PLANT DENSITY IMPACT ON GRAIN YIELD OF MAIZE (*Zea mays* L.) HYBRIDS ON CHERNOZEM SOIL OF THE EASTERN HUNGARY

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Abstract

The plant density response of 12 maize hybrids was tested in a favourable year (2013) under optimum agrotechnical conditions on chernozem soil by applying plant densities of 50, 70 and 90 thousand plants ha^{-1}. Due to the favourable ecological and agrotechnical conditions yields varied between 11400 and 16300 kg ha^{-1} depending upon the hybrid and the plant density. From among the hybrids, 5 and 7 produced the maximum yield at 70 and 90 thousand plants ha^{-1}, respectively however the yield increment was not significant between 70 thousand plants ha^{-1} and 90 thousand plants ha^{-1}. No relationship was found between the season length and the optimum plant density of hybrids. Those hybrids were the most favourable, which gave a stable high yield at different plant densities that is their optimum plant density range was wide (P 9175, P 9494, SY Afinity). Hybrids with a small optimum plant density range (P 9578, DKC 4490, PR 37N01) gave the highest yield at a specific plant density (70 thousand plants ha^{-1} or 90 thousand plants ha^{-1}). A special complex coordinate system was developed for evaluation for the plant density response of maize genotypes specific ecological and agrotechnical conditions can be evaluated jointly.

Keywords: maize, plant density, hybrids, grain yields

Introduction

In Hungary, the number of registered hybrids has been the highest in maize for decades among the field crops. The number of maize hybrids has been around 400 for several years. This large hybrid portfolio provides the farmers with a great selection potential on the one hand, however, it also hinders the judgement of the objective traits of the hybrids. From among the agrotechnical elements applied in maize production technology several have a direct or indirect effect on the yield and the agronomical and economic efficiency of production.

According to Tokatlidis and Koutrubas (2004), the optimum plant density resulting in maximum yield has increased due to the great plant density tolerance of the new maize hybrids, but the potential yield per plant has not changed. Modern hybrids are highly dependent upon the plant density, because they can produce the maximum yield only in a small range due to the high number of plants. According to Sárvári (2005), plant density has a decisive effect on yield. With increasing plant density, the yield per plant decreases, but the yield per unit area increases until the optimal number of plants ha^{-1} is reached. Vad et al. (2007) found that, the optimum plant density is an important factor in sustainable maize production. Besides the genotypes and agrotechnical elements (fertilization etc.) the ecological factors (water supply, rainfall quantity and its distribution, physical and chemical properties of soil etc.) strongly modify the optimum plant density of maize. In the study of Pepó et al. (2006), increasing population density results in small amounts of additional yields (0.2-1.6 t ha^{-1}). In the study of Dawadi and Sah (2012), the highest yield (11.19 t ha^{-1}) was obtained at a plant density of as compared to the plant density of 55555 plants ha^{-1}. There was no significant difference between the yields of 66666 plants ha^{-1} and 83333 plants ha^{-1} (10.54 t ha^{-1}). Gozübenli et al. (2004) and Lashkari et al. (2011) found that plant density has a significant effect on yield. The yield increased up to the plant density of 90000 plants ha^{-1} (10973 kg ha^{-1}), above that value it was reduced. Widdicombe and Thelen (2002) also obtained the highest yield at the plant density of 90000 plants ha^{-1}. Hoshang (2012) also found that there is a significant difference between the

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yields at different plant densities and that the yield increases with increasing plant density. In the study of Mohseni (2013), the increase of plant density from 60000 plants ha^{-1} (9.09 t ha^{-1}) to 80000 plants ha^{-1} (11.14 t ha^{-1}) resulted in a yield increment. Roekel and Coulter (2011) stated that there is a close relationship between maize yield and plant density. The tested hybrid reached its maximum yield at the plant density of 81700 plants ha^{-1}.

Materials and methods

The plant density response of maize hybrids was studied in a small-plot field experiment at the experimental site of the University of Debrecen Centre for Agricultural Sciences at Látókép, which is located in Eastern Hungary in the loess region of Hajdúság (47° 33' N, 21° 27' E). The experiment was set up in four repetitions. The parcel size was 15.2 m^2. Three different plant densities (50, 70, 90 thousand ha^{-1}) were applied. In the season of 2013, an experiment was set up in which the plant density response of 12 maize hybrids of different genotypes and different vegetation period on a calcareous chernozem soil. The fertilizer doses applied in favour of the site-specific fertilization were N 108 kg ha^{-1}, P 0 kg ha^{-1} and K 0 kg ha^{-1}.

The hybrids were from the FAO 290-470 range. Most of the hybrids were developed in Hungary and taking into consideration on the local conditions. The examined hybrids were grown across the country. For example, the sowing area of NK Lucius was more than 40,000 hectares in 2013. In the last three years PR 37N01 were grown in the largest area in Hungary.

When evaluating the weather of 2013 and its effect on maize yields, the early spring weather should also be taken into consideration in addition to the weather during the season. The extremely high amount of precipitation (163.3 mm) in March 2013 greatly contributed to the fill-up of the water stock of the chernozem soil. The weather of May-June provided favourable conditions for the vegetative development of maize hybrids. The favourable fore crop (winter wheat), the applied proper agrotechnique and the water stock of the chernozem soil could reduce the unfavourable effects of the dry and hot weather of July (precipitation: 15.6 mm) and August (precipitation: 32.2 mm) (Table 1).

For the statistical analysis of the experiment, we used bi-factorial variance analysis in SPSS 13 for Windows.

Results

The significant vegetative mass provided for the physiological conditions of the extremely high yields obtained in 2013 (Table 2). The yields of maize hybrids varied between 11400 and 16300 kg ha^{-1} in 2013 depending upon the

Table 1. The meteorological data in the maize vegetation period (Debrecen, 2013 and 30-year average 1961-1990)

Months	March	April	May	June	July	August	September	Total/ Average
Precipitation (mm) 30-year average (1961-1990)	33.5	42.4	58.8	79.5	65.7	60.7	38.0	379.2
Precipitation (mm)	136.3	48.0	68.7	30.8	15.6	32.2	47.6	378.6
Difference (mm)	102.8	5.6	9.9	-48.7	-50.1	-28.5	9.6	0.6
Temperature (°C) 30-year average	5.0	10.7	15.8	18.7	20.3	19.6	15.8	15.1
Monthly average temperature (°C)	2.9	12.0	16.6	19.6	21.2	21.5	14.0	15.4
Difference (°C)	-2.1	1.3	0.8	0.9	0.9	1.9	-1.8	0.3

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Table 2. Effect of plant density on maize hybrids yield (Debrecen, chernozem soil, 2013)

Hybrids (the factor A)	Grain yield (kg ha^{-1}) Plant density (thousand plants ha^{-1}) (the factor B)			Average
	50000 plants ha^{-1}	70000 plants ha^{-1}	90000 plants ha^{-1}	
Sarolta (290)	11878	11997	11826	11900
P 9578 (320)	12463	15046	13826	13778
DKC 4014 (320)	12247	13770	12832	12950
DKC 4025 (330)	11908	12637	13748	12764
P 9175 (330)	15859	15948	15219	15675
NK Lucius (330)	13377	12935	13751	13354
PR 37M81 (360)	12991	12483	13182	12885
PR 37N01 (380)	13765	15421	16296	15161
DKC 4490 (380)	11882	12802	13214	12633
P 9494 (390)	15116	15619	14300	15012
Kenéz (410)	11388	11862	12387	11879
SY Afinity (470)	14682	15372	15946	15333
Average	13130	13824	13877	13610
LSD5% (A)	459 kg ha^{-1}			
LSD5% (B)	687 kg ha^{-1}			
LSD5% (A*B)	1190 kg ha^{-1}			

hybrid and the plant density. The higher plant density demand and plant density response of modern maize hybrids were proved by our experimental results. In our study, the lowest yield was obtained at the plant density of 50 thousand plants ha^{-1}. In 2013, the optimum plant densities of hybrids were 70 thousand plants ha^{-1} and 90 thousand plants ha^{-1}. Maximum yield was achieved at a plant density of 70 thousand plants ha^{-1} for the hybrids Sarolta, P9578, DKC 4014, P 9175 and P 9494 and at 90 thousand plants ha^{-1} in the case of DKC 4025, NK Lucius, PR 37M81, PR 37N01, DKC 4490 and SY Afinity. However, the results also proved that there was no significant yield increment in most hybrids when the plant density was increased from 70 thousand plants ha^{-1} to 90 thousand plants ha^{-1}.

Based on our experimental results, the effect of plant density on the yield of maize hybrids was evaluated as an average of the hybrids and also for the minimum and maximum values (Table 3). As an average of the hybrids, no difference was found in the yield between the different plant densities. The yields of the hybrids were 13130 kg ha^{-1} at 50 thousand plants ha^{-1}, 13824 kg ha^{-1} at 70 thousand plants ha^{-1} and 13877 kg ha^{-1} at 90 thousand plants ha^{-1}. It is very important to evaluate the minimum and maximum values at the different plant densities and the difference between the two values (Table 3). There were no significant differences in the yield for any of the plant densities neither in the minimum (11388 kg ha^{-1}, 11682 kg ha^{-1} 11826 kg ha^{-1}), nor in the maximum (15859 kg ha^{-1}, 15948 kg ha^{-1}, 16296

Table 3. Parameters of the plant density response of maize hybrids (Debrecen, chernozem soil, 2013)

	Plant density		
	50 thousand ha^{-1}	70 thousand ha^{-1}	90 thousand ha^{-1}
a) Yield average of hybrids (kg ha^{-1})	13130	13824	13877
b) Minimum yield (kg ha^{-1})	11388	11862	11826
c) Maximum yield (kg ha^{-1})	15859	15948	16296
d) Differences of minimum and maximum yield (kg ha^{-1})	4471	4086	4470

kg ha^{-1}), or in the difference interval (4471 kg ha^{-1}, 4086 kg ha^{-1}, 4470 kg ha^{-1}). This means that the evaluation of the hybrids' average obscures the real differences in the plant density response between the different genotypes. According to our study, the optimum plant density of the late 200 FAO and the early 300 FAO hybrids Sarolta and P 9578 was 70 thousand plants ha^{-1}, while the 400 FAO hybrids Kenéz and SY Afinity gave the maximum yield at 90 thousand plants ha^{-1}.

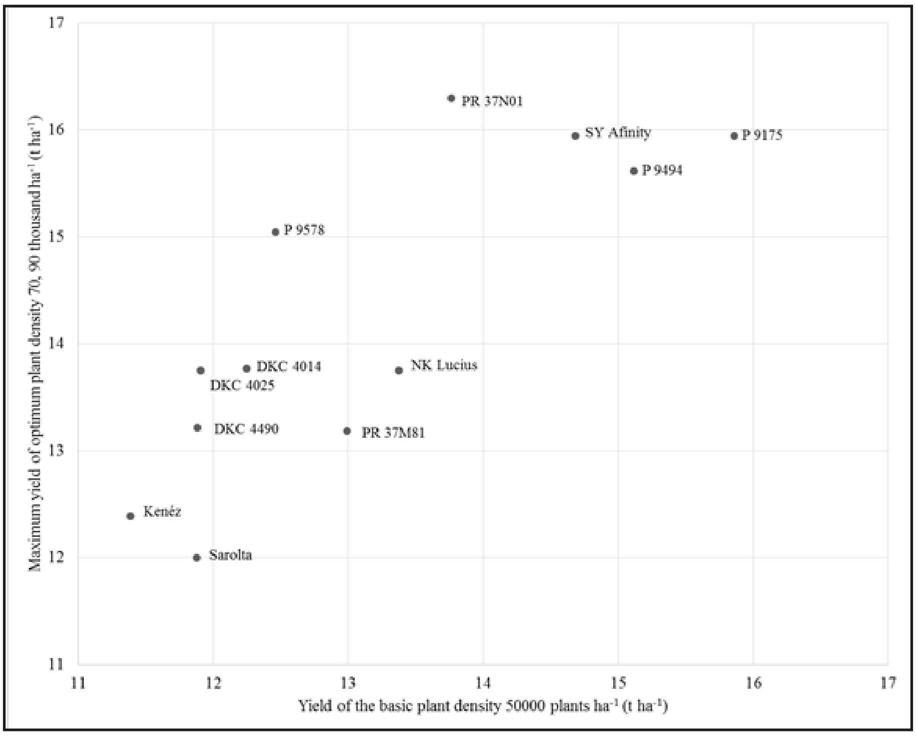
The tested hybrids differed in their yield in the different plant density treatments. In 2013, the hybrids with the highest yield were as follows:

- At 50 thousand plants ha^{-1}: P 9175 (15.9 t ha^{-1}), P 9494 (15.1 t ha^{-1}), SY Afinity (14.7 t ha^{-1});
- At 70 thousand plants ha^{-1}: P 9175 (15.9 t ha^{-1}), P 9494 (15.6 t ha^{-1}), P 37N01 (15.4 t ha^{-1}), SY Afinity (15.4 t ha^{-1}), P 9578 (15.0 t ha^{-1});
- At 90 thousand plants ha^{-1}: PR 37N01 (16.3 t ha^{-1}), SY Afinity (15.9 t ha^{-1}), P 9175 (15.2 t ha^{-1}).

The classification of the hybrids proved that there were hybrids which could tolerate the extreme changes in the plant density (20 thousand plants ha^{-1} lower and higher than the anticipated average 70 thousand plants ha^{-1}) with a very moderate yield fluctuation. These hybrids can be of special value in the production technology as their favourable adaptation ability to the different plant densities is asserted at a high yield level. In our study, such hybrids were P 9175, P 9494 and SY Afinity. However, some genotypes were very sensitive to the plant densities lower or higher than the average (70 thousand plants ha^{-1}), consequently, these hybrids require a very precise sowing and production technology (P 9578, DKC 4490, PR 37N01).

Based on our experimental results, we have developed a special, complex method, which can be used well for determining the actual yield of the hybrids (under the given ecological and agrotechnical conditions) and the plant density response of the maize genotypes (Figure 1). The experimental data were plotted in such a coordinate system in which the yields obtained at the basic plant density (50 thousand plants ha^{-1}) were presented at the horizontal (abscissa) axis, while the yields obtained at the optimum plant density (70 thousand plants ha^{-1} and 90

Figure 1. The plant density response of maize hybrids in a special coordinate system (Debrecen, chernozem soil, 2013)



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thousand plants ha^{-1} depending upon the hybrids) were plotted against the vertical (ordinate) axis. Those hybrids can be regarded favourable which give a high yield at the different plant densities. These hybrids are located in the top right part of the coordinate system (P 9175, PR 37N01, P 9494, SY Afinity). Those hybrids which are less favourable based on their actual yield and plant density response can be found in bottom left part of the coordinate system (Sarolta, Kenéz).

Discussion

The plant density response of 12 maize hybrids of different genotypes was studied on chernozem soil under favourable agrotechnical conditions in 2013. The chernozem soil of excellent water and nutrient management and the significant amount of precipitation in the spring could compensate for the dry and hot weather in July and August. Accordingly, very favourable yields were obtained (11400-16300 kg ha^{-1}) in 2013 depending upon the hybrid and the plant density. Significant differences were found between the hybrids in the maximum yields and optimum plant densities. In 2013, the optimum plant densities were 70 thousand plants ha^{-1} and 90 thousand plants ha^{-1} for the tested hybrids. However, the results showed that the increase of plant density from 70 thousand plants ha^{-1} to 90 thousand plants ha^{-1} resulted only in a minimal yield increment (412-1111 kg ha^{-1}) but it could considerably increase the risk of production under such ecological and agrotechnical conditions which are inferior to the optimal. In the experiments of Dawadi and Sah (2012), Mohseni (2013) and Roekel and Coulter (2011), the maximum yields were obtained at similar plant densities (60-80 thousand plants ha^{-1}), though under different ecological and agrotechnical conditions. The optimum plant density was higher (90 thousand plants ha^{-1}) in the experiments of Widdicombe and Thelen (2002), Gozübenli et al. (2004) and Lashkari et al. (2011). The evaluation of the hybrids' yields at different plant densities proved that the hybrids responded with a different yield fluctuation to the changes in the plant density. Those hybrids were the most favourable which gave a stable, high yield at different plant densities. Such hybrids were P 9175, P 9494 and SY Afinity. As opposed to these, there were hybrids (P 9578, DKC 4490, PR 37N01), which showed a great fluctuation of yield between the different plant density treatments. A special complex evaluation method has been developed for determining the potential yield and plant density response of maize hybrids.

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