

STUDIES ON THE ADAPTABILITY OF MAIZE HYBRIDS UNDER VARIOUS ECOLOGICAL CONDITIONS

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Abstract

The adaptability of twelve single cross maize hybrids was investigated at five different locations in Hungary over a three-year period. The characters examined were individual plant production (total mass of the ears on a single plant), thousand kernel mass, number of kernel rows, ear length, number of kernels per row, shelling % and the assimilating leaf area above the main ear.

Among these yield components, the individual plant production, the ear length, the number of kernels per row and the grain-cob ratio (shelling %) were influenced to the greatest extent by the year, followed by the variety and the location. The greatest average yield was achieved by the tested hybrids at all five locations in 1997 (263 g/plant). The average yields in 1998 and 1999 were significantly lower (221 and 203 g/plant, respectively). The outstanding yields achieved in 1997 could be attributed to the favourable ecological conditions, which led to the development of secondary ears in Keszthely and Sopronhorpács. At the other three locations there was only one ear per plant, but these ears were longer than in the following years. The greatest year effect was recorded in Sopronhorpács, where the individual plant production amounted to 305 g/plant in 1997 and 238 g/plant in the worst year, 1999. In Gyöngyös conditions were very dry in all three years, so the year effect was least pronounced at this location (grand mean of 195 g/plant in 1997 and 201 g/plant in 1999). Stability analysis was carried out using the coefficient of variance for individual plant production. Hybrids Mv 3, Mv 5, Mv 9 and Mv 12 were found to have the best adaptability. The shelling % was not significantly influenced by the location; the grain-cob ratio is relatively stable for maize hybrids. A correlation was found between the individual plant production and the leaf area above the main ear ($R^2=0.66$). Hybrids with the largest leaf area above the main ear also had the greatest ear mass.

Key words: maize hybrid, adaptability, location effect, year effect, yield, yield components, assimilating leaf area

Introduction

The behaviour of maize hybrids in response to production and ecological factors can be described in terms of their adaptability or yield reliability. Maize is produced under varying ecological conditions. Agroecological factors can be divided into two fundamental groups: climatic factors (temperature, light, precipitation, relative air humidity) and edaphic (soil-linked) factors (Villax, 1944). Maize has great adaptability, so the soil is not as important in determining yields as in other crops. Precipitation and temperature, however, are important production conditions. Under Hungarian conditions the quantity and distribution of rainfall during the vegetation period is unfavourable (Marton *et al.*, 1999). In an analysis of the agrometeorological conditions required for maize production, Polerecky (1976) found that 155–180 mm rainfall was required in July and August if high yields were to be achieved. Berényi (1945) also considered that under Hungarian production conditions the most critical month as regards rainfall was July, when the crop has the greatest water requirements, but there is very little rainfall at most locations. According to this author, fluctuations in rainfall quantities in July have a greater influence on the grain yield than variations in the temperature. A correlation coefficient of 0.6–0.8 was found between maize yields and the rainfall sum in July.

A wise choice of hybrid is an important factor in making maize production profitable. Varieties capable of high yields in favourable years and satisfactory yields in dry years should be given preference. The yield stability of the hybrids can be estimated from the yield fluctuations over years and locations (Szél, 1998).

Values of the heritability index (h^2) of maize yield components were reported by Hallauer and Miranda (1981), who found that the number of kernel rows was the yield component least influenced by environmental conditions ($h^2=0.57$), while the yield ($h^2=0.18$), the thousand kernel mass ($h^2=0.28$), the number of ears per plant ($h^2=0.39$) and the ear length ($h^2=0.38$) were controlled by a large number of genes and were thus more sensitive to changes in the environment. The most important of the yield components are the number of ears per plant, the number of kernel rows, the thousand kernel mass and the grain-cob ratio, or shelling percentage. According to Kapás (1961) the year had the greatest influence on the number of ears per plant, but also exerted a substantial effect on the thousand kernel mass. Averaged over locations and varieties, the year had no effect on the number of kernel rows or the grain-cob ratio. The present authors also found that the shelling % (grain-cob mass ratio) was a stable index of the hybrids, which was not modified by the location (Gyenesné, 2000, Gyenesné *et al.* 2002).

The influence of environmental factors on the harvest index was investigated by Vulchinkov *et al.* (1995), who found that the year had the greatest effect. Other authors (Horner *et al.*, 1971; Kim, 1975) also reported that the grain yield and the thousand kernel mass were influenced by the environment, being modified not only by the location but also by the year. Dornescu (1979) also found that the location and the year had a substantial influence on the manifestation of heterosis. Among the yield components, the ear length was studied by Pavlicic (1974) and was found to be more dependent on the temperature and the humidity than on the genotype. Salazar and Hallauer (1986) carried out mass selection for ear length. The subpopulation from which the longest ears were selected had the most sensitive response to environmental effects. In experiments conducted by Mathur *et al.* (1997) the relationship between the yield components (number of kernel rows, kernel number, ear length, thousand kernel mass) and the grain yield remained constant and was not influenced by the environment to the least extent. In studies on variability in the yield components, Veneni (1974) reported that the kernel mass per ear was the most variable over years and varieties (CV=16.8–35.4 %), followed by the ear length (CV=9.2–15.6 %) and the ear diameter (CV=4.66–8.24 %). Stability analysis on yield components (Gyenesné *et al.*, 2002) revealed that the most variable traits were the individual ear mass production (CV=9.3–42.4 %), the grain mass (CV=17.5–30.0 %) and the thousand kernel mass (CV=11.1–20.3 %). Moderate variance was recorded for the length of the main ear (CV=7.1–13.3 %), while the number of kernel rows proved to be the least variable, being relatively insensitive to the environment (CV=6.6–9.2 %).

Materials and Methods

Twelve hybrids (Mv 1– Mv 12) were produced from seven inbred maize lines in the nursery of the Agricultural Research Institute of the Hungarian Academy of Sciences in 1996. From 1997 to 1999 these hybrids were tested at five locations (Keszthely, Gönc, Gyöngyös, Sopronhorpács, Martonvásár) in a random block design with three replications. The locations were chosen to give a good representation of the ecological differences existing within Hungary. The hybrids were sown at a plant density of 68,880 plants/hectare. The experimental soil was chernozem in Martonvásár and Gyöngyös and brown forest soil in Keszthely, Gönc and Sopronhorpács.

Morphological traits (length and breadth of the leaf next to the ear) were measured in the field after flowering on 5 plants from each treatment, and the number of leaves above the main ear was counted. The assimilating leaf area above the main ear was calculated using the equation reported by Montgomery (1906). Individual plant production (mass of all the ears per plant), the thousand kernel mass, number of kernel rows and length of the main ears, the number of kernels per row, and the shelling % (grain-cob ratio) were recorded under laboratory conditions.

The climatic data for the experimental years and the 30-year data for these parameters at the five locations were provided by the National Meteorological Service. An analysis of the weather data revealed that in 1997 the rainfall distribution during the vegetation period was far better than in the following two years, especially as regards the quantity of rainfall in July. In this same year the mean temperature data were also more favourable, with fewer very hot days than in later years. Although there was more rainfall during the vegetation period in 1998, the distribution was unfavourable and there was a high number of very hot days at all the locations (129 in all). In Gyöngyös, for example, there were 31 days when the temperature was above 30°C for a long period. The experimental areas were all stricken by drought in all three years. The quantity and distribution of rainfall in 1999 was similar to that in 1998, but the mean temperatures were even higher. In Gyöngyös the mean temperature in July was 22.9°C, 2.2°C higher than the 30-year average, while it was only 19.5°C in the coolest location, Gönc. In Martonvásár, the experiments were irrigated with a water quantity equivalent to 80–100 mm rainfall in all three years to relieve the symptoms of drought.

The data were statistically analysed using the three-factor ANOVA program Agrobases'99, while discriminant analysis was carried out using the program package SPSS 11.0 for Windows.

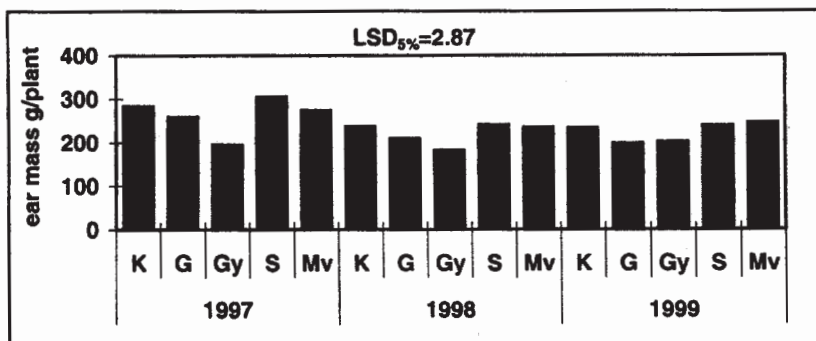
Results

Individual plant production (total mass of the ears per plant)

The main treatment effects and the interactions were significant at the $P=0.1$ % level for this character. The MQ values indicated that the year had the greatest effect on the individual plant production of the hybrids, followed by the variety, while the location had the least influence. The hybrids produced the greatest individual plant yield in 1997, when the grand experimental mean was 263 g/plant, while this value was significantly lower in 1998 and 1999 (221 and 203 g/plant, respectively).

At the various locations, the greatest individual plant production was recorded in Sopronhorpács in 1997, with a grand experimental mean of 305 g/plant and an ear number/plant of 1.3 (Figure 1). The grand mean was significantly lower in Keszthely (283 g/plant) and Martonvásár (274 g/plant), where the ear number/plant was 1.1 and 1.0, respectively. In Gönc the mean individual plant yield of the hybrids was 259 g/plant, while the lowest yield was recorded in Gyöngyös (195 g/plant), with a single ear per plant at both locations. In 1998 the best production conditions were again found in Sopronhorpács, where the grand experimental mean was 241 g/plant. In this year the plants at all the locations produced only one ear. The difference between the Keszthely and Martonvásár locations was not significant (237 and 235 g/plant), while the grand experimental mean was again the lowest in Gönc (209 g/plant) and Gyöngyös (182 g/plant).

In 1999 the weather was most favourable for the hybrids in Martonvásár, where the highest individual plant production of 245 g/plant was achieved, with significantly lower average yields in Keszthely (233 g/plant) and Sopronhorpács (201 g/plant).



K = Keszthely, G = Gönc, Gy = Gyöngyös, S = Sopronhorpács, M = Martonvásár

Figure 1. Individual plant production recorded for years and locations, averaged over the hybrids

In Gönc the average yields were only a little lower than in Sopronhorpács (197 g/plant), though the difference was significant. In 1999, as in the other years, the lowest yields were observed for hybrids grown in Gyöngyös, where the individual plant production averaged 138 g/plant.

The order of locations based on the individual plant production of the experimental hybrids was the same in 1997 and 1998 (Sopronhorpács, Keszthely, Martonvásár, Gönc, Gyöngyös), while in the third year (1999) it changed (Martonvásár, Keszthely, Sopronhorpács, Gönc, Gyöngyös).

In all three years the hybrids Mv 1, Mv 4 and Mv 8 gave the highest individual plant production. In these hybrids there was a great genetic distance between the parental components, while the individual plant production of hybrids developed from related lines (Mv 7, Mv 10, Mv 11) was smaller. The year had the greatest effect on the individual plant production of hybrids Mv 1, Mv 6, Mv 8 and Mv 9 which responded with high yields to the favourable ecological conditions in 1997, but gave yields far below their maximum yield potential in 1998 and 1999, though these values were still higher than the grand experimental mean (Figure 2).

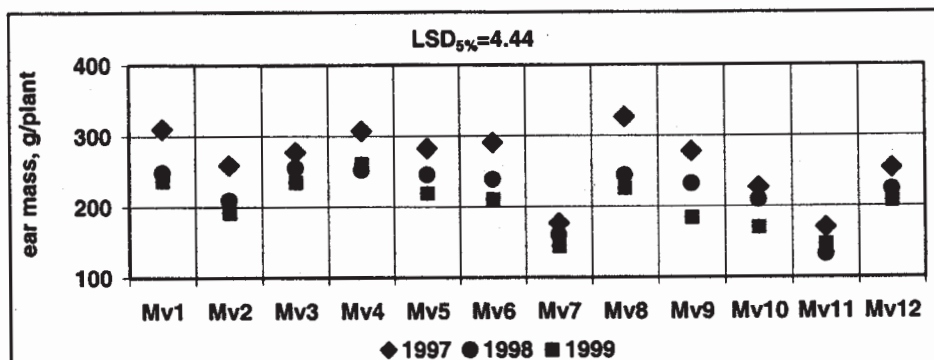


Figure 2. Effect of year on the individual plant production of the hybrids, averaged over locations and hybrids

The stability of the hybrids at the various locations, averaged over the years, was analysed on the basis of the coefficient of variation (Table 1). The hybrids were divided into three groups on the basis of individual plant production, and those with small and large relative deviation (CV) were distinguished in each group. Among the seven hybrids that had individual plant yields in excess of the grand experimental mean (229 g/plant), Mv 3, Mv 4, and Mv 5 also had outstanding yield stability. These hybrids had ear masses above the grand experimental mean even in Gyöngyös, indicating their excellent adaptability. Hybrids Mv 1, Mv 6, Mv 8 and Mv 9 had high individual plant production values, but gave a sensitive response to extreme conditions (dry soil and air). The individual ear mass of hybrid Mv 1, for instance, averaged over the other factors, was 300 g/plant in Martonvásár, but only 212 g/plant in Gyöngyös. Hybrids Mv 2 and Mv 10 had moderately high yields (above the grand experimental mean), but also had high CV values. They were only capable of achieving their maximum yield potential under favourable conditions (Keszthely, Martonvásár), while they responded with yield losses to unfavourable environmental effects. The lowest yield level, combined with little relative deviation, was observed for two hybrids (Mv 7 and Mv 11). These hybrids, produced from related lines, proved extremely sensitive to environmental effects and produced yields below the grand experimental mean at all the locations.

Table 1. Stability of the hybrids in terms of the coefficient of variance (CV) for individual plant production

Individual plant production (1)					
200 g/plant (2)		200-229 g/plant (2)		229 g/plant < (3)	
CV (6-14 %)	CV (14 % <)	CV (6-14 %)	CV (14 % <)	CV (6-14 %)	CV (14 % <)
Mv 7	Mv 10	Mv 12	Mv 2	Mv 3	Mv 1
Mv 11				Mv 4	Mv 6
				Mv 5	Mv 8
					Mv 9

Thousand kernel mass

The results of analysis of variance (MQ values) demonstrate that, of all the factors analysed, the location had the greatest effect on thousand kernel mass, followed by the variety and the year (in decreasing order). Averaged over three years, the thousand kernel mass of the hybrids was greatest in the Keszthely trials (378 g), while the lowest values were recorded in Gyöngyös (301 g). The greatest difference between the locations was thus 77 g, compared with 20 g between the years. The hybrids with the greatest thousand kernel masses (Mv 1, Mv 4, Mv 8) also produced the highest yields (378.9, 371.7 and 362.7 g, respectively), while the smallest thousand kernel mass (239.3 g) was recorded for the only flint hybrid (Mv 11), which had the lowest individual plant production.

Number of kernel rows

Among the factors tested, the variety had the greatest influence on the number of kernel rows, followed by the year, while the location had the least effect. Among the yield components the number of kernel rows had the highest value of h^2 (0.57), indicative of the substantial genetic determination for this trait and the slight effect of the environment. The Mv 11 hybrid, the only flint hybrid tested, had the largest number of kernel rows (17.2), while the smallest number was counted for Mv 1 (14.4) and Mv 10 (14.6).

Averaged over all the factors, the number of kernel rows did not differ significantly in 1997 and 1998 (16.2 and 16.1, respectively), while in 1999 all the hybrids had a smaller number of kernel rows (15.8, averaged over all the factors). This value was significantly lower than in the other two years.

Ear length and number of kernels per row

The MQ values demonstrated that of all the factors tested the year had the greatest effect on the ear length and number of kernels per row, followed by the variety and the location. The longest ears were found in 1997 (20.2 cm), while the main ears were significantly shorter in 1998 (19.1 cm) and 1999 (17.6 cm). The greatest year fluctuation for this parameter was recorded in Gyöngyös, where there was a difference of 5 cm between the length of the main ear in the best (1997) and worst (1999) years. The smallest difference between these same years was recorded in Martonvásár (0.3 cm).

The value of the Bravais correlation coefficient between ear length and the number of kernels per row was 0.74. In Gyöngyös the ear tips were not fertilised due to the drought, and this reduced the closeness of the correlation.

Grain-cob ratio (shelling %)

The MQ values calculated by analysis of variance indicated that the grain mass and cob mass were both influenced to the greatest extent by the year, followed by the variety and the location, but even this effect was not great. The grain-cob ratio was 84:16 % averaged over all the factors in 1997, while this value was 85:15 % in 1998 and 86:14 % in 1999. The location had no significant effect on the ratio, the shelling percentage being 85:15 % at all the locations.

Hybrids Mv 4, Mv 6, Mv 8 and Mv 12 had the best shelling percentages (85:15 %), while the lowest values were recorded for hybrid Mv 7, where the grain-cob ratio was 81:19 %.

Correlation between the assimilating leaf area above the main ear and the individual plant production

The MQ values calculated by analysis of variance indicated that the assimilating leaf area was influenced to the greatest extent by the year, followed by the variety and the location. This parameter had the highest value in 1997 (4267 cm²) and was significantly lower in 1998 (4088 cm²) and 1999 (3805 cm²). The values recorded for the different genotypes ranged from 3249 to 4871 cm². A moderately strong correlation was observed between the assimilating leaf area above the main ear and the individual plant production, the value of Pearson's correlation coefficient being 0.66 (Figure 3).

The data were also analysed using discriminant analysis to determine the extent to which the tested parameters were able to discriminate between the locations. The program compared pairs of locations and calculated the values of the F test, indicative of the differences between the locations.

The analysis indicated that the Gönc and Gyöngyös locations differed from each other to the greatest extent, as the value of the coefficient was greatest for this pair (38.210). The closest correlations were obtained between Sopronhorpács and Keszthely (10.335) and between Martonvásár and Keszthely (9.911).

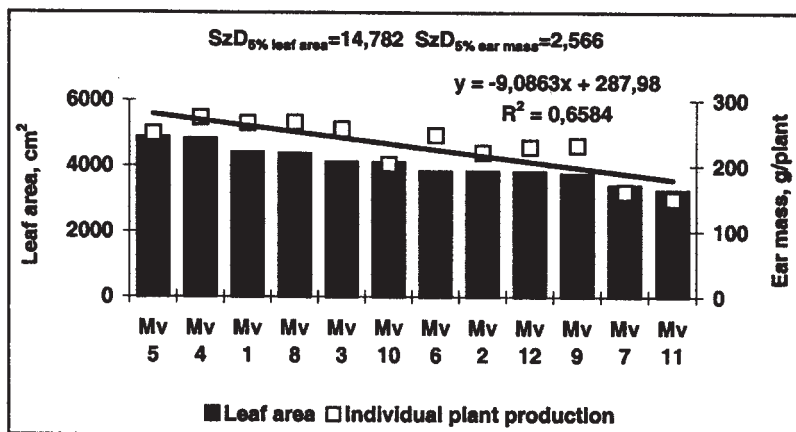


Figure 3. Ranking of hybrids based on the correlation between assimilating leaf area and individual plant production, averaged over all the factors

Discussion

The experimental results confirmed those of Berényi (1945) and Polerecky (1976), who found that the quantity of rainfall in July had a decisive effect on the maize yield. The individual plant production of the hybrids was greatest at locations where the rainfall quantity in July reached the average over many years (Keszthely, Sopronhorpács) or where irrigation was carried out during flowering (Martonvásár). The location and the year both modified the frequency with which secondary ears were formed, though the effect of the year was greater than that of the location (Kapás, 1961). In agreement with the results published by Kapás (1961), Lucas and Remison (1984) and Gyenesné-Hegyí *et al.* (2002), the data demonstrated that the grain-cob mass ratio of the hybrids was a stable trait, not influenced by the location. Among the yield components, the most variable were the ear mass, the thousand kernel mass, the ear length and the number of kernels per row, in agreement with other authors (Horner *et al.*, 1971; Kim, 1975; Dornescu, 1978; Pavlicic, 1974). The most constant yield component was the number of kernel rows, as indicated by Hallauer and Miranda (1981). The year had the greatest effect on the assimilating leaf area, confirming the results of Duncan (1975), who stated that the environmental effects experienced during leaf development had an influence on the size of the leaf blades. The leaves with the largest leaf area were grown in Keszthely and the smallest in Gönc, probably due to the cooler weather in the latter. The value of Pearson's correlation coefficient between the individual plant production and the assimilating leaf area above the main ear was high (0.88), as also reported by Seka and Cross (1995) when investigating the effect on plant size of the genes responsible for grain mass.

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