was obtained in 2008 when 407 mm of water reached the soil surface (rainfall 247 mm + irrigation 160 mm). Water deficiency in this year resulted in the greatest difference in yields (3.60 t ha^{-1}) between both variants. Furthermore, a great difference in yields was also obtained in 2007 (2.28 t ha^{-1}). The analysis of gained results indicates that the water limiting value for the yield increase was equal to the corresponding value for the hybrid ZP 341 (440 mm) with approximate values of the maximum yield (12.76 t ha^{-1}) ($Y=-2.336+0.0686x-0.000078x^2$). However, higher values of the reduction yield coefficient, particularly in 2008 (k=0.264) and 2007 (k=0.180), pointed the lower drought tolerance of this hybrid in relation to ZP 341. Under the same thermal conditions (x_1) during the growing season, the reduction of the water amount for every 10 mm decreased the yield of the hybrid ZP 434 by 156.7 kg ha^{-1} ($Y=0.3179+0.3003x_1+0.01567x$).

Table 3 Grain yield (t ha^{-1}) of the hybrid ZP 578 under different conditions and dependence of grain yield on the water amount (mm) during the growing season

Year	Rainfed conditions	Irrigation
2004	12.91	14.09
2005	13.56	13.48
2006	11.67	12.75
2007	10.26	13.10
2008	9.68	13.49
Average	11.62	13.38



Analysis of variance – Yields of ZP 578

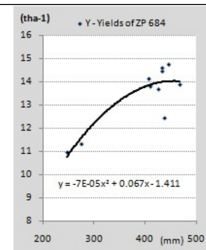
Source of variation (Cv- 4,79)	F value	Prob.	0.05	0.01
Years	44.6951	0.0000**	0.4289	0.5930
Condition	87.3615	0.0000**	-	-
Years x Condition	13.3185	0.0001**	0.9018	1.2470

The highest susceptibility to water deficiency during the growing season was recorded in the hybrid ZP 578 (Table 3). On the average, the yield was reduced by 1.77 t ha^{-1} (k=0.132), while the difference in dry years (2008, 2007) amounted to 3.81 t ha^{-1} (k=0.282) and 2.84 t ha^{-1} (k=0.217), respectively. Agro-meteorological conditions in 2004 were favourable for this hybrid (14.09 t ha^{-1}), and there was just one irrigation intervention (20 mm) at the beginning of the growing season. The average maximum yields of this hybrid could be expected at the level of 13.17 t ha^{-1}, with 424 mm of water reaching the soil surface ($Y=-8.0646+0.10012x-0.00012x^2$). Under the same thermal conditions (x_1) during the growing season, the reduction of the water amount for every 10 mm decreased the yield of ZP 578 by 172.3 kg ha^{-1} ($Y=5.4543+0.0095x_1+0.01723x$).

The highest average yields in the observed period under both conditions, rainfed and irrigation, were recorded in the hybrid ZP 684 (12.58 and 14.24 t ha^{-1}, respectively), respectively (Table 4). The difference of 1.66 t ha^{-1} pointed out a high dependence of yielding potential use on water amounts, but also the lower reduction yield coefficient (k=0.224) in the extremely dry year of 2008 in relation to hybrids ZP 578 and ZP 434. It can be expected that the hybrid will achieve the maximum average yield with the water amount of 457 mm with 14.03 t ha^{-1} ($Y=-1.4116+0.0676x-0.000074x^2$). Under the same thermal conditions (x_1) during the growing season, the reduction of the water amount for every 10 mm decreased the yield of the hybrid ZP 684 by 148.9 kg ha^{-1} ($Y=9.6193-0.113x_1+0.01489x$).

Table 4 Grain yield (t ha^{-1}) of the hybrid ZP 684 under different conditions and dependence of grain yield on the water amount (mm) during the growing season

Year	Rainfed conditions	Irrigation
2004	13.69	14.76
2005	14.47	14.61
2006	12.45	13.89
2007	11.33	13.81
2008	10.97	14.14
Average	12.58	14.24



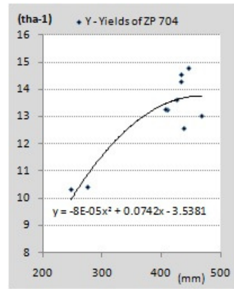
Analysis of variance – Yields of ZP 684

Source of variation (Cv- 3,17)	F value	Prob.	0.05	0.01
Years	14.8220	0.0000**	0.7252	1.003
Condition	152.6035	0.0000**	-	-
Years x Condition	15.6829	0.0000**	0.6394	0.884

The average difference in yields of the hybrid ZP 704 between rainfed and irrigation conditions was 1.54 t ha^{-1} (Table 5). The grain yield in dry 2008 and 2007 was reduced by 2.95 t ha^{-1} (k=0,223) and 2.84 t ha^{-1} (k=0.215), respectively. The best results were recorded under irrigation conditions in 2004 (14.77 t ha^{-1}) and in 2005 under both, rainfed and irrigation conditions (14.53and 14.27 t ha^{-1}, respectively). In relation to all observed hybrids, the water requirements of this hybrid during the growing season were the highest (466 mm). With this amount of water ZP 704 had the maximum average yield of 13.75 t ha^{-1} ($Y=-3.5381+0.0742x-0.000079x^2$). Under the same thermal conditions (x_1) during the growing season, the reduction of the water amount for every 10 mm decreased the yield of the hybrid ZP 704 by 151.1 kg ha^{-1} ($Y=16.5405-0.5066x_1+0.01511x$).

Table 5 Grain yield (t ha^{-1}) of the hybrid ZP 704 under different conditions and dependence of grain yield on the water amount (mm) during the growing season

Year	Rainfed conditions	Irrigation
2004	13.6	14.77
2005	14.27	14.53
2006	12.55	13.01
2007	10.39	13.23
2008	10.3	13.25
Average	12.22	13.76



Analysis of variance – Yields of ZP 704				
Source of variation (Cv- 4,02)	F value	Prob.	0.05	0.01
Years	78.2872	0.0000**	0.4282	0.5930
Condition	85.9370	0.0000**	-	-
Years x Condition	12.1317	0.0001**	0.7875	1.0890

Environmental effects on observed hybrids were significant for investigated period. The highest average grain yields of hybrids (13.63 t ha^{-1} and 13.49 t ha^{-1}) were recorded in 2004 and 2005, respectively. (Figure 1). Very significantly lower values were obtained in other three years: 2006 - 12.51 t ha^{-1}, 2008 - 11.88 t ha^{-1} and 2007 - 11.86 t ha^{-1} (LSD: 0.05-0.2390, 0.01-0.3157).

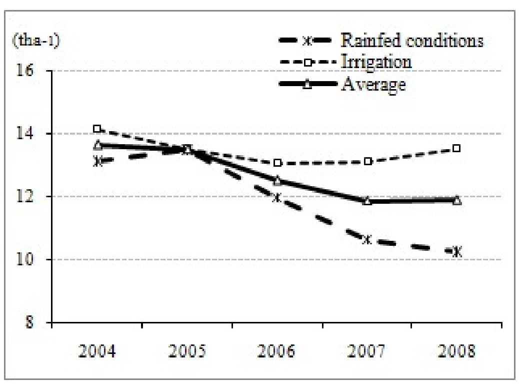


Fig 1 Average grain yields for all hybrids (t ha^{-1}) of maize under different growing conditions

The highest average yield of 13.48 t ha^{-1} was recorded under rainfed conditions in 2005. This year was relatively favourable for maize cultivation and there was no need for irrigation. A significantly lower average yield (13.13 t ha^{-1}) was recorded in 2004. The precipitation sum during the 2004 growing season amounted to 426 mm, but there was a soil moisture deficit during the early maize growth. A period prior to the growing season was characterised with small amounts of rainfall, while April rains (73.9 mm) were not sufficient to provide necessary soil moisture in relative dry May, (precipitation sum amounted only 32 mm). Very significantly lower yields were recorded in 2006 (11.97 t ha^{-1}), 2007 (10.62 t ha^{-1}) and 2008 (10.27 t ha^{-1}). Precipitation deficit was accompanied with high temperatures during July in 2006 and 2007, as well as during the June-August period in 2008, which adversely affected anthesis and therefore the yield. The studies carried out by PANDEY *et al*., (2000) show that maize grain yield was reduced by 6.6%–11.1% and 22.6%–26.4% if water deficit was shorter during the growing season and early reproductive stage, respectively, but yield was reduced by over 52% if water deficit lasted much longer.

The average grain yields of over 13 t ha^{-1} were obtained under irrigation conditions in all years of investigation. The highest average of 14.13 t ha^{-1} was recorded in 2004, while significantly lower yields were obtained in remaining years: 2005 (13.50 t ha^{-1}); 2006 (13.05 t ha^{-1}); 2007 (13.10 t ha^{-1}) and 2008 (13.50 t ha^{-1}). The effect of irrigation was higher in the extremely dry year of 2008 (31.6%), as well as in 2007 (23.3%) than in 2004 (7.6%) and 2006 (9.1%) in which the precipitation sum during the growing season was over 400 mm. During the five-year studies, the effect of irrigation of 13.2% was lower in comparison with results obtained by other authors. The differences in results are primarily due to studying hybrids of a diverse genetic background (maturity groups), as well as dissimilar meteorological conditions in years of investigation, first in the sum of air temperatures during the growing season and the precipitation sum during certain stages of plant growth and development. For instance, PEJIĆ *et al*. (2007) also have tested maize hybrids of different maturity groups on calcareous chernozem and have obtained the average irrigation effect of 25.9%. Furthermore, TAPANAROVA (2011) has recorded a higher average effect (34.5%) in the hybrid ZP 684 under conditions of irrigation. The author has also performed study on chernozem, with two dry out of the three years of investigation.

Different amounts of rainfall present during the growing season in the five-year investigation period resulted in the differences in maize grain yields between conditions with and without irrigation in the amount of 1.57 t ha^{-1} (rainfed - 11.89 t ha^{-1}, irrigation - 13,46 t ha^{-1}). All hybrids, even under conditions of insufficient soil moisture, expressed a relatively high genetic potential of the yield, but it has to be emphasised that applied sowing densities and fertiliser rates were appropriate for obtaining high yields on chernozem. Regardless of the variant of investigation, higher yields were recorded in hybrids of higher maturity groups. The highest average grain yield was recorded in the hybrid ZP 684 (13.41 t ha^{-1}), and then as follows: ZP 704 (12.99 t ha^{-1}), ZP 587 (12.50 t ha^{-1}), ZP 341 (12.24 t ha^{-1}) and ZP 434 (12.23 t ha^{-1}) (LSD: 0.05-0.2390, 0.01-0.3157). The greatest, i.e. lowest drought tolerance was found in the hybrid ZP 341, i.e. ZP 578, respectively.

CONCLUSION

The studies on dependence of five maize genotypes on the amount of water reaching the soil surface during the growing season were carried out on chernozem under rainfed and irrigation conditions. The gained five-year results show that water amounts significantly affected average yields of all genotypes in variants with and without irrigation: 1.33 t ha^{-1} (ZP 341); 1.53 t ha^{-1} (ZP 434); 1.77 t ha^{-1} (ZP 578); 1.66 t ha^{-1} (ZP 684) and 1.54 t ha^{-1} (ZP 704). The regression analysis indicates that maximum grain yields of genotypes can be expected with water amounts between 424 mm and 466 mm. The reduction of the water amount for every 10 mm decreased the yield by 119.4 kg ha^{-1} (ZP 341), 156.7 kg ha^{-1} (ZP 434), 172.3 kg ha^{-1} (ZP 578), 148.9 kg ha^{-1} (ZP 684) and 151.1 kg ha^{-1} (ZP 704). The greatest, i.e. lowest drought tolerance was found in the hybrid ZP 341, i.e. ZP 578, respectively.

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ZAVISNOST PRINOSA HIBRIDA KUKURUZA (Zea Mays) OD KOLIČINE VODE KOJA DOSPEVA NA POVRŠINU ZEMLJIŠTA

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R e z i m e

Cilj rada je bio proučavanje genotipova kukuruza u prirodnom i irigacionom vodnom režimu zemljišta, kako bi se utvrdila zavisnost korišćenja potencijala rodnosti od količine vode koja dospeva na površinu zemljišta u toku vegetacionog perioda. Ogled je izveden na černozemu, po metodi blok sistema u četiri ponavljanja. Predzalivna vlažnost zemljišta iznosila je oko 70% od poljskog vodnog kapacitete, a sadržaj vlage u zemljištu određivan je termogravimetrijskom metodom.

Za petogodišnji period proučavanja, različite količine vode uticale su da se izmedju varijanti sa i bez navodnjavanja, u proseku ostvare sledeće razlike prinosa po hibridima: 1,33 t ha^{-1}(ZP 341); 1,53 t ha^{-1} (ZP 434); 1,77 t ha^{-1} (ZP 578); 1,66 t ha^{-1} (ZP 684) i 1,54 t ha^{-1} (ZP 704). Analiza pokazuje da se maksimalni prinosi mogu očekivati na nivou sledećih vrednosti: 12,68 t ha^{-1} (ZP 341); 12,76 t ha^{-1}(ZP 434); 13,17 t ha^{-1} (ZP 578); 14,03 t ha^{-1}(ZP 684) i 13,75 t ha^{-1}(ZP 704) u uslovima, redom 440 mm, 440 mm, 424 mm, 457 mm, 466 mm vode. Najveću tolerantnost prema suši ispoljio je hibrid ZP 341, a najmanju ZP 578. Smanjenje količine vode za svakih 10 mm, umanjuje prinos za 119,4 kg ha^{-1} (ZP 341), 156,7 kg ha^{-1} (ZP 434), 172,3 kg ha^{-1} (ZP 578), 148,9 kg ha^{-1} (ZP 684) i 151,1 kg ha^{-1} (ZP 704).

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