EFFECTS OF DIFFERENT VARIANTS OF STERILE AND FERTILE PLANTS ON MAIZE HYBRID YIELDS

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Abstract
Maize is a very important field crop according to both, its distribution and sown areas. The possibility of different utilisation of maize for food, feed and industrial processing is greatly contribute to high economic significance of this crop. The aim of conducted studies was to determine the effect of various proportions of fertile and sterile plants on the yield by performing trials in a certain location. The three-replication trial was set up according to the randomised complete block design in the location of Zemun Polje under conditions dry land farming. A mixture of different variants of sterile and fertile plants of the commercial hybrid ZPSC 341 was made. Statistical data processing included the analysis of variance according to the randomised complete block design, regression and correlation analyses of grain yield and the percentage of fertile plants in the hybrid ZPSC 341, in order to determine the changes in grain yields in relation to the percentage ratio of sterile to fertile plants. Obtained results indicate that the highest (15.472 t ha^{-1}), i.e. lowest (14.046 t ha^{-1}) average yield was recorded in the hybrid with 80%, i.e. 5% fertility, respectively. The coefficient of correlation points to a weak dependence of the yield and the fertility percentage (rxy=0.101). Based on the coefficient of determination, the percentage dependence between the yield and the percentage of fertile plants was low (R^2=0.010).

Keywords: cytoplasmic male sterility, maize, yield.

Introduction

Maize (*Zea mays* L.), alongside with wheat and rice, is the most important crop in the modern global agricultural production. Based on sown areas and the production, maize ranks third and second, respectively (Glamočlija, 2004). The first description of male sterility was provided by Rhoades (1931). Further researches showed that cytoplasmic factors were responsible for sterility. Cytoplasmic male sterility (CMS) refers to the inability of the plant to produce functional pollen. This trait is conditioned by mutations in the mitochondrial genome, so it is transmitted through the cytoplasm, i.e. it is not transmitted by pollen and is not subjected to the Mendelian inheritance. CMS has found its application in the production of hybrid maize seed, because this production is based on the sterility and therefore it is not necessary to detassel female inbred lines. Maize hybrids developed on the sterile basis are derived by crossing of the female component with a sterile cytoplasm, and the male component with restorer genes for that type of sterility in the nuclear genome, so that male fertility would be restored in the F1 generation, i.e. in the hybrid. Along with the introduction of such a system in the hybrid production, studies on effects of CMS on traits of maize genotypes have been initiated. Many unrelated studies have shown a positive effect of cytoplasmic male sterility on maize grain yield, especially under adverse conditions of drought, deficit of water and nutrients.

Nitrogen requirements of sterile plants are lower by approximately 10-30 kg ha^{-1} than of fertile plants, hence this amount of nutrients instead of being used to form pollen is directed into female reproductive organs, thus resulting in the grain yield increase. The sink strength of maize ears is great and they continuously import N assimilates during grain filling (Hirel et al., 2005). On the other hand, CMS plants may store and redirect nitrogen into the ear so as to contribute to a higher grain yield. Reduced consumption of nitrogen, water and energy for pollen formation in sterile plants during the flowering period may result in a greater number of kernels per ear (Vega et al., 2001). Moreover, the cultivation of commercial crops in this way can prevent contamination by genetically modified (GMO) pollen, in case the sterile hybrid is genetically modified. Considering that the production of sterile hybrids is not more complicated than the production of fertile ones, the proposed production system may be a simple answer to the constant requirements for increasing maize yield without increasing the cultivation areas. The main goal in the commercial maize production is the highest possible grain yield, along with other favourable agronomic traits. Increasingly strong competition in the maize seed market requires studies on the effect of the type of cytoplasm and its interaction with a genotype on yield and some morphological traits for the purpose of the production.

Material and methods

Total of 21 mixtures of 0, 5, 10, …up to 100% fertile plants mixed with the sterile variant of the hybrid ZP 341 were made and used as a basic material. In order to control reliability of the experiment, the original fertile hybrid ZPSC 341 was included three times as a check (ZPSC 341 from manual pollination, ZPSC 341F1 and ZPSC 341 from reciprocal crossing). The ZPSC 341 is a medium early maturity hybrid belonging to the FAO maturity group 300-400 and it has been developed at the Maize Research Institute, Zemun Polje and has been used in the commercial production for years.

Material and methods in performing field trials

The three-replication trial was set up according to the randomised complete block design in the location of Zemun Polje in 2013. The elementary plot size was 5.18 m^2. The plot consisted of two rows with the inter-row distance of 0.7m, 10 hills with the inter-hill distance of 0.37m and 2 plants per hill. Sowing was done manually on the chernozem type of soil in the first week of May. The common cropping practices were applied: autumn ploughing; seedbed preparation; crop cultivation was done immediately after sowing when herbicides were sprayed (2 L Acetochlor ha^{-1} (a.i. acetochlor)), while corrective spraying was done after emergence at the 3-4-leaf stage (1 L Motivell ha^{-1} (a.i.nicosulfuron) + 0.25 L Callisto ha^{-1} (a.i. mezotrion)). The total number of plants, including a separate number of both, fertile and sterile plants, were recorded for each elementary plot during the pollen season. Harvest was done manually at the stage of physiological maturity. A sample of five ears was taken from each plot to analyse agronomic traits. After harvest, samples were placed in a dryer at 35°C for several days to achieve equilibrium moisture.

Methods of experimental data processing

Statistical data processing encompassed the following: analysis of variance according to randomised complete block design, regression analysis and correlation analysis of grain yield and the percentage of fertile plants in the hybrid ZPSC 341, in order to establish the changes in grain yields related to the sterile to fertile plants ratio (Hadživuković, 1991).

Results and discussion

According to data presented in Table 1, it is obvious that the highest (15.472 t ha^{-1}), i.e. lowest (14.046 t ha^{-1}) average yield was recorded in the hybrid with 80%, i.e. 5% fertility (ZPSC 341F1), respectively. Based on the findings, it was concluded that the soil quality and climatic conditions were of crucial importance in the given location. Similar studies have been performed by

Weingartner et al. (2002b). These authors pointed out that sterility affected the yield increase in maize hybrids, but not significantly. Munsch (2008) has observed 12 hybrids with different types of sterility and determined that the effect of CMS on grain yield varied from - 8% to +8%. Although the type of cytoplasm was not decisive, three hybrids with the C type of cytoplasm expressed a consistent growth of the number of kernels (8.7%, without significance), while one hybrid with the type T of cytoplasm had a significantly lower 1000-kernel weight (-8%, $p<0.05$). On the other hand, Uribelarrea et al. (2002) have compared CMS and detasselled hybrids with their fertile versions and did not determine the yield increase. This is, to a certain extent, explained by modern hybrids that have smaller tassel and higher tolerance to stress (Duvick, 2005).

Table 1. Average yield and its interval variation for the check and different levels of the fertility percentage

Ordinal number	% Fertility	Average yield t ha^{-1}	95% confidence interval for mean yield	
			Lower limit	Upper limit
1	ZP341manual	14.956	11.710	18.202
2	ZP341F1	15.278	13.532	17.024
3	ZP341Rec.	15.178	11.779	18.577
4	0%	14.558	12.819	16.296
5	5%	14.046	10.127	17.965
6	10%	15.087	14.389	15.784
7	15%	14.747	10.666	18.828
8	20%	14.905	12.690	17.119
9	25%	14.771	12.942	16.600
10	30%	14.767	12.578	16.957
11	35%	14.787	13.522	16.053
12	40%	15.148	13.691	16.605
13	45%	14.951	12.145	17.757
14	50%	15.282	15.154	15.409
15	55%	14.932	12.030	17.834
16	60%	15.197	10.769	19.624
17	65%	14.911	14.088	15.734
18	70%	14.688	12.469	16.907
19	75%	14.393	14.037	14.749
20	80%	15.472	12.905	18.038
21	85%	15.197	11.029	19.365
22	90%	14.612	13.003	16.221
23	95%	14.554	13.123	15.984
24	100%	14.519	12.854	16.184

Furthermore, Kaeser (2002) carried out studies on the effects of both, sterile cytoplasm and types of cytoplasm on maize grain yield. Higher grain yields were established in all observed sterile hybrids with all types of cytoplasm in comparison to their fertile counterparts, which was a result of the increased number of kernels per area unit, and of a greater 1000-kernel weight registered in some hybrids. It was also observed that the yield of sterile hybrids were more stable under stress conditions. According to everything stated, it can be concluded that the V generation of ZP hybrids (FAO 300-400) expressed exceptional potential and stability of yield. Moreover, the growing season of these hybrids is shorter and the moisture content at harvest is significantly lower, which is a great advantage due to reduced costs of drying and storing. Results presented in Table 2, indicate that different ratios of sterile to fertile components in the mixtures of seed used for sowing do not significantly affect yield ($r=0.101$).

Table 2. Correlation coefficient of yield and fertility percentage

Location	rxy
Zemun Polje	0.101

In addition, an effect of each independent variable (relative humidity) on a dependable variable (yield) cannot be determined (Table 3). A low effect of various fertile to sterile component ratios is observable over small coefficients of regression (β). Their contribution to the modification of the yield is only 1.0 % (R^2).

Table 3. The values of parameters of quadratic regression model and coefficient of determination

Location	β_0	β_1	β_2	R^2
Zemun Polje	7E-05X^2	0.0082X	11.136	0.010

The coefficient of determination shows the variation of the trait (in this case the yield) and this variation amounted to 0.010. Based on the value of the coefficient of determination it is observable that the percentage dependence is small, which points out that the encompassed variability percentage of factors affecting yield variability was not great. The equation of the estimated quadratic regression is schematically presented in Figure 1, whose abscissa represents the percentage of fertile plants, while its ordinate represents the maize yield. Beside the estimated quadratic regression, Figure 1 shows the value of the coefficient of determination, which shows the extent to which the yield variability of maize is affected by the variation of the percentage of fertile plants. The coefficient of determination in the location of Zemun Polje (0.010) is presented within Figure 1.

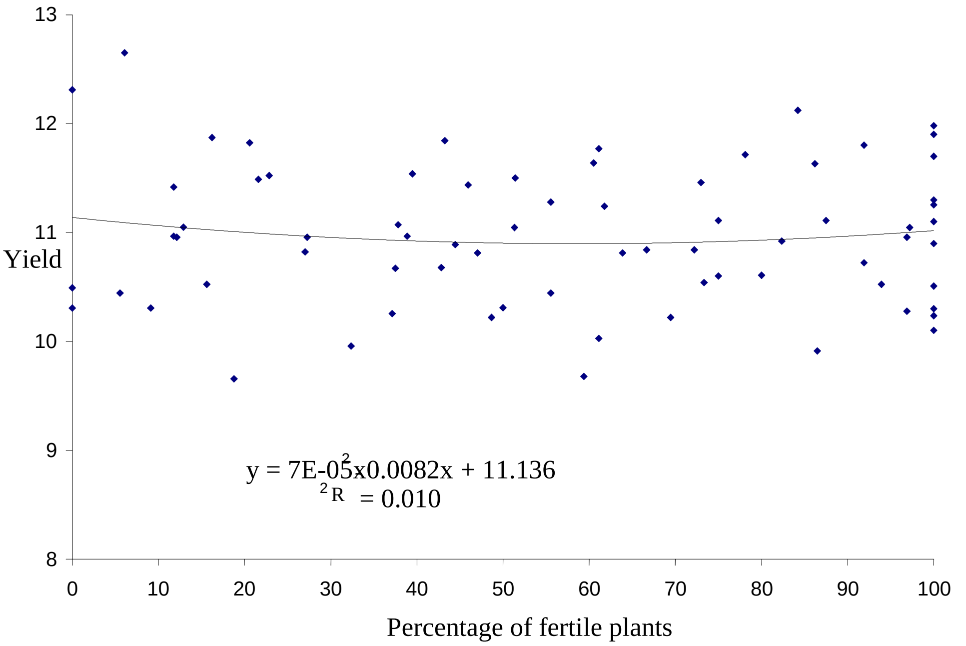

Figure 1. Equation of the estimated quadratic regression for the location of Zemun Polje

The regularity of effects of the percentage of fertility on yield is not observable in Figure 1, which indicates the possibility of their independence.

Conclusions

According to results obtained on the seed production of the commercial hybrid ZPSC 341, i.e. on effects of different percentages of fertile and sterile plants on the yield of the hybrid ZPSC 341, the following may be concluded:

The effect of the location on maize grain yield was significant;

Environmental conditions significantly affected variation of yields over locations;

The highest average yield was 15.472 t ha^{-1};

The lowest average yield was 14.046 t ha^{-1};

80% of fertile plants was the most favourable fertile to sterile variant ratio;

5% fertility was the least favourable ratio;

Coefficients of correlations were positive, but there were no statistical significances of yield and the fertility percentage.

Although obtained results do not provide sufficient information to establish the optimum ratio of sterile to fertile variant of the hybrid ZPSC 341 for the purposes of its commercial production, there are a lot of reasons to assume that the previously applied fertile to sterile variant ratio of 75% to 25% is most likely the optimum ratio for the commercial production of the hybrid ZPSC 341.

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