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INFLUENCE OF PLANT DENSITIES ON SEED PRODUCTION IN SOME PARENTAL INBRED LINES OF TURDA MAIZE HYBRIDS

Alexandru Bogdan Ghețe[1], Voichița Haș[2*], Ana Copândean[2], Roxana Vidican[1], Loredana Suciu[1], Dan Ioan Vârban[1], Sorin Muntean[1], Béla Biro-Janka[3], Marcel Matei Duda[1]

[1]University of Agricultural Sciences and Veterinary Medicine of Cluj-Napoca, 3-5 Calea Mănăștur, Cluj-Napoca, Cluj County, Romania

[2]Agricultural Research and Development Station Turda, 27 Agriculturii str., 401100 Turda, Cluj County, Romania

[3]Faculty of Technical and Human Sciences, Sapientia Hungarian University of Transylvania, 1/C Sighișoarei str., 540553 Târgu Mureş, Mureş County, Romania

[*]Corresponding author. E-mail: hasvoichita@yahoo.com

ABSTRACT

The sowing density of the parental inbred lines of maize hybrids shoud be chosen in such a way as to obtain the maximum seed yield without affecting the quality of the seed. Based on the data published in other articles on the production of hybrid maize seed, it is considered that for parental inbred lines, optimum density is in the range of 50-80000 plants/ha, while for parental single hybrids between 40-60000 plants/ha. Sowing density is conditioned both by environmental factors as well as suitability of parental forms to different densities. The present study was carried out in 2015 to 2017, at the ARDS Turda, to investigate the impact of three plant densities on behavior of five parental inbred lines of maize hybrids. The obtained results indicated that increasing the plant density (≥70000 plants/ha) determined the increase of the seed yield (kg/ha) for all genotypes. Although several production characters were reduced by increasing density, this decrease did not influence the level of yield, because it was compensated by higher number of plants per unit area. Parental forms TA 452 and TA 447 were identified as the most stable at changing the sowing density, while the lines TC 344 and TA 426 were sensitive to the increase of the plant density, with negative effects on the quality of the seeds.

Keywords: sowing density, maize seed production, parental inbred lines, productivity, nutrition area, leaf, ear, kernels, cob, environment.

INTRODUCTION

Seed production is a dynamic activity that follows the process of creating hybrids. The registration of new hybrids imposes the study of the behavior of new parental lines and hybrids under different aspects and adapting the technology of seed production to their needs. In order to achieve this, a permanent transfer of information has to take place between specialists involved in plant breeding research and those involved in seed multiplication (Sarca, 2004; Păcurar and Grünberg, 1970; Muntean et al., 2014; Racz et al., 2013).

Seed production of maize hybrids is based on the use of the first hybrid generation (F1) heterosis effect. Heterosis or hybrid vigor refers to superiority of F1 hybrids compared to their parental forms, which may be represented by inbred lines or single hybrids (Sarca, 2004). The subject of maize seed production technology has been regarded with increased interest by plant breeders and researchers from Romanian research institutes, as well as by farmers, who are looking for continuous improvement of maize cultivation technology. This could lead to an increase of maize cultivated area, promotion of autochthonous biologic material and enhancement of crop efficiency (Ghețe, 2019).

Plant density is referring to the number of plants grown on a certain area and is considered an important factor in increasing yield. With increased density, interplant competition can play an important role in determining the yield (Ngoune and Mutengwa, 2020). Maize is more sensitive than other cereals to variations in plant

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density and exceeding optimum plant density has negative consequences on the ear development (Sangoi, 2000).

Sowing density must ensure maximum production, but without decreasing seed quality. Researches of Wych (1988) showed that an increase of plant density for inbred lines parental forms causes a negative response, reflected in the decrease of seed quality. Maize genotypes can differ in regard to their tolerance to high plant density (Al-Naggar et al., 2017; Çarpici et al., 2017).

Plant density must be correlated with the type and vegetation period of parental forms and cultivation conditions, to ensure higher seed quantity and quality at lower costs. Wych (1988) and Otegui (1995) recommended that the current sowing density of parental forms be between 45-65 thousand of plants per hectare, while Mirițescu (2000) recommended densities between 45-70 thousand plants per hectare. Density should not act as a stress factor because it can reduce the size of seeds and their quality (Cox, 1978; Boyat et al., 1984).

MATERIAL AND METHODS

Experiment design

Field experiments were conducted during 2015-2017 at the Agricultural Research and Development Station (ARDS) from Turda, Romania. Five maize inbred lines were used, which are part of the germplasm collection and have good prospects for breeding programs.

The experiment had following factors:

Factor 1 – experimental year, with three graduations: 2015, 2016, 2017.

Factor 2 – maize inbred lines parental forms, with five graduations: TC 344, TA 426, TC 385A, TA 447, TA 452.

Factor 3 – the plant density with three graduations: 50000 plants/ha, 70000 plants/ha, 90000 plants/ha.

Experimental variants were established in complete randomized design with three replicates. Each plot covered 7.0 m^2, resulting a total surface area of 315 m^2 (5 lines × 3 densities × 7 m^2 × 3 replicates) in addition to 126 m^2 protection bands. Thus, in the three years the trial covered a surface of 945 m^2 (315 m^2 × 3 years) excluding protection bands.

The following observations were conducted:

- seed yield and grain moisture at harvest;
- ear characters: ear weight, kernel weight/ear, ear length, number of rows/ear, number of kernels/row, percentage of kernels/ear;
- kernel characters: thousand kernels weight (TKW), volumetric weight, kernel depth.

Cultivation technology applied in the three experimental years was similar with the one presented in previous researches of Tritean (2015), Ona (2014) and Tinca (2017).

Statistical tests applied were: analysis of variance and Fishers' Least Significant Difference (LSD).

Climatic conditions

Meteorological conditions during the experiment were registered by weather station from ARDS Turda (longitude: 23°47´; latitude 46°35´; altitude 427 m), and are presented in Figures 1 and 2, compared with average values for last 58 years.

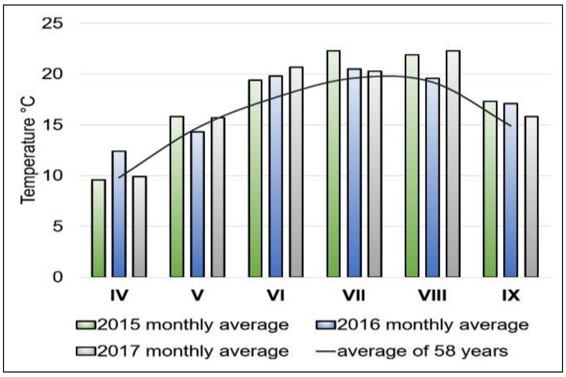

Figure 1. Temperatures during 2015-2017

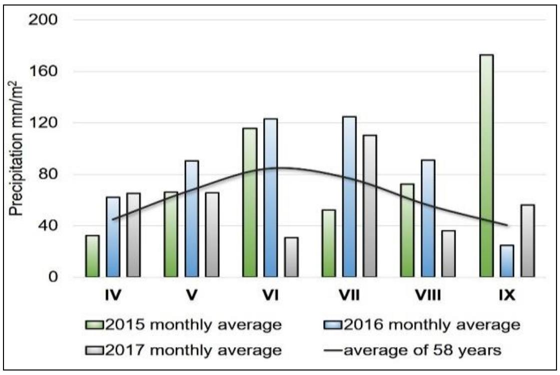

Figure 2. Precipitation levels during 2015-2017

Analyzing Figure 1, one can observe a warming tendency during the experimental interval, average monthly temperatures being over the average of the last 58 years. Higher temperatures and lack of precipitation during months of June and August influenced negatively, causing poor pollination and low grain filling and consequently lower production capacity. Temperatures from months of August and September caused the fast loss of grains moisture (Tinca, 2017; Ghețe, 2019). Maize growing season in first experimental year (28 April - 24 September 2015) was characterized by low precipitation levels during sowing-sprouting period when the water deficit was 12.5 mm/April, and during July at flowering-pollination-grain filling, when levels with 24.5 mm lower compared with last 58 years average were registered.

For third experimental year, during maize growing season (4 May - 25 September 2017), optimum conditions for a good development of plants were met. Precipitation levels (363.7 mm) during this interval was very close to average interval for last 58 years (374.6 mm).

RESULTS AND DISCUSSION

Seed yield

Analysis of variance presented in Table 1, revealed that grain yield of the parental inbred lines was distinctly significant influenced by experimental years as well as by plant density.

In addition, inbred lines as well as interaction between inbred lines and experimental years also exercised distinctly significant influence on grain yield.

Our results evidentiated that, with increase of plant density, the yield increased for all five inbred lines and that regardless of plant density, highest yield was recorded by two inbred lines TA 447 and TA 452 (Table 2).

Inbred line TA 426 registered a highly significant increase of seed yield with increasing plant density. This line registered an increase with 1143 kg/ha at density of 70000 plants/ha and an increase of 1045 kg/ha at density of 90000 plants/ha (Table 2).

Table 1. Influence of experimental factors and their interaction on seed yield, 2015-2017

Source of variability	*DOF*	Seed yield (U% = 15.5) kg/ha	
Total	134	s^2	Proba F
Years (A)	2	128438700	1236**
Repetition (R)	2	106789	-
Error (A)	4	103885	-
Density (D)	2	10728840	19.9**
AxD	4	4584268	8.50**
Error (D)	12	538759	-
Lines (L)	4	29236150	154**
AxL	8	4683507	24.7**
DxL	8	303980	1.60
AxDxL	16	227337	1.19
Error (L)	72	189832	-

Table 2. Influence of interaction between inbred lines and plant density on seed yield, 2015-2017

Line	Density (plants/ha)	Seed yield (kg/ha)	Significance
TC 344	50000	3425	Control
	70000	3813	n.s.
	90000	4003	*
TA 426	50000	4058	Control
	70000	5201	***
	90000	5103	***
TC 385A	50000	4172	Control
	70000	4866	**
	90000	5113	***
TA 447	50000	5410	Control
	70000	6253	**
	90000	6299	**
TA 452	50000	5726	Control
	70000	6301	*
	90000	6910	***
LSD (p 5%)		497	
LSD (p 1%)		677	
LSD (p 0.1%)		912	

The highest seed production was recorded by the TA 452 inbred line, which at a density of 90000 plants/ha achieved a seed production of 6910 kg/ha, with 1184 kg/ha more compared with control. This difference was highly significant (Table 2).

Ear characters

Ear weight and kernels weight/ear are productivity elements which have polygenic determinism, explained by the influence exercised by a multitude of factors on these traits, such as the genetic constitution of each line as well as the interaction between genotype and environment.

The three factors analyzed exercised significantly distinct influence over both ear weight as well as on kernels weight/ear at harvest. The interaction between experimental years and inbred lines studied also had a contribution to variability of these traits (Table 3).

The length of the ear was significantly influenced by the three experimental factors as well as by interactions between these (AxL, DxL and AxDxL). Maize ear length is recognized as a productivity characteristic that is often highly influenced by unfavorable environmental conditions, as well as by plant density (line TC 385A) (Sarca, 2004).

The following statistical analysis identified, according to Table 3, a distinctly significant influence of experimental factors (inbred line, plant density) and their interaction as well as the interaction between line and experimental year on the number of kernels per row and number of rows per ear.

Table 3. Analysis of variance for some ear characters, 2015-2017

Source of variability	*DOF*	Ear weight (g)	Kernels weight/ear (g)	Ear length (cm)	No. of kernels/row	No. of rows/ear	Percentage of kernels/ear (%)
Total	134	s^2					
Years (A)	2	19515**	16062.5**	88.4**	683**	19.4**	466.8**
Repetition (R)	2	66.5	81.7	1.6	0.8	0.4	5.7
Error (A)	4	79.2	110.4	0.3	8	0.03	18.7
Density (D)	2	2961.3**	2402.3**	10.7**	13.8*	0.5**	6.6
AxD	4	78.7	88.7	0.3	4.1	0.9*	16.3
Error (D)	12	47.2	64.2	0.1	2	0.2	24.8
Lines (L)	4	61.8**	2287.8**	100.0**	346.2**	182.1**	181.7**
AxL	8	3336.2**	2084.5**	20.3**	130.8**	12.3**	78.1**
DxL	8	116.1	134.2	2.6**	5.1	0.17	27.4
AxDxL	16	114.7	103.2	0.8**	4.5	0.8	11.7
Error (L)	72	61.8	67.2	0.3	2.8	0.6	16.4

Interaction between experimental years and inbred lines studied contributed as well to the variability of these traits. Notably, inbred line TA 426 presented the highest number of rows per ear, while inbred line TC 385A presented the lowest number of rows per ear, but at the same time the highest number of kernels per row. This genotype maintained the highest number of kernels per row even at high density of 90000 plants/ha (Table 4).

Regarding the output of kernels yields per ear (%), this was influenced significantly distinct by experimental years, inbred line and the interaction between them (AxL), but not by plant density (Table 3).

Surprisingly, for inbred lines TC 344 and TC 385A, presented a positive response to increase of plant density (90000 plants/ha) translated in output of higher kernels weight/ear (Table 4).

In fact, the increase of yield per ear output is due to forced drying of kernels, and a reduction of TKW.

Although seed yield increased significantly at a density of 90000 plants/ha compared to the density of 50000 plants/ha for late maize genotypes, seed quantity was significantly lower due to lower output at conditioning (Sarca et al., 1980; Sarca, 2004).

In the case of inbred lines TA 426, TA 447 and TA 452 a reduction in a number of kernels per ear with the increase of plant density was observed (Table 4).

Analysis of the relationship between genotype and plant density, indicates that an increase of plant density with 10000 plants/ha (between interval 50000-90000 plants/ha) corresponds to an increase of grain yield of 3.4 quintal/ha and a decrease of TKW of 5.3 g (Sarca, 2004; Haş et al., 1982; Haș, 2006). Thus, these are useful to be taken into consideration in breeding programs, for hybridization fields.

In evaluating the results, it is necessary to keep into account the differences between the three plant densities tested, but most important influence was the differences between the three experimental years. These were the major sources of variability in the behavior of the inbred lines studied. We highlight in this context the fact that phenotypic expression of the maize ears was the result of interaction between genotype and environmental conditions. In order to improve the seed production technology for maize, such results are valuable since they could be used to establish the limits until which genetic material is suitable for obtaining high quality harvests, as well as the moment when the genetic material is becoming vulnerable to the action of environmental factors, leading to low quality seed.

Table 4. The influence of inbred lines and plant density on ear characters, 2015-2017

Line	Density (plants/ha)	Ear weight (g)	Kernels weight/ear (g)	Ear length (cm)	Number of kernels/row	Number of rows/ear	Percentage of kernels/ear (%)
TC 344	50000 - Control	100.3	78.6	16.3	25.5	16.6	74.5
	70000	92.7^{0}	74.0	15.5^{00}	24.2	16.5	77.0
	90000	82.4^{000}	62.7^{000}	14.0^{000}	25.7	16.7	79.9*
TA 426	50000 - Control	114.2	94.6	14.8	28.3	20.7	82.5
	70000	106.9	92.7	14.5	29.0	20.6	83.3
	90000	100.5^{000}	82.8^{00}	14.7	28.8	20.6	82.5
TC 385A	50000 - Control	118.5	98.0	17.7	34.0	13.9	82.5
	70000	99.1^{000}	81.7^{000}	16.4^{000}	31.8^{00}	13.7	82.3
	90000	101.4^{000}	84.5^{00}	16.4^{000}	32.2^{0}	13.6	83.1
TA 447	50000 - Control	127.1	108.6	12.2	24.5	17.8	85.6
	70000	116.2^{00}	94.8^{00}	11.7	23.7	17.4	81.4^{0}
	90000	105.8^{000}	87.2^{000}	11.4^{00}	22.6^{0}	17.2	82.3
TA 452	50000 - Control	108.9	91.5	13.2	26.8	15.3	84.0
	70000	104.8	86.8	13.8*	25.2^{0}	15.2	82.7
	90000	98.3^{00}	81.3^{0}	12.8	25.5	15.2	82.7
LSD (p 5%)		7.3	7.8	0.5	1.6	0.7	4.1
LSD (p 1%)		9.8	10.5	0.7	2.1	1.0	5.5
LSD (p 0.1%)		12.9	13.9	0.9	2.8	1.3	7.4

Regarding the behavior of the five inbred lines under higher plant densities of 70000 plants/ha and, respectively, 90000 plants/ha, a reduction of ear weight and of kernels weight/ear, caused by reduction of ear size, was observed.

Thus, unfavorable conditions such as drought, heat, lack of precipitations in the most important part of the maize vegetation period, as well as increased plant densities, could contribute to inhibition of productivity potential of the inbred lines - parental forms studied. Similar results were presented by Tinca (2017), who argued that by increasing the density of plants, the productivity potential of some lines is limited, especially in the years unfavorable for this crop.

According to Table 4, between plant densities, ear and kernels weight/ear there was a very close negative correlation.

In most cases, at higher plant densities (70000 plants/ha and 90000 plants/ha) a significant decrease of average weight both of ear and of kernels weight per ear was registered, particularly at a density of 90000 plants/ha.

According to Sarca (2004), kernel density/ear decreases with the increase of plant density particularly for late genotypes. Previous research showed that although seed yield increased significantly at a density of 62500 plants/ha compared to 50000 plants/ha for late lines, seed yield was significantly lower due to lower output at conditioning (Sarca et al., 1980).

Plant density has to be correlated with the type and vegetative period of parental forms, as well as with climatic conditions, in order to lead to the highest possible yield quality and quantity at lowest costs.

In this study, inbred line TA 447 presented highest ear weight and highest kernels weight/ear, regardless of plant density. This aspect was further confirmed in the case of average seed yield (kg/ha) in all experimental years.

By increasing plant density (from 50000 to 90000 plants/ha) a significant decrease of ear weight and kernels weight/ear was registered for all inbred lines studied.

Although there was an increase in seed production, with the increase in density, for all the lines from 578 kg/ha for line TC 385A, respectively, 1184 kg/ha for TA 452 (Table 2), its quality was negatively influenced due to decrease of TKW.

The length of the ear for all five inbred lines studied, decreased with the increase of plant density (Table 4). This impact is expected as a result of the limitation of available nutrients with the decrease of the area around each plant.

The longest ear was registered by inbred line TC 385A (which also registered the highest decrease of ear length with an increase of plant density), while shortest ear was identified for lines TA 447 and TA 452.

Researches of Sarca (2004), Tokatlidis et al. (2005) and Al-Naggar (2012) explain the decrease of ear length associated with an increase of plant density as caused by mutual plant shading which results in reduced photosynthetic activity, besides reduction of the nutritive area - cumulative factors which inhibit the expression of the productivity potential of the biologic material.

By analyzing the results from Table 4, it can be observed that some characteristics of the inbred lines, such as the number of rows per ear and number of kernels per row, as well as the percentage of kernels per ear, were less affected by the increase of plant density.

Similar results were obtained by Tinca (2017) by applying three sowing densities.

Although in the case of increased density: 70000-90000 plants/ha, the ear length, ear weight and ear diameter decreased for some lines, still, number of rows per ear remained unchanged since this is a trait with additive genetic determinism and thus it is characteristic to each genotype.

Kernel characters

Table 5 presents the analysis of variance for TKW, kernel depth, volumetric weight and dry matter of kernels.

Volumetric weight and dry matter of kernels were not influenced statistically by plant density, but they were influenced distinctly significant by experimental years, inbred line and several double (AxL, DxL) and triple (AxDxL) interactions (Table 5).

Interaction between inbred line and experimental years, although exercised a distinctly significant influence on these four kernel characteristics, proved to be more important for TKW. It can be asserted that TKW is characteristic of each genotype, which can be influenced by environmental conditions and according to Căbulea et al. (1985), Tritean (2015) and Tinca (2017) in the genetic determinism of the reaction to plant density, highly significant non-additive genetic actions prevail.

Table 5. Influence of experimental factors and their interaction on some kernels characters, 2015-2017

Source of variability	*DOF*	TKW (g)	Kernel depth (cm)	Volumetric weight (kg/hl)	Dry matter of kernels (%)
Total	134	s^2			
Years (A)	2	18663.1**	0.222**	270.3**	57.6**
Repetition (R)	2	781.9	0.0009	0.64	0.08
Error (A)	4	13.1	0.001	2.8	0.15
Density (D)	2	5124.9**	0.013	0.85	2.94
AxD	4	1057.06*	0.002	1.20	2.23
Error (D)	12	342.4	0.004	3.03	1.28
Lines (L)	4	21281.8**	0.204**	155.41**	74.25**
AxL	8	4196.7**	0.03**	51.50**	73.45**
DxL	8	364.5	0.002	5.49**	2.47**
AxDxL	16	183.3	0.003	2.57**	2.49**
Error (L)	72	303.07	0.002	3.51	0.86

Results from the current study showed that in the case of inbred lines TC 385A and TA 452, plant density did not affect TKW.

Thus, the parental form TA 452 is more suitable for high plant density (90000 plants/ha), which leads to the highest yield while having no effect on seed quality, respectively, TKW. The highest dry matter of kernels was registered for inbred line TC 385A (the line which also presents the shortest vegetative period from sowing to silking and full maturity) regardless of plant density (Table 6).

Table 6. Influence of interaction between inbred lines and sowing density on the kernels characters, 2015-2017

Line	Density (plants/ha)	TKW (g)	Volumetric weight (kg/hl)	Kernel depth (cm)	Dry matter of kernels (%)
TC 344	50000 - Control	251.2	59.6	0.74	77.4
	70000	229.8^{0}	60.7	0.74	77.7
	90000	220.4^{000}	59.1	0.71	78.9**
TA 426	50000 - Control	221.3	58.6	0.84	75.8
	70000	201.6^{0}	59.8	0.80	76.5
	90000	193.6^{00}	59.6	0.79^{0}	76.9*
TC 385A	50000 - Control	237.4	65.1	0.70	80.5
	70000	230.7	64.6	0.66	81.0
	90000	226.3	65.7	0.64^{0}	81.5*
TA 447	50000 - Control	291.1	61.4	0.91	78.5
	70000	289.1	59.8	0.87	77.8
	90000	267.0^{00}	59.7	0.90	77.9
TA 452	50000 - Control	256.4	60.4	0.82	78.6
	70000	240.7	59.5	0.83	78.6
	90000	244.6	59.5	0.81	78.1
LSD (p 5%)		16.9	1.76	0.06	0.9
LSD (p 1%)		22.8	2.37	0.07	1.3
LSD (p 0.1%)		30.1	3.13	0.10	1.7

The lowest percentage of dry matter of kernels was found for inbred line TA 426 (Table 6). This line is characterized by a high number of rows per ear (20-24) being part of germplasm group BSSS, from which lines of high productivity belong.

Promoting the genotypes with fast loss of water from the grains at maturity such as TC 385A could present some advantages. As Sarca (2004) indicated, these prove useful in areas with limited thermic resources.

CONCLUSIONS

In the distinct weather conditions from ARDS Turda, the following conclusions regarding the influence of plant density on productivity traits of some inbred lines parental forms of hybrid maize can be drawn:

1) Seed yield increased following increase of plant density, including in 2015 - year characterized by the less favorable distribution of precipitation levels for maize in Transylvanian Plain.

2) By using high plant density ≥70000 plants/ha, productivity elements of the inbred lines studied, respectively, ear and kernels weight/ear, ear length and the number of rows per ear registered decrease in average values, but the quality of the final yield was not influenced, because yield/plant losses were compensated by the higher number of plants per hectare.

3) Thousand kernels weight for inbred lines TC 344, TA 426 and TA 447 were significantly reduced by high plant densities of 70000-90000 plants/ha. This fact indicates that increased plant density for these particular lines could affect seed quality, and respectively, germination energy.

4) For obtaining high seed quantity in hybridization field, we recommend inbred lines TA 452 and TA 447, as parental forms, complementary with the application of optimum cultivation technology. These two lines are the most stable at changes in sowing density.

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