Theses of Doctoral (Ph. D.) dissertation

STUDY OF PRODUCTION AREA AND REACTION TOWARDS PLANT DENSITY OF MAIZE HYBRIDS' WITH DIFFERENT GENOTYPES

Eszter Murányi

Supervisor:

Dr. Péter Pepó

university professor

University of Debrecen

Kálmán Kerpely Doctoral School

Debrecen

2016

1. INTRODUCTION AND OBJECTIVES OF THE DISSERTATION

Yield and yield safety of maize are influenced by several ecological, biological and agrotechnical factors. These factors affect yield results directly and in interaction with each other. Today the aim is to produce the highest possible yield amounts on a unit area by even higher yield safety. Ecological including soil and weather conditions shall be considered in the production. Agrotechnical elements, just as hybrids shall be chosen according to the properties of these factors. Hybrids with different genotypes and vegetation period lengths show different, hybrid-specific reaction towards the change of production area, including row spacing and plant density. However, the given crop year has the highest impact on produced yield amount. Extreme weather conditions, just as the application of too high plant densities may lead to significant yield decrement. In order to increase yield safety of maize production it is important to know the reaction of hybrids with different genotypes towards the application of different production areas. Weather conditions of the vegetation period are unknown before, long-term forecasts are unsure, but it is determining to have information on the amount of precipitation before the vegetation period.

Even more hybrids are produced both nation- and worldwide: the available hybrid palette has become even wider. This wide range of available hybrids can be considered as a hindrance for the objective evaluation of different hybrids' properties. In the present research work a wide range of studies has been carried out in order to evaluate these characters. These studies included the study of the reaction of different maize genotypes towards the application of different row spacings and plant densities in different crop years. Beside the registration of yield amounts, plant morphological (plant height, ear height, growth dynamics) and physiological (LAI, SPAD, LAD) parameters were measured during the whole vegetation period. Different index values were calculated from these measurement results, such as photosynthetic capacity, individual production and leaf area yield efficiency. Beside these changes in yield producing factors were monitored as affected by production technology elements and weather conditions. Hybrids showed specific reaction towards increasing plant density and decreasing production area. Optimal plant density, just as its optimal interval and the reaction of hybrids to plant density were determined in the experimental crop years.

The present research work set following objectives:

- to study the effect of the crop year, row spacing, plant density and hybrid on plant morphologic (plant height and ear height, growth dynamics) and physiologic (leaf area index, relative chlorophyll content, leaf area durability) parameters,
- to elaborate and introduce new indexes,
- to study the effect of ecological and sowing technology factors on yield producing factors (such as thousand seed weight, cob length, cob diameter, number of rows per cob, number of kernels per row, kernel : cob rate),
- to study the effect of weather conditions and agrotechnical factors (row spacing, plant density) on the yield and harvest grain moisture content of maize hybrids with different genotypes,
- to determine the demand and reaction of maize hybrids to plant density and its increment,
- to study the effect of the crop year and the applied hybrid on the plant density optimum and the development of optimum interval,
- to determine the correlations between the studied parameters and factors.

The obtained scientific results can promote the refinement of production site- and hybrid-specific production area- and plant density-reactions of the latest hybrids.

2. MATERIALS AND METODHS

2.1. Location and soil conditions of the experimental field

The effect of the application of different row spacing values and plant densities was studied in the crop years of 2013, 2014 and 2015 at the Látókép Research Site of the University of Debrecen. The experimental site is located at the Hajdúság loess ridge, 15 km far from the city of Debrecen, its geographical coordinates are 47^{o}33' N, 21^{o}27' E. The experimental soil is flat, levelled, regarding its soil genetic properties it belongs to the type of calcareous chernozem.

2.2. Experimental settings and arrangement

The three-factor experiment was set up in split-split-plot design (double split plots) in four replications. The three studied factors were row spacing (A), plant density (B) and hybrid (C). Production area was the same for both applied row spacing values, spacing of plants changed due to the application of different row spacings and plant densities. In the present research work the effect of the application of the row spacings 45 and 76 cm, just as the plant densities of 50,000, 70,000 and 90,000 plants ha^{-1} on plant morphological and physiological parameters, just as yield producing factors and yield amounts were studied. Each plot consisted of two rows; the area of each was 9 m^2 when applying the row spacing of 45 cm, while in case of the row spacing of 76 cm it was 15.2 m^2.

12 maize hybrids with different genotypes and vegetation period lengths were studied in the experiment in the crop years 2013, 2014 and 2015. One very early (FAO 240-299), nine early (FAO 300-399) and two medium (FAO 400-499) ripening hybrids were involved into the experiment. The very early hybrid was Sarolta (FAO 290). Early hybrids were P 9578 (FAO 320), DKC 4015 (FAO 320), DKC 4025 (FAO 330), P 9175 (FAO 330), NK Lucius (FAO 330), PR 37M81 (FAO 360), PR 37N01 (FAO 380), DKC 4490 (FAO 380) and P 9494 (FAO 390). Medium ripening hybrids were Kenéz (FAO 410) and SY Afinity (FAO 470).

2.3. Weather characters of the studied crop years

Weather conditions of the studied crop years were different: extreme weather conditions were observed in all crop years. Apart from a few exceptions registered temperature values were higher in all studied vegetation months than the respective several-years average values.

Water supply of the crop year 2013 was determined by the high amount of fallen precipitation in March (136 mm), which – together with the winter precipitation amount – filled the water stock of the chernozem soil, thus the water amount was ensured for the vegetative development of maize plants during the spring and early summer months *(Figure 1)*.

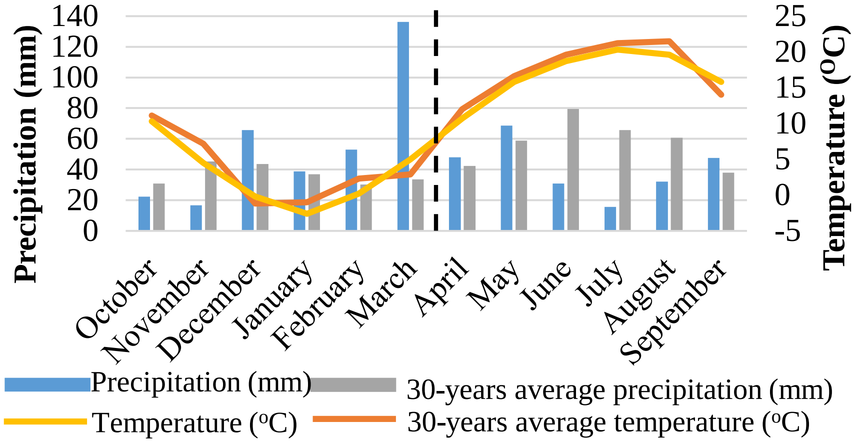

Figure 1 Development of precipitation amount (mm) and temperature (˚C) values before and during the vegetation period (Debrecen, Látókép 2012-2013)

In the intensive plant growth phase of the crop year 2014 72 mm less precipitation was registered than the several-years average that hindered the vegetative development of the maze population. The high amount of precipitation in July (128 mm) ensured favourable water supply conditions for the grain filling processes in the beginning of August *(Figure 2.)*. More than two times higher amount of precipitation was measured in September than the several-years average. Due to the wet weather conditions ripening processes of maize populations, just as the drying of grain yield were slower. Thus harvest date was delayed till the 20th October. The total amount of fallen precipitation could be considered as favourable in the crop years 2013 and 2014, but its distribution was rather unfavourable in both years.

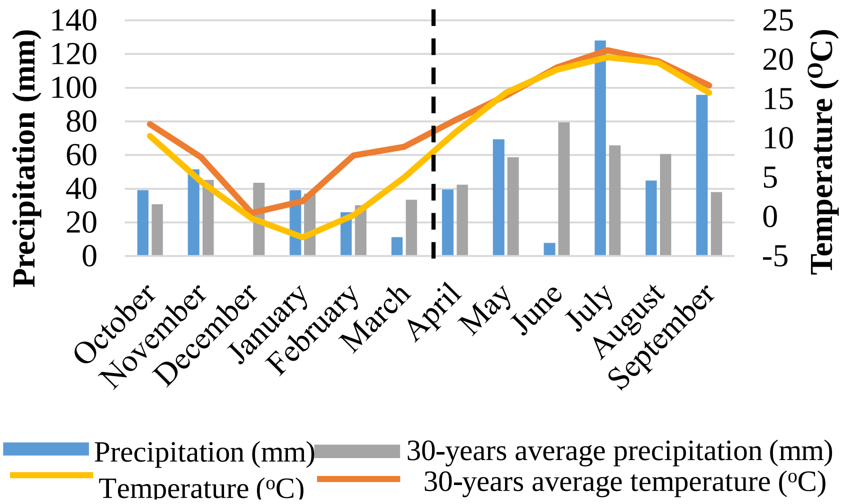

Figure 2 Development of precipitation amount (mm) and temperature (˚C) values before and during the vegetation period (Debrecen, Látókép 2013-2014)

Most of the vegetation period of 2015, just as the previous months were lack of precipitation with temperature values higher than the several-years average values *(Figure 3.)*. The heatwave and drought between the second half of July and the second half of August were explicitly unfavourable from the aspect of maize grain filling processes. Temperature values were extreme high in this period, due to which maize populations lost their assimilation area rapidly. This affected maize grain filling processes unfavourable and shortened the vegetation period significantly.

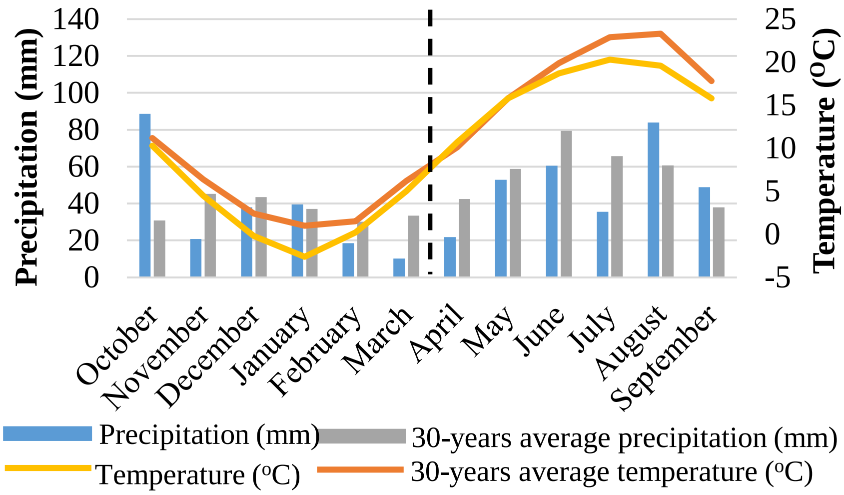

Figure 3 Development of precipitation amount (mm) and temperature (˚C) values before and during the vegetation period (Debrecen, Látókép 2014-2015)

2.4. Determination of maize morphological and physiological parameters, just as yield and yield producing factors

Determination of maize morphological and physiological parameters

Plant morphological parameters

Plant morphological parameters were measured in case of all studied row spacing values, plant densities and hybrids.

- *Plant height (cm)* was measured each two weeks period from the development stage of 2-4 leaves until the development of the final plant height (male flowering, approx. the middle of July). The heights of 5 average developed plants were measured per each plot. Until the male flower appeared plant height was considered to be measured as the distance from soil surface to the highest point of the upper leaf initiatives, while after that as the distance between soil surface and the highest point of the male flower.
- *Ear height (cm)* was measured once in the vegetation period. It has been defined as the distance between soil surface and the attachment point of the most developed cob.

Plant physiological parameters

Plant physiological parameters were monitored in case of 6 selected hybrids (Sarolta, DKC 4025, P 9175, NK Lucius, P 9494, SY Afinity), all row spacings (2), plant densities (3) and replications (4) at different development stages which were 4-6 leaves, stem elongation, male and female flowering, grain filling and ripening phases.

- *Relative chlorophyll content (SPAD-value)* was measured by a SPAD-502 Plus (Konica Minolta) portable device. Its advantage is that chlorophyll amount can be measured by it under field conditions, without any plant destruction.
- *Leaf area index (LAI)* (m^2 m^{-2}) was determined by a Sun Scan Canopy Analysis System portable device. Leaf area size per each square meter is considered as leaf area index.
- *Leaf area durability (LAD)* was determined as well: this expresses the duration (days) while a plant or plant population maintains its active photosynthesizing area.

Definition of indexes used in the present research work

- *Photosynthetic capacity (Ph. C.)* is calculated according to the index calculation introduced by Prof. Péter Pepó for the complex evaluation of yield, maximal leaf area index and relative chlorophyll content.
- *Individual productivity (IP) (g plant^{-1})* informs about the yield amount realized by an individual within a population.
- *Leaf area yield efficiency (LYE) (g cm^{-2})* shows the yield amount per unit leaf area. This informs about the efficiency of solar energy utilization of a plant population.

Definition of yield producing factors

Cob samples were collected after the finish of the grain filling and the appearance of the black layer in September. In the first two years of the experiment 2 cobs, while in 2015 3 cobs were collected from each plot of 2 replications of each treatment combination in order to study yield producing factors. The studied yield producing factors were cob length, cob diameter, the number of rows, number of kernels per row, thousand seed weight and corn: cob rate. At harvest grain moisture content and the harvested grain yield amount were measured and yield results were unify recalculated (14% grain moisture content) using these results.

2.5. Method of results' evaluation

Result data were processed and statistically evaluated using the software Microsoft Excel 2013 and SPSS for Windows. In order to define significant differences three-way analysis of variance (row spacing, plant density and hybrid) was used and in case it did not show any significant difference two-way ANOVA (plant density, hybrid) was run. Probability level was set for $P = 0.05$ which is commonly used in agricultural research. In order to define correlations between the studied factors Pearson correlation analysis was run. Correlation coefficient r-values can range from -1 to 1. The calculated value describes the strength of the correlation. In case r-value <0.4 loose, 0.4-0.7 medium, 0.7-0.9 strong, >0.9 very strong correlations can be determined.

In order to determine the optimum plant density quadratic regression analysis was used and the plant density optimum interval of the studied hybrids was defined using the calculated significant difference values.

3. RESULTS

3.1. The effect of crop year and production area on the development of maize hybrids' morphological and physiological parameters

Plant and ear height

Regarding plant height and ear height development differences between the studied genotypes were determining, just as the weather conditions of the given crop year. The intensive growth phase was observed in June: the lack of precipitation in this period implied lower plant height development. The impact of plant density on plant height could be statistically verified only in case of the application of a row spacing of 45 cm in the crop year of 2013, just as in case of the row spacing of 76 cm in 2015. Plant height and ear height showed increasing tendency in 2013, however this was not that significant. In the crop year of 2014 the highest plant height was measured in case of the row spacing of 45 cm and the loosest plant density. The highest plant height values were measured in case of the application of a plant density of 70,000 plants ha^{-1} for both row spacings in the crop year of 2015.

In the vegetation period of 2013 the studied hybrids reached a plant height of 277-284 cm in case of the application of a row spacing of 45 cm, while in case of that of 76 cm between 281 and 284 cm depending on the applied plant density and regarding the average of the hybrids *(Table 1.).* Plant heights of the two different row spacing populations were different in 2014. Applying the row spacing of 45 cm the highest plant height was measured in the population with a plant density of 50,000 plants ha^{-1} (regarding the average of the hybrids plant height was 253 cm), while in case of the row spacing of 76 cm the highest plants were measured in the populations with densities of 70,000 and 90,000 plants ha^{-1} (260, just as 258 cm resp.). In the crop year of 2015 plant height values ranged between 278 and 281 cm in case of the row spacing of 45 cm, while in case of that of 76 cm values between 282 and 288 cm were measured.

The studied hybrids showed higher ear height uniform when applying the row spacing of 76 cm in the crop year of 2013. In case of both studied row spacings – apart from some exception hybrids – the highest ear height values were measured in the populations with a plant density of 90,000 plants ha^{-1}, that was 126 cm in case of the row spacing of 45 cm and 134 cm by that of 76 cm regarding the average of the hybrids. Ear height values ranged between 117 and 126 cm in case of row spacing of 45 cm, and between 125 and 134 cm in case of that of 76 cm depending on the studied factors. In the crop year of 2014 the highest ear height value was measured in the populations with plant densities of 50,000 and 70,000 plants ha^{-1} when applying a row spacing of 45 cm (106 cm), and in case of that of 76 cm for the most hybrids in the population with 90,000 plants ha^{-1} (105 cm) regarding the average of the hybrids. In the crop year of 2015 the highest ear height values were measured for both studied row spacing values in the populations with a plant density of 70,000 and 90,000 plants ha^{-1}.

Depending on the studied factors ear height ranged between 109 and 116 cm for the row spacing of 45 cm and between 110 and 115 cm for that of 76 cm.

Medium correlation (0.397-0.568**) was found between plant and cob height values.

Table 1 The effect of row spacing and plant density on maize plant and cob height values (cm) regarding the average of the studied hybrids (Debrecen, Látókép 2013-2015)

Years	Row spacing	Plant density (thousand plants ha^{-1})							
		Plant height (cm)				Ear height (cm)			
		50	70	90	**Average**	50	70	90	**Average**
2013	45 cm	277	283	284	**281**	117	120	126	**121**
	76 cm	281	283	284	**283**	125	131	134	**130**
2014	45 cm	253	237	226	**239**	106	106	102	**105**
	76 cm	255	260	258	**258**	99	102	105	**102**
2015	45 cm	279	281	278	**279**	109	115	116	**113**
	76 cm	282	288	283	**284**	110	114	115	**113**

Development of relative chlorophyll content (SPAD) and leaf area index (LAI), just as leaf area durability (LAD) values

Relative chlorophyll content (SPAD) and leaf area index (LAI)

Relative chlorophyll content (SPAD) and leaf area index (LAI) values showed seasonal dynamic development. These values were measured in the main development stages during the vegetation period, which were 4-6 leaves development, stem elongation, male and female flowering stage, grain filling and ripening. Hybrids of different ripening groups were selected from the studied hybrids that were Sarolta (FAO 290), DKC 4025 (FAO 330), P 9175 (FAO 330), NK Lucius (FAO 330), P 9494 (FAO 390) and SY Afinity (FAO 470).

An increasing phase could be observed until a maximum value that was reached by the different hybrids at the flowering or grain filling stage in July; after that parallel to the drying of plants LAI and SPAD values decreased during the ripening phase. Maximal SPAD and LAI values of the studied hybrids were measured in July, during the male and female flowering, just as in the grain filling phases. Parallel to the increasing plant density relative chlorophyll content decreased, while leaf area index increased *(Table 2)*. Production area decreased parallel to increasing plant density and maize plants shadowed each other to a higher extent. The reason for the increasing leaf area index was that individual plants competed for water, light and nutrients due to the increasing plant density.

Regarding the average of the studied factors and the crop year SPAD $_{max}$ values ranged between 57.1 and 64.4, while LAI $_{max}$ values between 3.1 and 5.1 $m^2\ m^{-2}$.

Table 2 The effect of row spacing and plant density on the maximum relative chlorophyll content and leaf area index ($m^2\ m^{-2}$) regarding the average of the hybrids (Debrecen, Látókép 2013-2015)

Years	Row spacing	Plant density (thousand plants ha^{-1})							
		SPAD $_{max}$				LAI $_{max}$ ($m^2\ m^{-2}$)			
		50	70	90	**Average**	50	70	90	**Average**
2013	45 cm	59.7	58.1	57.1	**58.3**	3.4	4.0	4.5	**4.0**
	76 cm	60.4	59.0	58.1	**59.2**	3.1	3.5	4.0	**3.5**
2014	45 cm	63.4	62.7	62.3	**62.8**	3.5	3.5	3.8	**3.6**
	76 cm	64.2	64.4	63.5	**64.0**	3.1	3.9	4.4	**3.8**
2015	45 cm	60.5	59.2	58.0	**59.2**	4.3	4.7	5.1	**4.7**
	76 cm	61.1	59.4	57.7	**59.4**	3.7	4.1	4.3	**4.0**

Leaf area duration (LAD, days)

LAD defines the duration while a plant or a plant population maintains its active photosynthesizing surface (days) in a quantitative form

Formula for LAD calculation is:

$$D_{2-1} = \frac{(L_1 + L_2) * (t_2 - t_1)}{2}$$

The highest LAD value was measured in the densest population in the studied crop years *(Table 3)*. Leaf area of the population was maintained longer in case of the denser population. Significant differences were found between the applied plant densities and hybrids in all studied crop years, while the effect of row spacing was verified only in 2015. Depending on the applied row spacing, plant density and hybrid LAD values ranged between 252 and 292 days in 2013, 210 and 279 days in 2014, and 226 and 312 days in the crop year of 2015.

Table 3 The effect of row spacing and plant density on leaf area durability (days) of maize hybrids regarding the average of the hybrids (Debrecen, Látókép 2013-2015)

Leaf area durability (LAD, days)					
Years	Row spacing	Plant density (thousand plants ha^{-1})			**Average**
		50	70	90	
2013	45 cm	227	267	292	**262**
	76 cm	225	253	278	**252**
2014	45 cm	235	253	262	**250**
	76 cm	210	248	279	**246**
2015	45 cm	257	289	312	**286**
	76 cm	226	252	269	**249**

3.2. Evaluation of correlations between yield and the studied factors using different indexes

– *Photosynthetic capacity (Ph.C.)*

In order to evaluate yield, maximal leaf area index and relative chlorophyll content in a complex way the photosynthetic capacity, referred as Ph. C. or P-index value – introduced by Prof. Péter Pepó – was calculated. The formula according to that photosynthetic capacity is calculated is the following:

$$Ph.C.(P\ index) = \left(\frac{Yield}{LAI\ max} * \frac{Yield}{SPAD\ max}\right)/1000$$

Different index values were calculated from the experimental results. Assimilation area of maize hybrids plays a determining role in yield development, therefore photosynthetic capacity (Ph.C.) value was determined using yield, LAI_{max} and $SPAD_{max}$ values. Significant differences were found between the photosynthetic capacity values calculated for different crop years *(Table 4)*. Differences were found between hybrids of diverse genotypes as well. Ph.C. value of the populations sown using the conventional row spacing were higher than that of the population sown with narrow row spacing: this difference was not significant in 2013 (5.61%), while significant differences were found in 2014 and 2015 (17.54%; 24.46%). The effect of the applied plant densities could be verified in the crop years 2014 and 2015: significant differences were detected between photosynthetic capacity for the applied plant densities of 50,000 and 70,000, just as between 70,000 and 90,000 plants ha^{-1}.

Table 4 The effect of row spacing and plant density on maize hybrids' photosynthetic capacity (Ph. C.) regarding the average of the hybrids (Debrecen, Látókép 2013-2015)

Photosynthetic capacity (Ph. C.)					
Years	Row spacing	Plant density (thousand plants ha^{-1}) 50	70	90	**Average**
2013	45 cm	869	946	907	**907**
	76 cm	1026	969	889	**961**
2014	45 cm	640	673	510	**608**
	76 cm	733	755	724	**737**
2015	45 cm	323	339	301	**321**
	76 cm	436	455	384	**425**

– *Individual yield productivity (IP) (g plant^{-1})*

The index of individual productivity shows the yield amount realized by one individual plant within a population. It is calculated according to the following formula:

$$IP = \frac{Yield\ (kg\ ha^{-1})}{Plant\ density\ (plant\ ha^{-1})} * 1000$$

Beside the yield amount per hectare individual yield productivity (g $plant^{-1}$) was quantified as well. This index presented decreasing individual production parallel to the increasing plant density. Negligible difference was found between the studied crop years in 2013, while both plant density and the applied hybrids resulted in significant differences of the studied parameter. Its value ranged between 166 and 258 g $plant^{-1}$ in case of the row spacing of 45 cm, while in case of that of 76 cm between 154 and 263 g $plant^{-1}$. The highest individual productivity values were measured in case of the plant population with a density of 50,000 plants ha^{-1}: it ranged between 258 and 263 g $plant^{-1}$ depending on the given plant density and hybrid. All studied factors had significant impact on the individual production parameter in both 2014 and 2015. Significantly higher individual productivity was observed in case of the application of the conventional row spacing: in 2013 its value was 10.17% (20 g $plant^{-1}$), while in 2015 6.78% (10 g $plant^{-1}$) higher than that of the population with narrow row spacing. Increasing plant density resulted in significant decrease of the individual production of plants in all studied crop years *(Table 5)*.

Table 5 The effect of row spacing and plant density on maize hybrids' individual productivity (IP) (g $plant^{-1}$) regarding the average of the hybrids (Debrecen, Látókép 2013-2015)

Individual productivity (IP, g $plant^{-1}$)					
Years	Row spacing	Plant density (thousand plants ha^{-1})			**Average**
		50	70	90	
2013	45 cm	258	202	166	**209**
	76 cm	263	197	154	**205**
2014	45 cm	238	170	123	**177**
	76 cm	241	192	159	**197**
2015	45 cm	184	139	108	**144**
	76 cm	200	151	110	**154**

– *Leaf area yield efficiency (LYE, g cm^{-2})*

Informs about the yield amount per unit leaf area; the efficiency of solar energy utilization of a plant population can be concluded from this index. The formula for the calculation of leaf area yield efficiency is:

$$LYE = \frac{Yield\ (kg\ ha^{-1})/10000}{LAI\ \text{max}\ (m^2\ m^{-2})}$$

In order to describe the efficiency of plant populations' solar energy utilization yield amount per unit leaf area (Leaf area Yield Efficiency LYE) was calculated too. Statistically significant differences in LYE values were resulted by the application of different row spacings, plant densities and hybrids. Leaf area yield efficiency (g cm^{-2}) values were higher in case of the application of the conventional row spacing in all studied crop years.

Table 6 The effect of row spacing and plant density on maize hybrids' leaf area yield efficiency (LYE) (g cm^{-2}) regarding the average of the hybrids (Debrecen, Látókép 2013-2015)

Leaf area yield efficiency (LYE, g cm^{-2})					
Years	Row spacing	Plant density (thousand plants ha^{-1})			**Average**
		50	70	90	
2013	45 cm	0.385	0.372	0.337	**0.365**
	76 cm	0.446	0.401	0.361	**0.403**
2014	45 cm	0.342	0.346	0.286	**0.325**
	76 cm	0.385	0.353	0.323	**0.354**
2015	45 cm	0.211	0.207	0.184	**0.201**
	76 cm	0.267	0.256	0.225	**0.249**

The population with row spacing of 76 cm utilized the incoming light energy more effective. In case of the application of the narrow row spacing the production area is similar to the square type, which is outstanding from the aspect of soil coverage and the reduction of transpiration; however plants have higher shadowing effect to each other. Higher extent of LYE decrease was observed when plant density was increased from 70,000 to 90,000 plants ha^{-1} *(Table 6).*

3.3. The effect of ecological and sowing technology factors of the development of yield producing factors

Parallel to increasing plant density the individual production decreased, but the higher plant number per unit area compensated this decrease. Individual production was determined by the development of yield producing factors. Significant difference was found between hybrids in case of all studied yield producing factors. The applied row spacing did not affect either thousand seed weight or cob parameters. The application of different plant densities resulted in decreasing thousand kernel weight; significant differences were found in all studied crop years except for the crop year 2013. The highest extent of thousand seed weight decrement was resulted by the increasing plant density from 70,000 to 90,000 plants ha^{-1}. Medium correlation ($r = 0.445\text{-}0.629^{**}$) could be observed between thousand kernel weight and cob length, just as cob diameter. Cob parameters less affected by plant density were cob diameter, the number of rows per cob and corn: cob rate. Regarding corn: cob rate only the effect of the applied genotype could be revealed. The lowest values were measured in all studied crop years in case of the hybrid Sarolta (FAO 290): 84-87:16-13. Several hybrids produced kernel percentage values of 90% or above in the experimental years. Kernel percentage values of the hybrids P 9578 (FAO 320) and DKC 4025 (FAO 330) were higher than 90% in two experimental crop years as well (2013, 2014).

3.4. The effect of weather conditions, row spacing and plant density on yield amount development

Weather conditions of the studied crop years were determining from the aspect of yield development. Regarding the average of plant densities and hybrids yield amounts were 14,012 kg ha^{-1} in 2013, 11,640 kg ha^{-1} in 2014 and 9,556 kg ha^{-1} in 2015 in case of the row spacing of 45 cm, while when applying that of 76 cm 13,610 kg ha^{-1} in 2013, 13,236 kg ha^{-1} in 2014 and 10,141 kg ha^{-1} in 2015, respectively *(Table 7).*

Parallel to increasing plant density yield amount increased as well in case of both applied row spacings in 2013. In the crop year of 2014 regarding the narrow row spacing negligible difference was found between the yield of populations with 50,000 and 70,000 plants ha^{-1}; the lowest yield amount was registered in case of the plant density of 90,000 plants ha^{-1}. In 2015 the highest yield was measured in the populations with densities of 70,000 and 90,000 plants ha^{-1}. Despite the extreme weather conditions increasing plant density resulted in yield increment as well. Special microclimatic conditions were observed in the population with narrow row spacing that could be attributed to the closed plant population.

Table 7 The effect of row spacing, plant density and crop year on yield amount (kg ha^{-1}) regarding the average of the hybrids (Debrecen, Látókép 2013-2015)

Grain yield (kg ha^{-1})					
Years	Row spacing	Plant density (thousand plants ha^{-1})			**Average**
		50	70	90	
2013	45 cm	12893	14169	14973	**14012**
	76 cm	13130	13824	13877	**13610**
2014	45 cm	11921	11892	11109	**11640**
	76 cm	12069	13415	14304	**13263**
2015	45 cm	9210	9697	9762	**9556**
	76 cm	9993	10571	9860	**10141**

Optimum and optimal interval of maize hybrids with different genotypes in case of different crop years and soil types mean important information. Optimal plant density and the corresponding yield maximum were determined using quadratic equation. Hybrids were classified into condensability groups according to their optimal plant density intervals which groups were less, medium and well condensability categories. Beside this it has been determined which hybrids could be produced with broad or even narrow row spacing intervals. Taking the difference between extremum values of optimum intervals as a basis three condensation categories were determined that are shown in *Table 8*.

Table 8 Condensation categories (thousand plants ha^{-1}) in the crop years 2013, 2014 and 2015

Condensability categories (thousand plants ha^{-1})	**2013**		**2014**		**2015**	
	45 cm	**76 cm**	**45 cm**	**76 cm**	**45 cm**	**76 cm**
Less condensable hybrids	3-14	5-17	2-15	1-8	3-15	8-15
Medium condensable hybrids	14-24	17-28	15-27	8-15	15-28	15-23
Well condensable hybrids	24-35	28-40	27-40	15-22	28-40	23-30

According to the range of the intervals hybrids with wide (20-40 thousand plants ha^{-1}) and narrow (0-20 thousand plants ha^{-1}) optimum intervals were differentiated.

Hybrids that produce high yield amounts by the application of different plant densities – in case of the present experiment between 50 and 90,000 plants ha^{-1} – are considered as favourable. Hybrids that produce moderate or below average yield amounts in case of the application of different plant densities are considered as less favourable regarding their realized yield amounts and reaction towards plant density changes. 50,000 plants ha^{-1} was chosen as basis and yield maximums related to the densities of 70,000 ad 90,000 plants ha^{-1} were determined as well. Hybrids that produce high yield amounts by relative high plant densities are considered as favourable.

Maize hybrids can be categorized according to their demand on plant density and the produced yield levels that is the reaction towards plant density into the following categories:

1. hybrids that produce low yield amounts in case of the basis plant density; that demand relative high plant densities,
2. hybrids that produced yields over average, high yield levels by the application of the studied plant densities; that can be characterized by a good reaction towards plant density,
3. hybrids that produced yields below average and low yield levels by the application of the studied plant density range; that showed unfavourable reaction towards plant densities in the studies crop years,
4. just as hybrids that produced high yield amounts in case of the application of the basis plant density; that have demand on low plant density.

In the crop year of 2013 the plant density optimum (45 cm: 86,177 plants ha^{-1}, 76 cm: 80,970 plants ha^{-1}) and optimum interval (45 cm: 75-90,000 plants ha^{-1}, 76 cm: 70-87,000 plants ha^{-1}) were similar in case of the application of the two different row spacing values and regarding the average of the hybrids *(Table 9.)*. When applying the narrow row spacing 10 hybrids, while when applying the conventional row spacing 7 hybrids reached their maximum by the application of a plant density higher than 80,000 plants ha^{-1}. Higher yield amounts were produced in case of the application of the narrow row spacing (45 cm: 15.1 t ha^{-1}, 76 cm: 14.3 t ha^{-1}). The amount of precipitation in March, i.e. before the vegetation period was considered as significant for it filled the water stock of the chernozem soil with good water management. In 2014 the yield of the conventional row spacing treatment (14.4 t ha^{-1}) was similar to that of the previous year, while the population with narrow row spacing produced far lower yield amount (12.3 t ha^{-1}) than in the previous year. Plant density optimum of the narrow row spacing treatment was 63,848 plats ha^{-1}; the application of higher plant density resulted in yield decrement. In case of the conventional row spacing all hybrids – except for one – reached their maximum yield by the application of plant density higher than 80 thousand plants ha^{-1}. The optimum plant density was 87,535 plants ha^{-1}. In case of the narrow row spacing maize plants could be produced in a wide, while in case of the conventional in a rather narrow interval. In the crop year of 2014 the lack of precipitation before the vegetation period, just as the extreme distribution of vegetation precipitation amount were determining. Lower average yield amounts were produced than in the previous years: maximum yield of hybrids ranged between 8.3 and 12.0 t ha^{-1} in case of the row spacing of 45 cm, while between 8.0 and 12.4 t ha^{-1} in case of that of 76 cm. Plant density optimum of the hybrids was 82,491 plants ha^{-1} in case of the narrow row spacing, while 66,567 plants ha^{-1} in case of the conventional. In the crop year of 2015 less amount of precipitation was characteristic to the periods before and during the vegetation. Parallel to the lack of water several days heatwave was registered in August. The present experiment confirmed that under extreme weather conditions similar yield amount can be produced in the narrow row spacing population than in the conventional one, due to the soil coverage, the closed population and the special microclimatic conditions resulted thus. Relative humidity is higher in a closed population, while temperature is lower and these both result in the decrease of transpiration intensity. Hybrids could be produced in a wide plant density optimum range: in case of the row spacing of 45 cm between 68,000 and 89,000 plants ha^{-1}, while by the application of the row spacing of 76 cm by lower plant density (57-77 thousand plants ha^{-1}).

Table 9 Effect of row spacing and plant density on maize hybrids' plant density optimum (plants ha^{-1}), maximal yield (t ha^{-1}) and plant density optimum interval (thousand plants ha^{-1}) regarding the average of the hybrids (Debrecen, Látókép 2013-2015)

Plant density optimum (plant ha^{-1}) and interval (thousand plants ha^{-1}), maximal grain yield (t ha^{-1})				
Year	**Row spacing**	**x'**	**y'**	**Interval**
2013	45 cm	86177	15,1	75-90
	76 cm	80970	14,3	78-89
2014	45 cm	63848	12,3	54-76
	76 cm	87535	14,4	80-89
2015	45 cm	82491	10,0	68-89
	76 cm	66567	10,6	57-77
x' = plant density optimum (plants ha^{-1}) y' = maximal yield (t ha^{-1}) Plant density optimum interval (thousand plants ha^{-1})				

Taking the yield amount of the population with a plant density of 50,000 plants ha^{-1} as a basis it was compared to the yields of the populations with 70,000 and 90,000 plants ha^{-1}. Beside this the reaction of hybrids towards plant density and based on them hybrids were classified into four categories. Hybrids with relative high or low plant density demand, just as with favourable or even unfavourable reaction towards plant density changes were identified. Favourable reaction to plant density was shown in all studied crop years by the hybrids P 9578 (FAO 320), P 9175 (FAO 330), PR 37N01 (FAO 380), P 9494 (FAO 390) and SY Afinity (FAO 470) *(Figure 4, 5).* Among these the hybrid that could be condensed well or to a medium extent and that could be produced within a wide plant density interval was P 9494 (FAO 390).

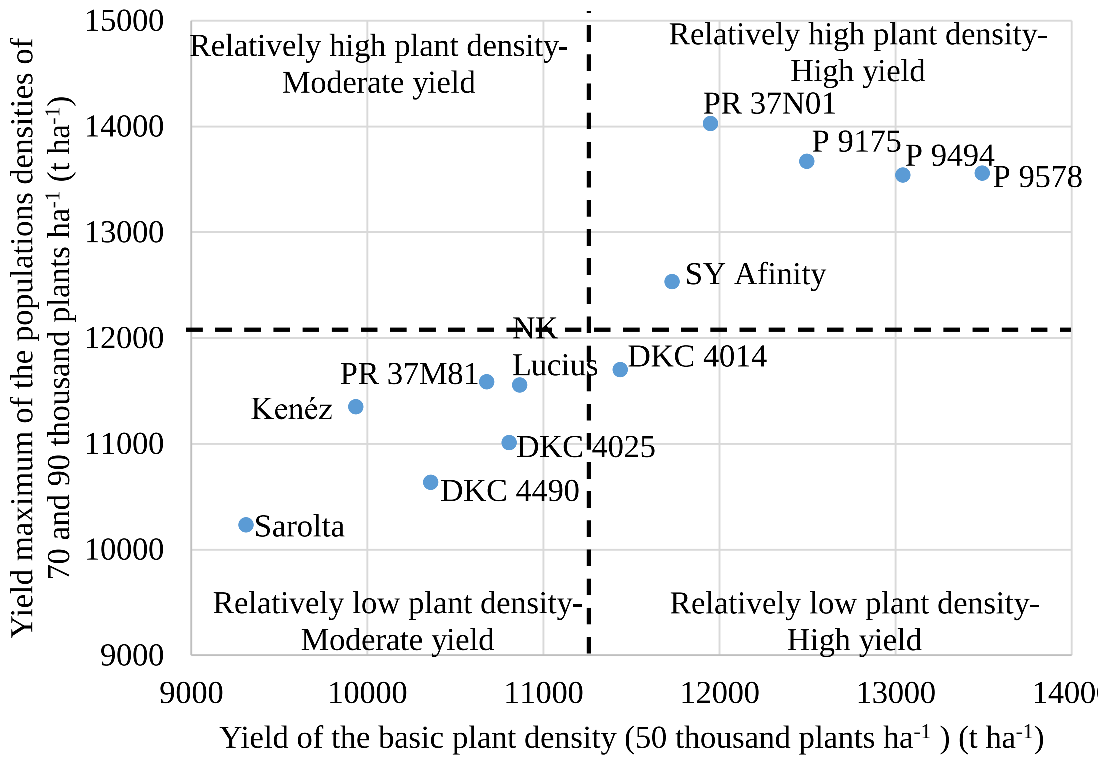

Figure 4 Evaluation of hybrids' reaction towards plant density in case of the row spacing of 45 cm (Debrecen, Látókép 2013-2015)

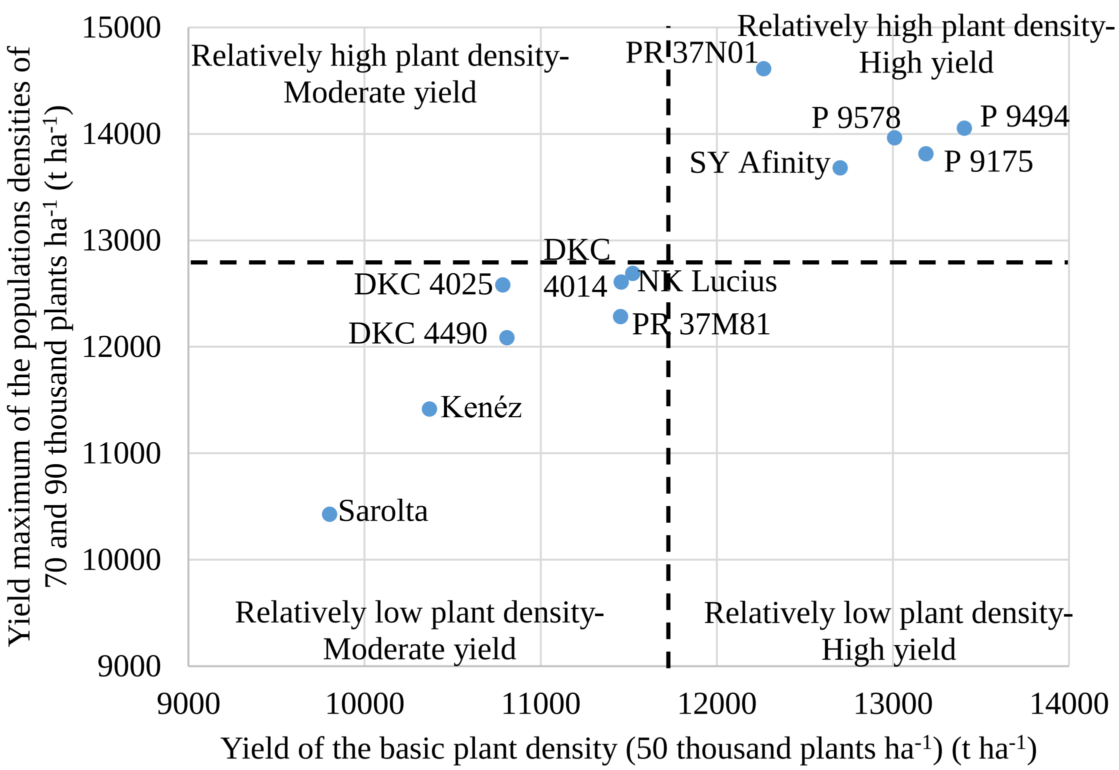

Figure 5 Evaluation of hybrids' reaction towards plant density in case of the row spacing of 76 cm (Debrecen, Látókép 2013-2015)

4. NEW SCIENTIFIC RESULTS OF THE DISSERTATION

1. According to our results strong correlation was confirmed in the complex system of crop year × row spacing × plant density. In case of the application of a row spacing of 76 cm yield amount results of maize hybrids were more balanced in different crop years by different plant density than in case of that of 45 cm. Regarding the average of plant densities and hybrids yield amounts were 14.0 t ha^{-1} in 2013, 11.6 t ha^{-1} in 2014, 9.6 t ha^{-1} in 2015 in case of the row spacing of 45 cm, while by 76 cm 13.6 t $ha^{-}1$ (2013), 13.3 t ha^{-1} (2014) and 10.1 t ha^{-1} (2015), respectively.
2. Optimal plant density values of maize populations of different genotypes were determined by the application of row spacing values of 45 and 76 cm in crop years with different water supply. Plant density optimum of hybrids was significantly affected by the crop year and row spacing as well. On the studied chernozem soil with excellent water and nutrient supply it ranged between 63.8 and 86.2 thousand plants ha-1 in case of the application of a row spacing 45 cm, while by that of 76 cm between 66.6 and 87.5 thousand plants ha^{-1} regarding the average of the hybrids.
3. Applying narrowed row spacing (45 cm) LAI_{max} values of maze hybrids increased, while $SPAD_{max}$ values decreased in case of the application of different plant densities. Applying the row spacing of 45 cm LAI_{max} values ranged between 3.4 and 5.1 m^2 m^{-2}, while $SPAD_{max}$ values between 57.1 and 63.4. In case of that of 76 cm these values were 3.1-4.4 m^2 m^{-2} and 57.7-64.4, respectively.
4. Higher plant density increased leaf area index values of maize populations in case of the application of both row spacing values; however, it decreased relative chlorophyll content.
5. In the intensive growth phase (June) maize hybrids increased their plant height by 5.7-8.8 cm day^{-1} depending on the given crop year, row spacing, plant density and hybrid.
6. The application of higher plant density increased leaf area durability (LAD). Medium positive correlation was found between plant density and LAD values (r = 0.594-0.670**).
7. The individual productivity (IP) index values – elaborated in the present research work – confirmed that applying higher plant densities resulted in the decrease of individual production in all studied crop years. The application of higher plant densities could compensate this and thus hybrids produced their maximum yields by the application of relative higher plant density values (70-90 thousand plants ha^{-1}).

8. The new introduced index of leaf area yield efficiency (LYE) showed significant differences for different row spacings, plant densities and hybrids in all studied crop years.
9. According to the present results maize hybrids were classified into wide (the width of the optimum interval is between 20 and 40 thousand plants ha^{-1}) and narrow (optimum interval is between 0-20 thousand plants ha^{-1}) optimum interval genotype categories.
10. Maize hybrids were classified into four different categories using a special coordinate system. Hybrids that produce low and high yield amounts in case of the application of the basic plant density, just as hybrids with favourable and unfavourable reaction towards plant density within the studied plant density range were distinguished.

5. PRACTICAL UTILIZATION OF THE SCIENTIFIC RESULTS

1. Yield maximum values of the produced latest maize genotypes ranged between 10.8 and 17.7 t ha^{-1} in 2013, 9.3-16.3 t ha^{-1} in 2014 and 6.9-12.3 t ha^{-1} in 2015 depending in the applied row spacing, plant density and genotype on the chernozem soil with excellent properties by the application of favourable agrotechnical elements.
2. Our research results confirmed that crop year × row spacing × hybrid interactions shall be considered in a complex way for the determination of the optimal plant density of maize hybrids in praxis.
3. The commonly used row spacing (76 cm) resulted in more balanced yield amounts in crop years with different water supply than that of 45 cm; thus it is recommended for the practical use.
4. In case of the application of higher plant densities individual production of hybrids decrease that is compensated by the higher plant number per unit production area (plants ha^{-1}) and thus higher yield amount can be produced.
5. Reaction of maize genotypes towards plant density is specific for the given hybrid, which shall be considered in practical production. According to the present research results no strong relationship could be confirmed between the length of the vegetation period of the applied latest hybrids and plant density.
6. On the chernozem soil with excellent properties and by the application of modern agrotechnical elements the optimal plant density of maize hybrids ranged in a relative wide interval (66.6-87.5 thousand plants ha^{-1}) in case of the commonly used row spacing of 76 cm depending on the given crop year. In case of the application of the narrow row spacing (45 cm) optimum plant density values of hybrids were similar to that (63.8-86.2 thousand plants ha^{-1}).
7. Maize hybrids with wide plant density optimum (the width of the optimum interval is between 20 and 40 thousand plants ha^{-1}) are recommended for the praxis that can compensate differences in plant density resulted by any sowing unevenness.
8. According to their yield results and reaction towards plant density maize hybrids can be classified into four categories. Good reaction towards plant density was observed in the studied crop years by the hybrids P 9578, P 9175, PR 37N01, P 9494 and SY Afinity.

6. LIST OF PUBLICATIONS RELATED TO THE DISSERTATION

Registry number: DEENK/96/2016.PL
Subject: Ph.D. List of Publications

Candidate: Eszter Murányi
Neptun ID: FVB2NW
Doctoral School: Kerpely Kálmán Doctoral School of Corp Production, Horticulture and Regional Sciences
MTMT ID: 10050841

List of publications related to the dissertation

Hungarian book chapter(s) (1)

1. **Murányi E.**: Eltérő genotípusú kukoricahibridek tőszámreakciójának vizsgálata mészlepedékes csernozjom talajon.
   In: A fenntartható növénytermesztés fejlesztési lehetőségei : Prof. Dr. Sárvári Mihály 70 éves. Szerk.: Pepó Péter, Debreceni Egyetemi Kiadó, Debrecen, 255-260, 2014. ISBN: 9789634737414

Hungarian scientific article(s) in Hungarian journal(s) (4)

2. **Murányi E.**: A tenyészterület hatása az eltérő genotípusú kukorica hibridek (Zea mays L.) termésképző elemeinek alakulására.
   Agrártud. Közl. 68, 67-72, 2016. ISSN: 1587-1282.

3. Pepó P., **Murányi E.**: Tenyészterület vizsgálatok eltérő genotípusú kukorica (Zea mays L.) hibrideknél.
   Növénytermelés. 64 (3), 59-75, 2015. ISSN: 0546-8191.

4. **Murányi E.**: Az állománysűrűség hatása eltérő genotípusú kukorica (Zea mays L.) hibridek termésére és levélterület-index (LAI) értékeire.
   Agrártud. Közl. 64, 51-56, 2015. ISSN: 1587-1282.

5. **Murányi E.**, Pepó P.: Különböző genotípusú kukoricahibridek tőszám sűríthetőségének vizsgálata csernozjom talajon.
   Agrártud. Közl. 56, 87-92, 2014. ISSN: 1587-1282.

Address: 1 Egyetem tér, Debrecen 4032, Hungary Postal address: Pf. 39. Debrecen 4010, Hungary
Tel.: +36 52 410 443 Fax: +36 52 512 900/63847 E-mail: publikaciok@lib.unideb.hu, ¤ Web: www.lib.unideb.hu

Foreign language scientific article(s) in Hungarian journal(s) (5)

6. **Murányi, E.**: Effect of sowing technology on the yield and harvest grain moisture content of maize (Zea mays L.) hybrids with different genotypes.
   Agrártud. Közl. 68, 17-22, 2016. ISSN: 1587-1282.

7. **Murányi, E.**: Effect of plant density and row spacing on maize grain yield on calcareous chernozem soil.
   Növénytermelés. 64, 115-118, 2015. ISSN: 0546-8191.

8. **Murányi, E.**: Effect of plant density and row spacing on maize (Zea mays L.) grain yield in different crop year.
   Columella. 2 (1), 57-63, 2015. ISSN: 2064-7816.
   DOI: http://dx.doi.org/10.18380/SZIE.COLUM.2015.1.57.

9. **Murányi, E.**, Pepó, P.: Investigation of the plant number reactions of maize hybrids on chernozem soil beside site-specific fertilization.
   Növénytermelés. 63 (Suppl.), 39-42, 2014. ISSN: 0546-8191.

10. Pepó, P., **Murányi, E.**: Plant density impact on grain yield of maize (Zea mays L.) hybrids on chernozem soil of the Eastern Hungary.
    Columella. 1 (2), 95-100, 2014. ISSN: 2064-7816.

Foreign language scientific article(s) in international journal(s) (3)

11. **Murányi, E.**: Complex evaluation of yield leaf area index and relative chlorophyll content development of maize hybrids of different genotypes.
    Anal. Univ. Oradea Fac. Protect. Med. 25, 43-48, 2015. ISSN: 1224-6255.

12. **Murányi, E.**: Effect of sowing technology on grain yield of maize hybrids.
    Anal. Univ. Oradea Fac. Protect. Med. 22, 21-26, 2014. ISSN: 1224-6255.

13. **Murányi, E.**: The effects of plant density and row spacing on the ear height of maize hybrids of different vegetation time and genotype.
    Anal. Univ. Oradea Fac. Protect. Med. 21, 145-149, 2013. ISSN: 1224-6255.

Hungarian conference proceeding(s) (1)

14. **Murányi E.**, Tótin Á., Vincze É., Szilágyi G.: Az állománysűrűség hatása eltérő genotípusú kukorica (Zea Mays L.) hibridek termésére és relatív klorofill tartalmára. In: "Nemzetközi összefogás a jövő agrárkutatásáért" konferencia kiadványa : 2015. június 11., Debrecen. Szerk.: szerk. Bodnár Karina Bianka, Erdős Zsuzsa, DE Tormay B. Szakkollégium, Debrecen, 49-52, 2015. ISBN: 9789634738169

Foreign language conference proceeding(s) (2)

15. **Murányi, E.**, Pepó, P.: The effect of plant density on the yield and LAI values of two maize (Zea mays L.) hybrids. In: 13th ESA Congress Proceedings. Szerk.: Pepó Péter, European Society for Agronomy, Debrecen, 161-162, 2014. ISBN: 9789634737230

16. **Murányi, E.**, Pepó, P.: The effects of plant density and row spacing on the height of maize hybrids of different vegetation time and genotype. *World Academy of Science, Engeneering and Technology. 83*, 60-63, 2013. ISSN: 2010-376X.

List of other publications

Foreign language conference proceeding(s) (2)

17. Szilágyi, G., **Murányi, E.**, Tótin, Á., Vincze, É.: Effect of grain maize forecrop and fertilization on values of leaf area index and on the yield of winter wheat.
    Anal. Univ. Oradea Fac. Protect. Med. , 1-4, 2015. ISSN: 1224-6255.

18. Szilágyi, G., **Murányi, E.**, Vincze, É., Tótin, Á.: The effect of fertilization and previous cropping of sunflower on the yield and the values of spad values of winter wheat.
    ProEnvironment Promediu. 8, 352-354, 2015. ISSN: 1844-6698.

The Candidate's publication data submitted to the iDEa Tudóstér have been validated by DEENK on the basis of Web of Science, Scopus and Journal Citation Report (Impact Factor) databases.

25 April, 2016