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Influence of zinc application on grain yield and leaf surface of different maize genotypes

Gorica Cvijanović[1], Vesna Stepić[2], Marija Bajagić[3], Vojin Đukić[4], Jovana Sekulić[1], Vojin Cvijanović[5], Zlatica Miladinov[4]

[1]*University of Kragujevac, Institute of Information Technologies, Serbia*
[2]*Megatrend University Belgrade, Faculty of Biofarming, Serbia*
[3]*University of Bijeljina, Faculty of Agriculture, RS, Bosna and Herzegovina*
[4]*Institute of Field and Vegetable Crops, Novi Sad, Serbia*
[5]*Institute for Science Application in Agriculture, Serbia*

Abstract

Maize production is intensified with a larger amount of mineral fertilizers, which leads to a decrease in micronutrient reserves in the soil. As maize is grown in different regions, research aimed at achieving stable grain yields is very important in the era of climate change. The aim of this study was to determine the influence of zinc application on yield and leaf mass area of three maize genotypes. A three-factorial experiment was performed in the Mačva region. For plant nutrition, 160 kg ha^{-1} of nitrogen was provided (30 kg ha^{-1} in basic cultivation, 90 kg ha^{-1} in pre-sowing, and 40 kg ha^{-1} in top dressing). Factor A are the years of research in the 2016-2018 period. Factor B: three hybrids ZP 427, ZP 548, and ZP 684. Factor C are different treatments, i.e., Zn_0 - control, Zn_1 - $ZnSO_4$ 25 kg ha^{-1} was introduced into the soil before sowing, and Zn_2 - seed treatment + foliar treatment. For seed treatment before sowing, 63 grains were immersed for 24 h in aqueous $ZnSO_4$ solution (0.129 g and supplemented with 200 ml of water). Sowing was done in the first ten days of April. Foliar treatments were done in the phenophase of 5-7 leaves with 2 l ha^{-1} liquid fertilizer (7% Zn). The grain yield of hybrids was highly influenced by the year. Treatments and their interactions significantly increased grain yield $p<0.05$. Compared to the control, Zn_1 increased grain yield by 14.56% and Zn_2 by 14.17%. The ZP 684 hybrid had the highest average yield. Leaf surface was highly influenced by all examined variables and their interactions. In 2018, the leaf surface was on average 3.24% higher than in 2017. The ZP 684 hybrid had the largest leaf surface, 8.30% higher than the ZP 548 hybrid, and 25.10% higher than the ZP 427 hybrid.

Key words: corn, zinc, grain yield, leaf surface

Introduction

Maize is one of the most common cereals for human and animal consumption. In terms of maize production, it ranks third with an estimated world production of 1,186 million metric tons in 2020. The increase in maize production intensifies inversely proportional to the areas. There is a need to increase production because it is used not only as a food source but also for other purposes (in industry and as an alternative fuel) **(**Budakli et al., 2010**).** Forecasts show that by 2025, world maize production will increase significantly, while the need for this crop will double by 2050 in developing countries (Rosegrant et al., 2008). Higher maize production has been the result of work on fertilization of maize plants of different physiological and phenotypic characteristics, adapted to different agroecological conditions, pronounced resistance to chemical agents, high genetic yield potential, and improved grain nutritional properties (Ferreira et al., 2014). A large number of studies relate to the application of various agrotechnical measures in achieving the genetic potential of fertility in conditions without irrigation systems. Since corn provides a large amount of biomass and grains, a large number of data can be found in the literature in which the influence of N on increasing yields and improving yield components can be examined and confirmed. Lin and Xing (2007) observed that zinc oxide nanoparticles colonize the root surface, pass through the root surface, and enter cells. For the uptake of zinc in plants, it is necessary that the zinc in the rhizosphere be in soluble form. In the soil solution, zinc does not stay in free form for a long time, but binds to colloids and precipitates with various anions. About 50% of the soluble fraction of zinc is Zn^{+2} and is the most important accessible form for plants. Out of the total amount of zinc absorbed, 15% is based on direct root contact (Kastori et al., 2020).

For the stable production of corn, the presence of microelements is necessary, primarily Zn. It is hypothesized that this microelement strongly affects corn in the critical phase of grain formation, which in turn affects the final grain yield. Zinc deficiency can reduce grain yield by up to 80% (Alloway, 2009). The importance of zinc fertilization for the early growth of maize plants is shown in the research done by Liu et al. (2016). The authors found that the use of zinc increases the intensity of photosynthesis in the leaf development phase. Zinc can be applied through soil, foliar treatment, or treatment of seeds. By applying zinc over the soil, in combination over soil + foliar application, and in combination foliar application + seed treatment before sowing, it increases the yield compared to the control by about 260%, while foliar application increases it by 204%. The aim of this study was to determine the yield and leaf surface of different maize genotypes in two years with very different agroecological conditions.

Materials and Methods

Design of experimental research

The experiment was set up during 2017-2018 on a plot in the municipality of Vladimirci, Mačva region (ΨN 44°36′ 31.8″, λE 19°47′4.2″). The area of the basic plot was 14 m^2. For each applied factor, 4 rows were sown. The plots were set according to the plan of divided plots in three repetitions. The pre-sowing crop in each study year was wheat. All agro-technical measures have been implemented within optimal deadlines. The total supply of nitrogen was 160 kg ha^{-1} (primary tillage 30 kg ha^{-1}, pre-sowing 90 kg ha^{-1}, and in top dressing 40 kg ha^{-1}).

Factor A: Meteorological conditions (temperature and precipitation) were taken into account because they differed significantly.

Factor B: Three hybrids, yellow grain tooth type, selection of the Institute for Maize Zemun Polje ZP 427 (FAO 400); ZP 548 (FAO 500); and ZP 684 (FAO 600).

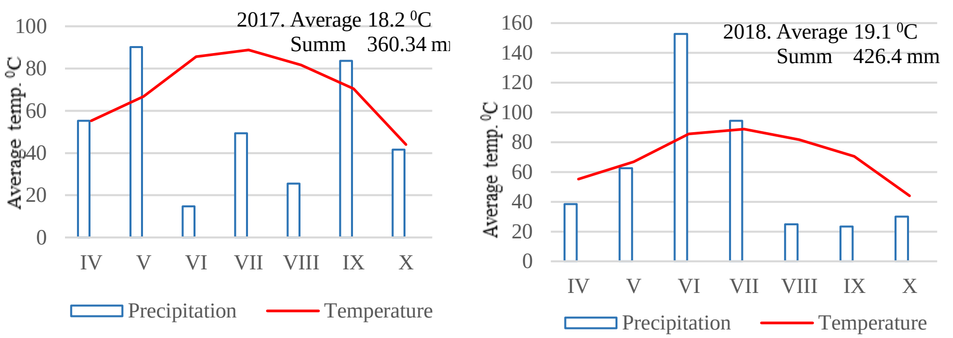
Factor C: Different zinc treatments were applied: Zn_0-control; Zn_1 - before sowing it was applied onto the ground $ZnSO_4$ 25 kg ha^{-1}; Zn_2 - before sowing + foliar treatment. Zinc sulfate $ZnSO_4$ was applied to the seed (63 seeds were kept in the dark for 24 hours in the solution of 0.129 g $ZnSO_4$ with 200 ml water). The seeds were dried on filter paper. Foliar treatment was done in the phenophase of 5-7 leaves. 2 l per ha of liquid fertilizer Nutri Znic Pro (Agrohemical) was applied. The fertilizer is used for fertilization of different plant species on different types of soil, for foliar applicaiton and through irrigation systems. Nutri Znic Pro contains a total of 7%, zinc (EDTA) 3,5%.

The leaf surface from the whole plant in the tasselling phase was determined. At the end of vegetation, grain yield was measured and calculated at 14% moisture. To evaluate data, wa descriptive statistics and analysis of variance (ANOVA) in DSAASTAT program were used. Three-way ANOVA was used to test the effects of year, genotype, treatment, and growing season. All results were calculated at a significance level LSD of 0.01 and 0.05.

Results and Discussions

Meteorological conditions (temperature and precipitation) for the 2017-2018 period

The average daily average temperatures during the vegetation period in 2017 (18.2°C) and 2018 (19.2°C) were optimal for maize development. The total amount and distribution of precipitation differed significantly by year. In 2017, the amount of precipitation was lower by 66.1 mm. During the month of May, in the phases of vegetative development of V3 plants in 2018, a lower amount of precipitation was measured, by 69.5 mm, compared to 2017, which did not significantly affect the further development of plants. However, the pronounced differences were in the June-July period, with 66.1 mm of rainfall in 2017 and 123.2 mm in 2018. In September 2017, a higher amount of precipitation was recorded, which did not affect the yield because the reserve of moisture in the soil was missing (Graph 1).



Graph 1. Average monthly temperatures (°C) and sum of precipitation (mm) for the vegetation period of maize. (*Source: Meteorological Station of the Sremska Mitrovica)*

Maize grain yield

Based on the analysis of variance, it was determined that the sources of variation had different effects on the yield and leaf area (Table 1).

Tab. 1. Results of three-factor analysis of variance on average for the effect of zinc treatment on grain yield and corn leaf area in two production years

Sources of variations	Grain yield		Leaf area	
	F	p-level	F	p-level
Year (A)	1682.41	0.00**	140.284	0.01**
Hybrid (B)	0.24	0.79^{ns}	6954.139	0.00**
Treatments (C)	4.69	0.04*	299.011	0.00**
Year x Hybrid (AB)	4.25	0.03*	1584.485	0.00**
Year x Treatment (AC)	2.04	0.15 ^{ns}	149.410	0.00**
Hybrid x Treatment (BC)	3.89	0.01*	712.524	0.00**
Year x Hybrid x Treatment (ABC)	3.27	0.03*	88.023	0.00**

In two-year average the grain yield was 5.64 t ha^{-1} (Table 2). In different meteorological conditions (A), maize yields varied in correlation with the amount of precipitation and its distribution, and the differences were very significant. So in 2018, the yield was 7.91 t $ha^{-1}$and 3.62 t ha^{-1} in 2017. Compared to 2017, the difference of 4.29 t ha^{-1} grain is the result of uneven distribution of precipitation and strong drought in the generative phases of maize development. In the AB interaction, differences in grain yield were significant at the level $p \leq 0.05$. In 2018, the ZP 427 hybrid had a significantly higher yield (8.64 t ha^{-1}), compared to the other two hybrids. ZP 427 belongs to an early ripening group and had more favourable meteorological conditions in the critical stages of development. Çakir (2004) found that all vegetative parameters and maize yield are significantly affected by lack of water in the soil during sensitive phenophases of generative growth. Pandey et al. (2000) found that the reduction in maize grain yield is almost proportional to the duration of the water deficit during the growing season. The characteristics of hybrids (B) did not significantly affect the yield level individually by year, but the interaction with treatments was significant. The hybrid had the highest grain yield, on average per treatment ZP 687 (5.65 t ha^{-1}), which was by 1.98% higher than ZP 548 and by 1.38% than the ZP 427 hybrid. The effect of treatment with zinc (C) was significant in terms of yield. By bringing zinc into the soil Zn_1 (5.90 t ha^{-1}), a significant difference was made from +6.30% relative to Zn_0 (5.15 t ha^{-1}). In relation to treatment Zn_2 (5.88 t ha^{-1}), there was a difference + 0.34%, but without significance. If the years are observed individually, treatment Zn_1 in 2017 increased the yield compared to Zn_0 by 9.34% and Zn_2 by 1.13%. In 2018 treatment Zn_1 increased the yield by 14.56% compared to Zn_0, Zn_2 by 14.17%. From the presented results, it can be noticed that in the year that is favourable for production, the use of zinc in both treatments had a greater impact on the yield. The hybrid had the highest yields according to the treatments ZP 427 (Zn_1 7.15 t ha^{-1} and Zn_2 6.00 t ha^{-1}). Both treatments significantly increased yield compared to control (5.05. tha^{-1}) and grain yields of the ZP 548 and ZP 684 hybrids. Treatment Zn_2 had a greater impact on the ZP 548 and ZP 684 hybrids than Zn_1, while in the ZP 427 hybrid it was reversed.

Tab. 2. Influence of zinc treatment on grain yield of different maize hybrids (t ha^{-1})

Year (A)	Genotype (B)	Treatments (C) Zn_0	Zn_1	Zn_2	$\bar{x}$ AB	$\bar{x}$ A
2017	427	3.10	3.97	3.41	3.49	3.62
	548	3.41	3.61	3.66	3.64	
	684	3.55	4.00	3.63	3.73	
$\bar{x}$ AC		3.53	3.86	3.57		
2018	427	7.00	10.33	8.58	8.64	7.91
	548	6.80	7.61	8.18	7.53	
	684	8.01	6.87	7.83	7.57	
$\bar{x}$ AC		7.27	8.27	8.20	$\bar{x}$ B	
$\bar{x}$ BC	427	5.05	7.15	6.00	5.57	
	548	5.10	5.61	5.92	5.54	
	684	5.78	5.43	5.73	5.65	
$\bar{x}$ C		5.15	5.90	5.88		
Average 2017-2018					5.64	

	A^{**}	B^{ns}	AB*	C*	AC^{ns}	BC^{*}	ABC*
LSD $_{0.01}$	0.39	1.33	1.88	0.53	0.75	1.31	1.25
LSD $_{0.05}$	0.50	0.99	1.29	0.72	1.02	0.92	1.77

Considering the availability of zinc for plants, Holloway et al. (2010) indicated that the mass and distribution of roots in the soil profile, as well as the uneven distribution of zinc particles when introduced into the soil, could have a significant impact (Ryan et al., 2013). Seed treatment with foliar treatment had less effect on the yield. Although the seed treatment is applied in order to improve germination and uniform germination, and the foliar diet retains the applied ion, the yields were not significantly higher compared to the application of zinc in the soil. Fageria (2002) pointed out that the effect of foliar treatment of crops may have little impact, because different responses of hybrids and varieties to different forms of applied zinc, as shown for barley (Moshfeghi et al., 2019).

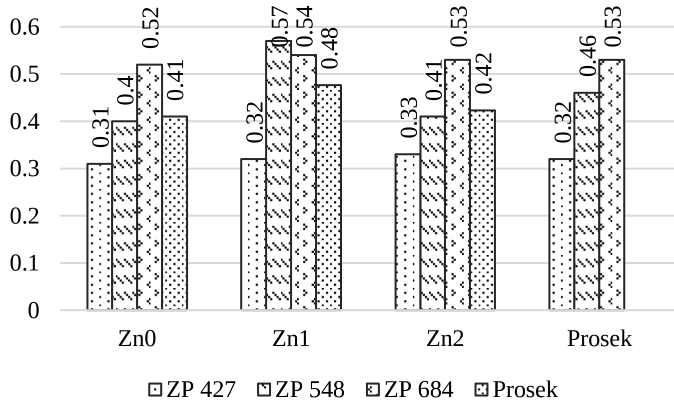
All examined variables and their interaction relationship had a very significant impact on the leaf surface (Table 3). In 2018, the leaf surface was on average 3.24% higher (700.10 cm^2) than in 2017 (678.10 cm^2), which is the result of a small amount of precipitation in the phases of intensive plant growth. In both years of research, the ZP 684 hybrid had a larger leaf surface, which averaged 759.27 cm^2, and the ZP 427 (606.98 cm^2) hybrid had the smallest, which is the result of different characteristics specific to maize ripening groups. Both zinc treatments significantly increased the leaf surface. The treatment Zn_1 (710.04 cm^2) increased the leaf surface in relation to Zn_0 (643.46 cm^2) by 10.34%, and in relation to the application of Zn_2 (713.80 cm^2) by 10.90%.

Tab. 3. Influence of zinc treatment on the leaf surface of different maize hybrids (cm^2)

Year (A)	Genotype (B)	Treatments (C)			$\bar{x}$ AB	$\bar{x}$ A
		Zn_0	Zn_1	Zn_2		
2017	427	501.99	635.61	595.17	577.59	678.10
	548	659.23	741.11	695.35	698.56	
	684	694.40	745.89	834.13	758.14	
	$\bar{x}$ AC	618.54	707.54	708.22		
2018	427	626.24	664.62	618.23	636.36	700.10
	548	666.85	752.39	691.39	703.54	
	684	712.05	720.60	848.55	760.40	
	$\bar{x}$ AC	668.38	712.54	719.39		
$\bar{x}$ BC	427	564.12	650.12	606.70	606.98	
	548	663.04	746.75	693.37	701.05	
	684	703.23	733.25	841.34	759.27	
	$\bar{x}$ C	643.46	710.04	713.80		
	Average 2017-2018				689.10	

	A**	B**	AB**	C**	AC**	BC**	ABC**
$LSD_{0.01}$	6.23	4.37	6.18	3.93	5.56	6.81	9.6
$LSD_{0.05}$	7.99	3.01	4.25	2.90	4.10	5.03	7.11

According to Basit et al. (2021), treatment of maize seeds with $ZnSO_4$ significantly increases the content of chlorophyll in the leaves and the intensity of photosynthesis compared to the control. Tondey et al. (2021) and Faizan et al. (2018) found that nanoparticles of zinc oxide (ZnONPs 40 mg L^{-1}) in maize significantly increase the content of total chlorophyll, carotenoids available nitrogen, and phosphorus in the soil, increases the total number of microbes in the soil and the activity of soil enzymes (dehydrogenase, acid and alkaline acid, and alkaline enzymes). Increasing the content of photosynthetic pigments leads to an increase in photosynthetic activity, which affects the increase in yield and nutritional properties of plants (Kolencík et al., 2019). They also pointed out that seed treatment improves the vegetative growth of corn in the field, and that this can be attributed to the role of Zn in the production of tryptophan - a precursor of the phytohormone indole-3-acetic acid. In addition, zinc plays the role of a cofactor in the physiological processes of plants for the efficient work of six enzymes (Estrada-Urbina et al., 2018**)**. Based on the results of the impact of treatment on the leaf area, and the calculated leaf area index (LAI), the intensity of photosynthesis can be assessed by individual treatments. Zn_1 treatment had on average the greatest impact on leaf mass index ranging from 0.41 to 0.53 (Graph 2).



Graph 2. Leaf mass index of different hybrids depending on the applied treatments

Conclusion

The corn grain yield in the years of research was largely influenced by climatic factors, while interactions with hybrids and zinc affected grain yield at the level of significance $p<0.05$. In 2018, which had a more favourable precipitation schedule, a significantly higher yield was achieved. The ZIP 427 hybrid had the highest average yield of 8.64 t ha^{-1}. Both zinc treatments at the significance level $p<0.05$ affected the difference in yield compared to the control. With the application of zinc to soil, yield increased by 6.30%, and the application of zinc to seeds and top-dressing by 0.34%. The ZP 684 hybrid had the highest yield for all treatments (5.64 t ha^{-1}), but without statistically significant differences compared to other hybrids. The leaf surface was under a very significant influence of the examined variables. In 2018, hybrids had an increase in leaf mass by 3.24% compared to 2017. The hybrid ZP 684 had the largest leaf surface. It was 8.30% higher than the leaf surface of the ZP 548 hybrid, and 25.10% higher than the ZP 427 hybrid.

In general, it can be concluded that the use of zinc can achieve higher yields even in unfavourable climatic conditions. The application of zinc in the soil in a higher percentage affected the achieved grain yield in all three maize hybrids. Further research should focus on zinc concentration in the grain.

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Утицај примјене цинка на висину приноса зрна и површину лисне масе различитих генотипова кукуруза

Горица Цвијановић[1], Весна Степић[2], Марија Бајагић[3], Војин Ђукић[4], Јована Секулић[1], Војин Цвијановић[5], Златица Миладинов[4]

[1]*Универзитет у Крагујевцу, Институт за информационе технологије, Србија*
[2]*Мегатренд универзитет, Факултет за биофарминг, Београд, Србија*
[3]*Универзитет у Бијељини, Пољопривредни, Република Српска, Босна и Херцеговина*
[4]*Институт за ратарство и повртарство Нови Сад, Србија*
[5]*Институт за примену науке у пољопривреди, Србија*

Сажетак

Производња кукуруза је интезивирана већом количином минералних ђубрива што доводи до смањивања резерви микроелемената у земљишту. Обзиром да се кукурз гаји на различитим регионима, у ери климатских промјена, веома су значајна истраживања која имају за циљ постизање стабилних приноса зрна. За циљ рада је постављено да се утврди утицај примјене цинка на висину приноса и површину лисне масе три генотипа кукуруза. Трофакторијалан експериментали оглед је постављен у региону Мачве. Фактор А су године истраживања у периоду 2016-2018. Фактор Б: три хибрида ЗП 427, ЗП 548, ЗП 684. Фактор Ц су различити третмани: Zn_0 – контрола, Zn_1 - у земљиште је пред сјетву унијето $ZnSO_4$ 25 kg ha^{-1} и Zn_2 - третман сјемена + фолијарни третман. За исхрану биљака обезбијеђено је 160 kg ha^{-1} azota (30 kg ha^{-1} у основној обради, 90 kg ha^{-1} предсјетвено и 40 kg ha^{-1} у прихрани). Третман сјемена: Пред сјетву 63 зрна је потопљено 24 h у водени раствор $ZnSO_4$ (0,129 g и допуњено са 200 ml воде). Сјетва је обављена у првој декади априла. Фолијарни третмани у фенофази 5-7 листова са 2 l ha^{-1} течног ђубрива (7% Zn). Принос зрна хибрида био је под високо значајним утицајем године. Третмани и њихове интеракције су значајно повећали принос зрна $p<0.05$. У односу на контролу, третман Zn_1, је за 14,56% повећао принос зрна, а Zn_2 за 14,17%. Хибрид ЗП 684 имао је највећи просјечан принос по свим третманима. Површина лисне масе била је под високо значајним утицајем свих испитиваних варијабли и њихових интеракција. У 2018. години површина лисне масе у просјеку била је за 3,24 % већа него у 2017. Хибрид ЗП 687 је имао највећу површину лисне масе, већу за 8,30% од хибрида ЗП 548, и за 25,10% од хибрида ЗП 427.

Кључне ријечи: кукуруз, цинк, принос зрна, површина лисне масе

Corresponding author: Gorica Cvijanović
E–mail: cvijagor@yahoo.com
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