RESPONSE OF MAIZE HYBRIDS TO INCREASING PLANT DENSITY AND ITS IMPACT ON YIELD

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Abstract
There is a close relationship between plant density and the yield of maize hybrids. The response to increasing plant density greatly varies among the hybrids. Optimum plant density is influenced by the growing site, the year effect and water and nutrient supply.
The relationship between plant density and the yield of maize hybrids was studied between 1999 and 2003 applying a uniform fertilization treatment of N 120, P_2O_5 80, K_2O 110 kg/ha active ingredient. The experiment was set up on typical meadow soil. Weather in the experimental years was: 1999, 2001, 2002 average precipitation, 2000, 2003 dry.
In addition to optimum plant density, the optimum plant density intervals also varied greatly, based on which the hybrids can be classified into four groups. For a safe yield, a lower plant density should be applied under field conditions. For hybrids with values between FAO 200-500, plant density should be 60-80 thousand plants ha^{-1}.

Keywords: maize, optimum plant density, yield stability

INTRODUCTION

In the course of the 20th century, there was an increased interest toward plant density experiments, especially in Western Europe and the United States where hybrids were applied earlier. However, the spread of the application of higher plant densities in Hungary has been quite slow.
In the average of hybrids, the optimum plant densities per hectare were 35-40 thousand in the 1950s, 50 thousand in the 1960s, 55-60 thousand in the 1970s (Győrffy, 1979), and 60-80 thousand in the 1980s (Sárvári, 1982).
In achieving twofold-threefold yields, the applicability of higher plant densities had a significant role (Carlone and Russel, 1987).
Among the factors determining maize yield, the number of plants has a 20 % contribution (Győrffy, 1976; Berzsenyi and Győrffy, 1995).
The toleration of higher plant densities is influenced also by the nutrient supply. In addition to soil characteristics and the intensity of the hybrid, climatic factors also determine the utilization of N (Pepó, 2001).
The toleration of higher plant densities is also dependent upon the vegetation period of the hybrid. The reduction of the heat threshold of maize has already been determined, therefore, its alteration is recommended (Marton et al., 2005).
At higher than optimal plant densities, the ratio of sterile plants reached 14 % in dry years, while at lower plant densities this value was 1-2 % (Szabó, 1998).
Too high plant densities induce a water deficiency resulting in a significant yield reduction (Bodnár, 1982; Széll, 1984; Nagy, 1995).

MATERIALS AND METHODS

The experiment was set up on meadow soil. The organic matter in the soil profile greatly reduces from 4-5 % at the surface to around 1.5 % in the 40-60 cm layer. The cultivated layer is prone to silting when wet and to cracking when dry.
In addition to the high humus content, N availability was also good, the soil was similar to meadow chernozem soil in certain parameters. However, based on its heaviness and major parameters, it could be classified as a typical meadow soil. Nitrogen and phosphorus and potash effects were weaker than the average and good, respectively.

Weather in the experimental years
The 30-year average of precipitation was 565.3 mm, in the vegetation period of maize (IV-IX.) it was 345.1 mm. Among the studied years (1999-2003) 1999 was rainy, while 2000 and 2003 was dry. The temperature was higher than the 30-year average in all years (Figures 1-2).

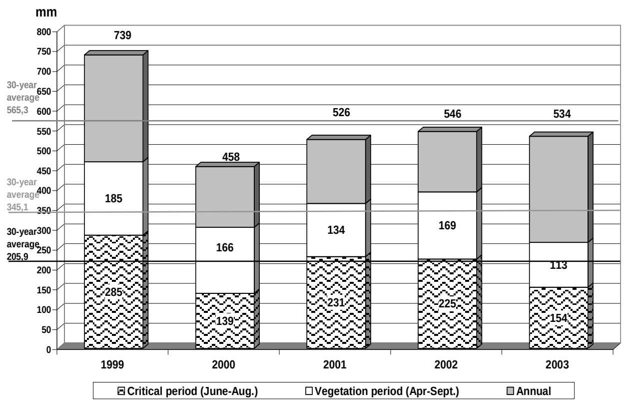

Fig. 1: Precipitation data (mm) Hajdúböszörmény, 1999-2003

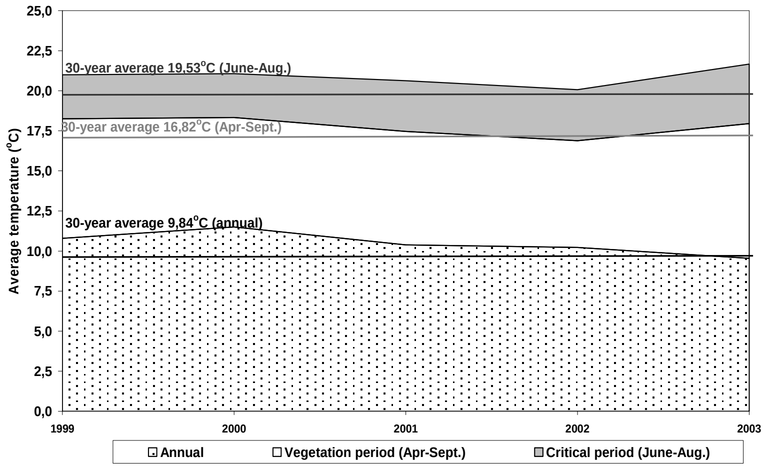

Fig. 2: Temperature data (°C) Hajdúböszörmény, 1999-2003

The forecrop was maize, fertilization was the same in all years with N 120, P_2O_5 80, K_2O 110 kg ha^{-1} active ingredient. The hybrids with different genetic characteristics and vegetation period were studied under plant densities of 30-100 thousand plants ha^{-1} with special regards to yield.
The cultivation was deep ploughing in all years in the autumn, seedbed preparation was performed by a multi-tiller.
Yields were calculated for 86 % dry matter content.
Results of the experiments were evaluated using the Windows XP operation system with Microsoft Excel 2003 and SPSS 13.0 programs.
For the analysis the following mathematical-statistical methods were applied: two-way analysis of variance (Sváb, 1981), parabolic regression analysis for determining the optimum plant density interval.

RESULTS

Plant density greatly determines the yield. The possible increase of plant density is determined greatly by ecological, biological and agrotechnical factors.
The relationship between plant density and year varied greatly with the hybrid and the year. Yield of hybrids Canada, DK 373, Ella and AW 641 ranging between 10.88-11.35 t ha^{-1} was significantly higher than that of MTC 272 (Table 1).

Table 1

Optimum plant density and plant density interval of the hybrids with the highest and lowest yields *(1999)*

Hybrid	***FAO No.***	***Yield in the average of plant densities t ha^{-1}***	***Optimum plant density thousand plants ha^{-1}***	***Optimum plant density interval thousand plants ha^{-1}***	***Interval range thousand plants ha^{-1}***	***R^2 value of parabolic regression***
DK 373	330	11.35	74	67-80	13	0.877
AW 641	450	11.29	81	73-90	17	0.804
Canada	310	11.00	100	97-100	3	0.807
Ella	360	10.88	74	65-82	7	0.613
Average			***64***		***12***	
Horus	450	9.72	72	65-79	14	0.715
AW 421	450	9.46	81	73-90	17	0.661
Kincs	400	9.37	70	62-79	17	0.802
Mv TC 272	280	8.22	69	61-77	16	0.864
Average			***73***		***16***	

$SD_{5\%}$	***Plant density******	**0.81**
	Hybrid***	**1.75**
	Interaction	**2.79**

***: P=0.1 %

The R^2 value of the function describing the relationship between plant density and yield for the hybrid Ella was 0.876; while for hybrid Alpha sensitive to increasing plant densities it was only 0.613; meaning a weaker relationship between plant density and yield.

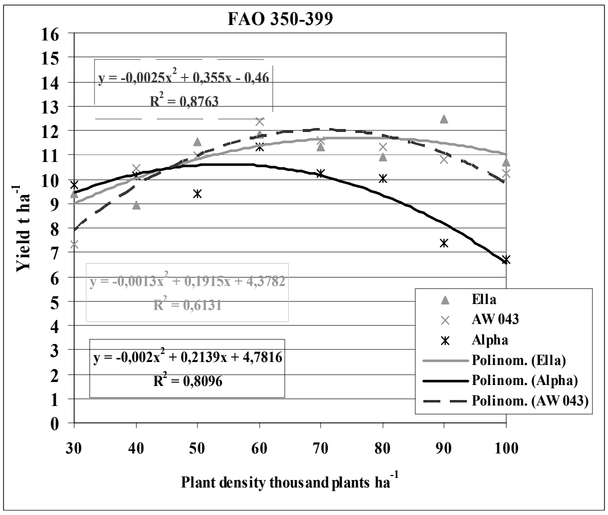

Fig. 3: Relationship between plant density and yield of maize hybrids, 1999

The response to climatic and agrotechnical factors, or the relationship between plant density and yield within the agrotechnical factors varies greatly among the hybrids.

In 2000, precipitation in the vegetation period (IV-IX) and in the whole year was considerably lower than the average of many years.

By increasing plant density from 40-50 thousand to 60 thousand, the yield increased significantly ($SD_{5\%}$ = 0.66). In the average of plant densities, the yield of Ella, Sprinter, DK 440 and Monalisa termése of 10.68-13.38 t ha^{-1} was consistently higher than that of hybrids AW 641, Mv TC 272 and Celest (7.89-9.92 t ha^{-1}) (Table 2).

Table 2

Optimum plant density and plant density interval of the hybrids with the highest and lowest yields *(2000)*

Hybrid	*FAO No.*	*Yield in the average of plant densities t ha^{-1}*	*Optimum plant density thousand plants ha^{-1}*	*Optimum plant density interval thousand plants ha^{-1}*	*Interval range thousand plants ha^{-1}*	*R^2 value of parabolic regression*
Monalisa	330	12.68	100	93-100	7	0.741
DK 440	330	12.32	100	96-100	4	0.829
Sprinter	260	11.26	100	97-100	3	0.874
Ella	350	10.68	79	68-90	22	0.739
Average			***95***		***9***	
Sze SC 278	310	9.60	87	79-96	46	0.770
Celest	440	8.88	68	62-73	11	0.783
Mv TC 272	280	8.65	68	59-77	11	0.420
AW 641	450	7.89	91	81-100	19	0.862
Average			***79***		***14***	

$SD_{5\%}$	***Plant density****	**0.66**
	Hybrid*	**0.88**
	Interaction	**2.29**

***: P=0.1 %

In the dry year of 2000, certain hybrids reached their maximum yield at very high plant densities. The explanation of this can be that while the individual yield (cob size) becomes smaller with increasing plant densities, their yield per unit area increases even up to 100 thousand plants ha^{-1}. However, it was extremely unfavorable that the optimum plant density interval was very tight for most hybrids, 3-77 thousand. The higher and lower yields were obtained at 95 thousand and 79 thousand plants ha^{-1}, respectively.
In 2001, the amount of precipitation was lower and considerably higher than the average of many years in the vegetation period of maize (IV-IX.) and in the critical period (VI-VIII.), respectively, therefore, favorable yields were obtained.
Yield of 60-100 thousand plant densities was significantly higher than that of 30-40-50 thousand plant densities ($SD_{5\%}$ = 0.62). The highest yield (13.70 t ha^{-1}) was obtained in hybrid Celest at a relatively low plant density of 69 thousand plants ha^{-1}, while the lowest yield was measured for Sprinter at 88 thousand plants ha^{-1} (7.94 t ha^{-1}). Of course, there is a great difference between the two hybrids in their vegetation period and productive capacity (Table 3).

Table 3

Optimum plant density and plant density interval of the hybrids with the highest and lowest yields *(2001)*

Hybrid	*FAO No.*	*Yield in the average of plant densities t ha^{-1}*	*Optimum plant density thousand plants ha^{-1}*	*Optimum plant density interval thousand plants ha^{-1}*	*Interval range thousand plants ha^{-1}*	*R^2 value of parabolic regression*
Celest	440	13.70	69	62-76	14	0.599
PR36B08	500	13.39	79	73-84	11	0.708
PR36R10	480	13.06	97	90-100	10	0.962
LG 2394	370	12.97	86	81-91	10	0.930
Average			***83***		***11***	
PR39K38	290	9.70	100	93-100	7	0.796
Sze 278	310	9.50	77	70-83	13	0.900
Borbála	310	8.85	86	79-93	14	0.825
Sprinter	260	7.94	88	80-96	16	0.893
Average			***88***		***13***	

$SD_{5\%}$	***Plant density****	**0.62**
	Hybrid*	**0.70**
	Interaction	**2.14**

***: P=0.1 % **: P=1 %

In 2002, precipitation was 20 mm higher in the critical period and the vegetation period than the average of many years, while the annual precipitation was lower. Yields remained under 10 t ha^{-1} in this year. The highest yield was given by hybrid DK 440 (9.96 t ha^{-1}) at a very low plant density of 30 thousand, while the value of parabolic regression was R^2 = 0.898.
For some hybrids – Mv 370, Goldacco, PR38A24 – R^2 values were small (0.475-0.689), indicating a weak relationship between plant density and yield. The yield of Mv 370 was only 6.79 t ha^{-1} at 74 thousand plants ha^{-1}.
In the average of hybrids, the optimum plant density was 71-78 thousand plants ha^{-1} (Table 4). The range of the optimum plant density interval was only eight thousand for the hybrid Mv 277, which is unfavorable, while for Goldacco and PR36R10 it was of a favorable value of 16 thousand plants ha^{-1}, which is related to the good adaptability of the hybrids.

Table 4

Optimum plant density and plant density interval of the hybrids with the highest and lowest yields *(2002)*

Hybrid	*FAO No.*	*Yield in the average of plant densities t ha^{-1}*	*Optimum plant density thousand plants ha^{-1}*	*Optimum plant density interval thousand plants ha^{-1}*	*Interval range thousand plants ha^{-1}*	*R^2 value of parabolic regression*
DK 440	320	9.96	30	21-33	12	0.898
Mv 277	320	9.40	100	92-100	8	0.700
PR38A24	370	9.35	76	69-82	13	0.592
MCA 4844	450	9.20	79	73-86	13	0.809
Average			***71***		***12***	
LG 2305	290	8.53	73	67-78	11	0.732
Goldacco	290	7.92	86	78-94	16	0.689
PR36R10	480	7.13	80	72-88	16	0.842
Mv 370	370	6.79	74	66-82	16	0.475
Average			***78***		***15***	

$SD_{5\%}$	***Plant density******	**0.53**
	Hybrid***	**1.02**
	Interaction***	**1.82**

***: P=0.1 %

In 2003, the amount of precipitation was considerably lower than the average of many years both in the critical period and in the vegetation period, it was a dry year.

The highest (9.41 t ha^{-1}) and the lowest yields were measured for Mv 370 and Goldacco, respectively. Its yield was 7.08 t ha^{-1} at 74 thousand plants ha^{-1} (Table 5).

Table 5

Optimum plant density and plant density interval of the hybrids with the highest and lowest yields *(2003)*

Hybrid	*FAO No.*	*Yield in the average of plant densities t ha^{-1}*	*Optimum plant density thousand plants ha^{-1}*	*Optimum plant density interval thousand plants ha^{-1}*	*Interval range thousand plants ha^{-1}*	*R^2 value of parabolic regression*
Mv 370	370	9.41	93	84-100	16	0.669
DK 440	330	9.38	79	71-87	16	0.763
DKC 4626	370	9.20	78	70-76	16	0.433
PR34B97	530	9.02	70	63-77	14	0.752
Average			***80***		***14***	
LG 2305	290	8.59	100	94-100	6	0.834
DK 537	510	8.49	77	71-83	12	0.808
Mv 277	320	8.13	85	75-95	20	0.801
Goldacco	290	7.08	74	67-80	13	0.552
Average			***84***		***13***	

$SD_{5\%}$	***Plant density******	**0.63**
	Hybrid***	**0.99**
	Interaction***	**2.19**

***: P=0.1 %

In spite of the dry year, the highest yields were obtained at the relatively higher plant densities, which proves that the response of these hybrids to higher plant density is better than their individual yield The only exception was the hybrid PR34B97, its maximum yield was 9.02 t ha^{-1} at 70 thousand plants ha^{-1}, at plant densities higher than this, its yield was significantly reduced (Figure 4).

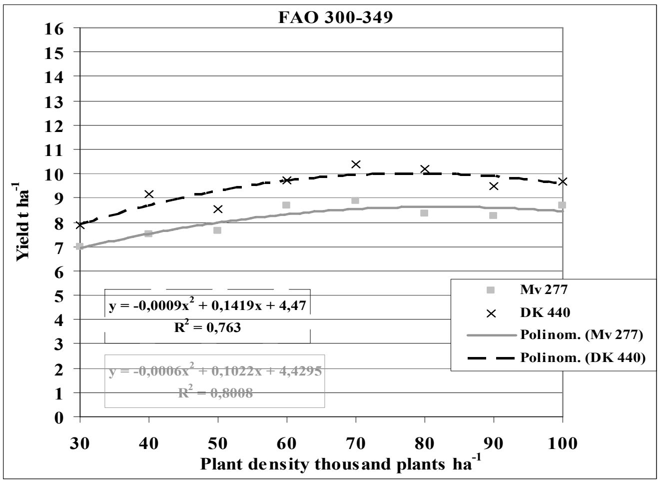

Fig. 4: The relationship between the plant density and yield of maize hybrids, *2003*

Plant density has a significant effect on the yield and yield stability of maize. The optimum plant density is influences by the genetic characteristic and the vegetation period of the hybrid. However, this is greatly modified by the growing site, the year effect and the degree of water and nutrient supply. If these were optimal, the next limiting factor would be the light, since the self-shadowing of maize has an effect on production.

A higher than optimal plant density increases the water requirement and the sensitivity to draught, the ratio of sterile plants, thereby, it reduces yield safety and yield.

The grower is interested in the plant density resulting in the maximum yield. Therefore, it is not enough to know the optimum plant density, but also the optimum plant density interval should be determined the application of which does not result in a yield reduction.

Maize hybrids can be classified into four groups based on their response to increasing plant density:

1. Hybrids reacting well to higher plant density, with a wide optimum plant density interval. Due to increasing plant density, the individual yield reduces, while the yield per unit area increases until a certain point. For example, Sze SC 278, AW 641, DK 440, Mv 370, PR36R10.
2. Hybrids not requesting high density, but having good individual production, prone to bringing several cobs. They have good yield safety, e.g. Ella, PR38A24, Goldacco.
3. Hybrids with flexible cob length: in favorable years, the cobs become longer resulting in a higher yield, e.g. Celest.
4. Hybrids sensitive to increasing plant density with a narrow optimum plant density interval. In this group, special attention should be paid to determining the plant density, e.g. Alpha, PR34B97.

With respect to the weather extremes caused by climate change, the following plant densities can be recommended under field production conditions:

FAO 200-300	70-80 thousand plants ha^{-1}
FAO 400	65-75 thousand plants ha^{-1}
FAO 500	60-65 thousand plants ha^{-1}

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