Theses of doctoral (PhD) dissertation

INCREASING THE YIELD STABILITY OF MAIZE BY THE RATIONALISATION OF AGROTECHNICAL FACTORS ON CHERNOZEM SOIL

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1. PRELIMINARIES AND OBJECTIVES OF THE DOCTORAL DISSERTATION

Maize is one of the most important plants of humanity. Due to the fact that maize is easy to grow, it can be used in a multitude of ways and it has high productivity, it plays a significant role in the crop production of the world, including Hungary.

In Hungary, the sown area of maize decreased below one million (989 thousand) hectares in 2017, for the first time in the recent decades, followed by a further decrease in 2018. Among the possible reasons for the decline in the sowing area of maize in recent years, profitability problems and the unpredictable weather conditions caused by global climate change come to mind. The risk of growing maize has increased. The national average yield fluctuation is large, reaching even 50-60%. Global climate change has an impact on the conditions of growing, necessitating further research into the plant's cultivation technology.

We can best adapt to the current natural and production conditions if, in addition to taking into account the already existing results, we continuously gather new and new knowledge about the yield and adaptability of new hybrids. As a consequence, we can increasingly adapt production, nutrient management and other agrotechnical parameters to the needs of the given genotype. Nutrient management (especially the effect of macro elements), the proper choice of hybrids, and the correct determination of population density are crucial for maize cultivation, as the can improve yield safety, in addition to increasing yields. The main research topic of my dissertation was to further clarify and quantify these factors.

The "art" of combining technological elements and environmental conditions can create the development of maize production to a degree that is a prerequisite for balanced, economical high yields (*Árendás et al.* 2018).

For my Ph.D. doctoral dissertation, I carried out the research work under the supervision, support and professional guidance of Prof. Dr. Mihály Sárvári. The large-plot, semi-field experiment was set up in Hajdúszoboszló in the period between 2015-2017.

The objectives of my research related to the sustainable development of maize production technology were:

- Quantification of the effects of agrotechnical factors to increase maize yield and crop safety.
- Development of new, modern hybrid-specific cultivation technologies on chernozem soil.
- Rationalization of agrotechnical factors properly adapted to ecological conditions and biological bases.
- Quantification of the development of hybrids, leaf area, photosynthetic activity and the dynamics of dry matter incorporation in relation to yield, and the clarification of the interactions between them. We searched for a correlation between leaf area index and yield results
- Working out a harmonious nutrient supply of maize hybrids of different genotype and different ripening periods and to determine the optimal population density and its range.
- Further development of hybrid-specific cultivation technologies that can promote sustainable, developing maize production, with special emphasis on yield safety.
- With the help of the obtained results we can decide which agrotechnical factors and parameters contribute to the highest yield to the greatest extent. We hope that this approach will also provide useful information for crop producers.

My research will primarily help growers in the future, as nutrient supply and increasing population density are the easiest and most commonly applied agrotechnical elements that greatly influence yield and yield stability. I hope that with the large plot experiment conditions, we could produce realistic results that will contribute to more economical and better yields in maize production in the years to come.

2. MATERIAL AND METHODS

2.1. Location, arrangement and design of the experiment

The experiment on the nutrient supply and population density of maize was set up in Hajdúszoboszló in 2015, 2016 and 2017 with the supervision, support and professional guidance of Prof. Dr. Mihály Sárvári. Since the main profile of our family farm is field crop production, I was given the opportunity to conduct the experiment in our own field. The location of the experiment on the Hajdúság loess ridge is located approx. 20 km away from the main road no. 4 bypassing Hajdúszoboszló on the Gém ridge. We had an 8-hectare plot for the experiment, i.e. we set up our experiment in large-plot, semi-field conditions, for which the machine park was also provided.

The size of a plot was 34 m x 6.08 m and its net area was 206.7 m^2. Six hybrids of different genotype and ripening periods were examined (P9241, P9486, Kamaria, DA Sonka, DKC4717, Kenéz) with three fertiliser doses (control (non-fertilised), N 80 P_2O_5 60 K_2O 70 kg ha^{-1} and N 160 P_2O_5 120 K_2O 140 kg ha^{-1}), three population densities (60, 70 and 80 thousand plants per hectare) and three replications. Consequently, the number of plots was 162. The experiment had a randomised block design. In order to avoid the border effect between treatments, we established the proper borders, which had been cut before the harvesting on the experiment site began.

The experiment site is flat, with even surface and calcareous chernozem soil. The production site is classified as mid-heavy meadow soil. This soil type is characterised by humus-rich and deep fertile layer and it is easy to cultivate, while it has outstanding water, air and heat management and excellent nutrient supply.

2.2. Weather during the examined years

In the three years of the experiment, weather played a decisive role in both in yield and grain moisture content. The extreme weather events caused by climate change could be tracked especially well in the research, as there was drought in the first year (-104.9 mm deviation from the 30-year average), excessive rain in the second year (+154.4 mm), while the amount of precipitation was in accordance with the 30-year average in the third year (+1.8 mm). The three greatly different crop years were also suitable for determining the adaptability of hybrids of different genotype.

2.3. Parameters examined during the research

In the three years of the experiment, we observed the response of the genotype to crop years, nutrient supply, and increasing population density. On the one hand, this work focused on changes in productivity, water release dynamics, grain moisture content at harvest, as well as biological surveys, where plant and ear height, leaf area index (LAI), photosynthetic activity, yield-forming elements and content parameters as a result of the treatment. Our aim was to determine, among many other analyses, how nutrient supply and increasing population density affect the activity of maize leaf area and photosynthesis, and how these factors affect yield formation and the amount of yield.

2.4. Method of evaluating the results

The obtained data were statistically processed by two-way analysis of variance by *Sváb* (1981), linear and parabolic regression analysis, and Pearson's correlation analysis. Data were processed using Microsoft Office Excel (2018) and SPSS 22.0.

3. RESULTS

3.1. The effect of nutrient supply and increasing population density of maize LAI

During the three years of our experiment, we did not observe any significant differences between the examined hybrids, but nutrient supply significantly increased the leaf area index except for the extremely dry year of 2015. Based on the results of our experiment, the effect of increasing population density on leaf area index values can also be shown. In 2016 and 2017, as well as in the average of the three examined years, we were able to show a significant difference between the treatments with a population density of 60,000 and 80,000 plants per ha (Table 1).

Table 1. The effect of population density on the LAI of the examined hybrids (m^2 m^{-2}) Hajdúszoboszló, 2015-2017

Population density	2015		2016		2017		Average	
	LAI m^2 m^{-2}	**LSD5%** m^2 m^{-2}	**LAI** m^2 m^{-2}	**LSD5%** m^2 m^{-2}	**LAI** m^2 m^{-2}	**LSD5%** m^2 m^{-2}	**LAI** m^2 m^{-2}	**LSD5%** m^2 m^{-2}
60,000	2,91	ns	2,92	0,31	3,35	0,36	3,05	0,19
80,000	3,19		3,35		3,84		3,45	

3.2. Maize grain yield as a function of leaf area

During our examinations, we were constantly following the correlations between the leaf area index (LAI) of maize hybrids and the achieved grain yield. Correlations between LAI values and the yield of maize hybrids were examined with bivariate linear regression analysis and correlation analysis.

In 2015, there was no correlation between leaf area size and the yield of hybrids, as the value of R2 was only 0.0387, which can be attributed to the fact that leaf area size did not affect yield. Due to the extreme drought, plants were unable to develop a proper leaf area for assimilation, and the existing green foliage also dried up early. In 2016 and 2017, when there was sufficient precipitation for the population, the regression analysis showed a close correlation between the leaf area index (LAI) and yield (Figure 1). The correlation is positive (R2 values: 0.8209 and 0.6968, respectively). Interestingly, we obtained similar LAI values in 2015 as in 2016, while yields differed significantly in both years. This can be explained by the fact that leaf area is not the only factors which plays a significant role in yield formation. In 2015, the large foliage was formed quickly, which plays a role not only in photosynthesis but also in evaporation. The severe lack of rainfall, which occurred during the most critical period of maize, caused significant disturbances in the plant's water balance, which also determined yield.

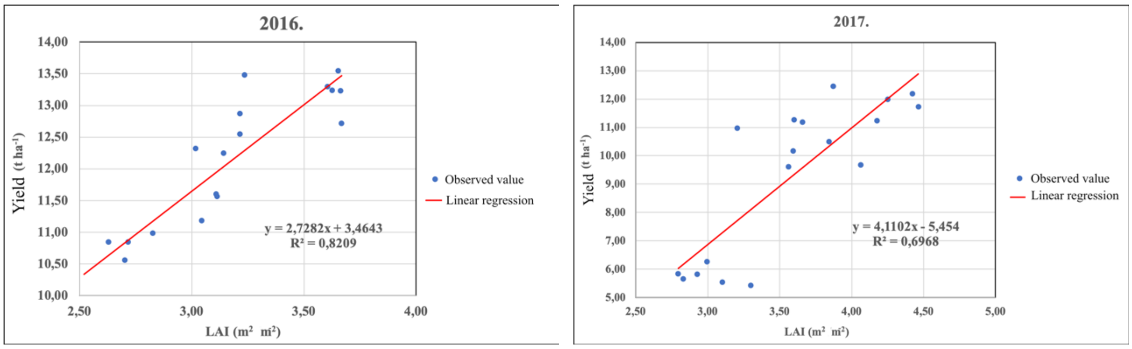

Figure 1. Linear regression between LAI and yield (Hajdúszoboszló, 2016-2017)

The leaf area index has a significant effect on yield in a favourable or average crop year. Larger leaf area makes better use of solar radiation and organic matter production is also improved. In extreme dry years, this effect cannot be demonstrated.

3.3. The effect of nutrient supply and increasing population density on the photosynthetic activity of maize hybrids

It can be clearly seen from the obtained results that the photosynthetic activity of maize hybrids gradually decreases with the aging of plants, the first measurement resulted in a value of 27.24 - 33.81 μmol m^{-2} s^{-1}, while the photosynthesis of the examined plants reached only 45%-50% compared to young plants. The effect of nutrient supply can also be observed, as the amount of CO_2 bound in photosynthesis decreased most significantly in the control plots with the aging of plant tissues. The (non-fertilised) control plots showed a lower LAI, which also reduced the rate of photosynthesis. It can be concluded that photosynthetic activity is also influenced by several factors and the interactions between these factors, e.g. the genetic background of hybrids, and their ripening periods, climatic factors and the applied agrotechnical solutions. Harmonious nutrient supply greatly enhances photosynthetic activity indirectly, since if the initial growth is rapid, the LAI index will also be higher. NPK nutrient supply is also able to increase the water conversion of maize to a certain extent, thereby maintaining the plant's photosynthetic activity.

3.4. The effect of nutrient supply and population density on the water release dynamics and grain moisture content at harvest of maize hybrids

In our experiment, we examined the water release dynamics of hybrids on a weekly basis after physiological maturation between 2015 and 2017. From the obtained results, it can be concluded that the effect of increasing population density on grain moisture content was minimal in our experiment. Nutrient supply and the hybrid's genotype had a greater effect on grain moisture content at harvest.

3.5. Examination of the quality parameters of maize hybrids

The analyses of our experiment also covered the content parameters of maize. It can be concluded that nutrient supply (especially N) has a significant effect on the raw protein content of maize, however, appropriate environmental factors (precipitation) are required for the positive role of nutrient supply to take effect. If the prevailing environmental factors are not adequate, a negative effect will be imposed on not only yield, but also the necessary qualitative changes, because the uptake of nutrients by plants is hindered. There was a significant negative correlation between the relative protein content and the relative starch content of the examined maize hybrids (Figure 2). In all three years, we found a close, inversely proportional relationship between protein and starch content (r = -0.60; -0.77; -0.83 in the order of the examined years). By increasing the dose of nitrogen fertilizer, the protein content of the hybrids can be increased. In addition, the change in starch content is inversely proportional to the amount of fertilizer applied.

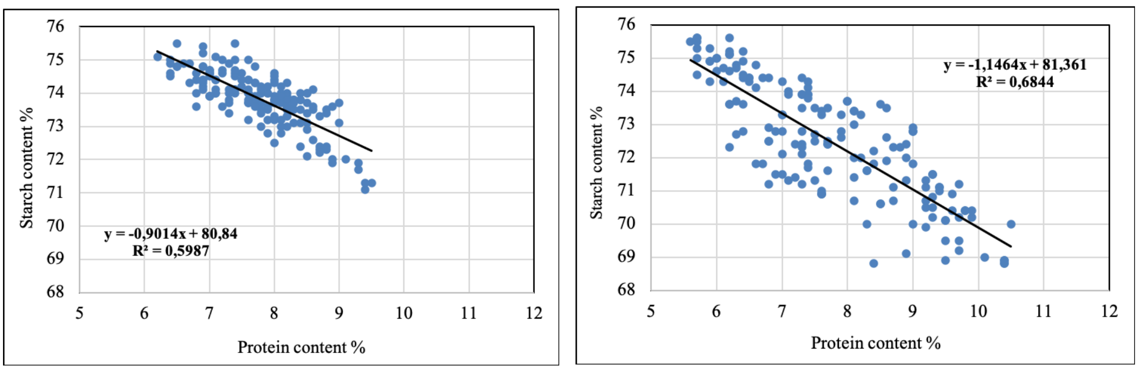

Figure 2. Correlation between protein content and starch content (Hajdúszoboszló 2016-2017)

With increasing population density, starch content increased steadily. The difference between the population densities of 60,000 and 80,000 plants per hectare was significant both in 2015 and 2016. In contrast, with an increase in nutrient supply, starch content was notably reduced both in 2016 and 2017.

The oil content of the examined hybrids varied between 3.5 and 4.7% during the experiment. Of the hybrids, the oil content of the Kenéz hybrid is outstanding, which was significantly higher than that of the other examined hybrids in all examined years. Population density and nutrient supply had no significant effect on oil content. However, crop year has a significant effect on the quality of maize, as we were able to reveal significant differences between the different years in the case of all three examined content values. For this reason, it can be concluded that the protein content is higher in extreme dry years than in average or rainy years, which also shows a negative correlation between the amount of yield and quality.

3.6. The effect of nutrient supply and population density on the yield-forming components of maize hybrids

Maize yield is mainly determined by the yield-forming elements (thousand grain weight, hectolitre weight, number of rows, number of grains in a row, cob length, number of grains per cob, shelling ratio).

Nutrient supply has a significant effect on the thousand-grain weight of maize. An increase in thousand-grain weight was observed compared to the control treatment in the case of fertilized treatments, which exceeded the level of significance in both 2015 and 2017 in the experiment. In the rainy crop year (2016), the values of the thousand-grain weight showed an outstanding difference compared to the dry and average crop years. In 2016, the average thousand-grain weight of hybrids was 85.8 grams higher than in 2015, which is significantly higher than the significant value, i.e. LSD5%: 25.3.

The number of grains in a row increased steadily as a result of nutrient treatment. Increasing the population density had a negative effect on the number of grains per row. A significant difference was observed each year.

The effect of nutrient supply on cob length was significant and positive. Although the smallest effect was observed in a rainy crop year (2016), nutrient supply still significantly increased cob length compared to control treatment. However, increasing the population density with the same significance reduced cob length.

3.7. Examining the ratio of plant height to infertile plants

Based on the results of the analysis of variance, we can conclude that, by increasing the nutrient level, the height of the examined hybrids was demonstrably increased in our experiment in all three years of examination. Hybrids had the lowest height in the (non-fertilised) control treatment, followed by significant increase in plant heights with improved nutrient supply. The difference between the control treatment and the N80 + PK treatment was 6 cm in 2015, 12 cm in 2016, and 29 cm in 2017. There were also significant differences in the height of the examined hybrids. The P9486 hybrid was significantly smaller than the other hybrids each year. The effect of crop year can also be observed, the height of hybrids ranged from 240 to 266 cm in the extremely dry year of 2015, while this value varied between 271 and 292 cm in 2016, when the amount of precipitation was excessive.

Our examinations also included the determination of the ratio of infertile plants. It can be concluded that the proportion of infertile plants decreased as a result of fertilisation. We could not detect a significant difference between the examined hybrids and the crop years during our analyses.

3.8. Changes in soil and maize stalk nutrient content as a result of nutrient treatments

In the last year of the experiment (2017), we examined how the nutrient content of the soil changed as a result of nutrient treatments. As a result of the nutrient supply, the humus content of the soil clearly increased, the extent of which was 2.42% in the case of non-fertilised plots, while the N160 + PK treatments resulted in an increase of 2.64%. In parallel, the nitrate and nitrite content of the soil increased from 2.37 mg kg^{-1} to 7.46 mg kg^{-1}. There was also a small increase in potassium, calcium and magnesium content. In 2016 and 2017, we examined the effect of nutrient supply on the nutrient content of maize stalks. An increase in the nitrogen content in the maize stalk can be clearly observed as a result of the increase in fertilizer doses. Compared to the control treatment, the nitrogen level increased by about 40% as a result of the highest dose nutrient treatment. No correlation was found between nutrient treatments and stem phosphorus and potassium content.

3.9. The importance of genotype

Based on the results of the three examined years, we can make several conclusions. The smallest yields were produced by the Kenéz hybrid, which was among the last in all three years of the experiment and was lagging behind the other hybrids (Figure 3). The DA Sonka hybrid may be able to produce excellent yields in rainy years, and low yields in the case of average or dry crop years. The stress tolerance of the DA Sonka hybrid is low and its yield safety is unsatisfactory. The DKC4717 hybrid can be considered to have medium performance in our experiment. The performance of the Kamaria hybrid is remarkable, especially considering that it is a hybrid bred in Hungary. In the case of the rainy crop year, this hybrid achieved the best yield of the examined hybrids and it was also tolerant to drought. The yield of the P9241 hybrid slightly lagged behind that of the best hybrids in the rainy crop year, as it is a hybrid with favourable yield safety and stress tolerance characteristics. In our experiment, the safest and highest yield was provided by the P9486 hybrid. In all three years of the experiment, this hybrid was among the 3 best yielding hybrids, thereby showing that it is capable of outstanding yields under both favourable and unfavourable conditions. The growing of this hybrid is especially recommended. We could not detect any significant difference between the yields of the examined hybrids averaged over the three years (Table 2). The lowest yield was 8.58 t ha^{-1} for the Kenéz hybrid and the highest yield was 9.67 t ha^{-1} for the P9486 hybrid, with the difference being 1.09 t ha^{-1}, i.e. more than 11%. The average yield of our experiment was 9.26 t ha^{-1}.

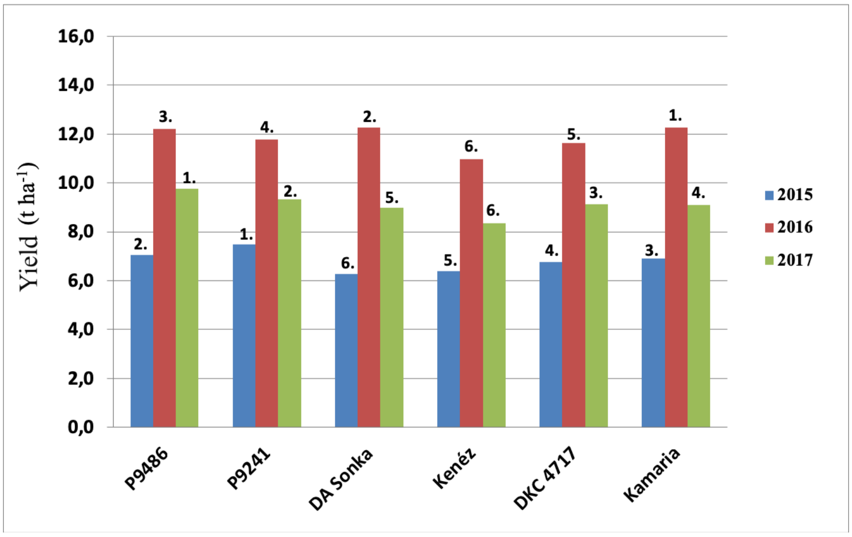

Figure 3. Hybrid yields averaged over the performed treatments (Hajdúszoboszló 2015-2016-2017)

Table 2. Hybrid yields averaged over the performed treatments (nutrient supply, population density) (Hajdúszoboszló, 2015-2017.

Hybrid	Yield t ha^{-1}					
	2015	2016	2017	Average	Difference	
P9486	7,05	12,2	9,76	**9,67**	-	-
P9241	7,47	11,79	9,33	**9,53**	0,14	-1,5%
Kamaria	6,92	12,28	9,11	**9,44**	0,23	-2,4%
DA Sonka	6,27	12,28	8,99	**9,18**	0,49	-5,1%
DKC4717	6,75	11,63	9,13	**9,17**	0,5	-5,2%
Kenéz	6,4	10,98	8,35	**8,58**	1,09	-11,3%
Average yield of the experiment				9,26		

3.10. The effect of crop year on yield

In addition to agrotechnical factors, the effect of crop year is particularly important in maize production. In order to examine this effect, we compared the yields of the three examined years averaged over the different hybrids and treatments (*Table 3*).

Table 3. Average, minimum and maximum yield of hybrids (Hajdúszoboszló, 2015-2017)

Yield t ha^{-1}	2015	2016	2017
Minimum	6,27	10,98	8,35
Maximum	7,47	12,28	9,76
Average	6,81	11,86	9,11

$LSD_{5\%}$: 0.38 t ha^{-1}

The average yield of the examined hybrids was 6.81 t ha^{-1} in 2015, 11.86 t ha^{-1} in 2016, and 9.11 t ha^{-1} in 2017. Crop year significantly affected yield, with an $LSD_{5\%}$ value of 0.38 t ha^{-1}. The difference between the year with the lowest and the highest average yield is 5.05 t, that is, the crop year effect can be observed to an extent of 5.05 t ha^{-1}, i.e. 42.58%. It can be concluded that crop year plays an extremely important role in yield.

Comparing the obtained yield results with precipitation data, it can be clearly seen that the precipitation during the growing season (April – September) was in direct proportion to the average yield of maize (Pearson's correlation coefficient: r = 0.97) (Figure 4). Dividing the average yield by the amount of precipitation during the growing season gives the amount of yield per mm. This value was 24 kg mm^{-1} in 2015 and 28 kg mm^{-1} in 2016 and 2017. It can be concluded that the rainfall during the growing season and maize yield are closely related.

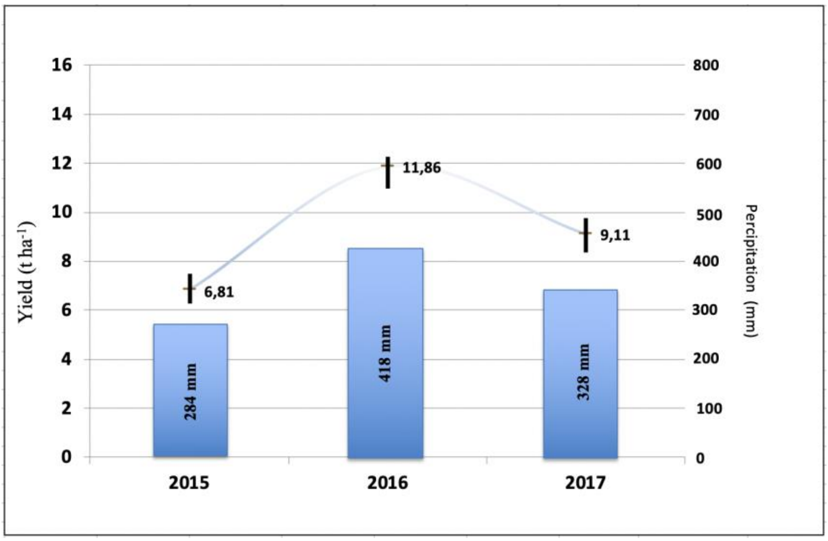

Figure 4. Average yield of hybrids and the amount of precipitation during the growing season (Hajdúszoboszló, 2015-2017)

3.11. The effect of population density on maize yield

We established our population density experiment in 2015-2017, in which we examined the potential of different genotypes to increase population density, as well as their population density response at 60,000, 70,000 and 80,000 plants per hectare. Taking the three-year data set into consideration altogether, the population density treatments did not cause a statistically significant difference in yield (Table 4). At the lowest population density, the obtained yield was 9.10 t ha^{-1}, while 70,000 plants per hectare resulted in 9.26 t ha^{-1}, and the highest population density resulted in 9.41 t ha^{-1}, averaged over the examined hybrids, fertilizer treatments and years. The difference between the yields achieved at the lowest and highest populations densities was only 0.31 t ha^{-1}.

Table 4. The effect of population density, averaged over the examined hybrids, years and the performed treatments (Hajdúszoboszló, 2015-2017)

Population density (plants ha^{-1})	Yield (t ha^{-1})	Yield surplus (t ha^{-1})	Percentage distribution	$LSD_{5\%}$ (t ha^{-1})
60.000	9,10	-	96,7%	ns
70.000	9,26	+ 0,16	+ 1,7%	
80.000	9,41	+ 0,15	+ 1,6%	

The small effect of population density was probably due to the fact that the values we chose (60-70-80 thousand plants ha^{-1}) show a relatively low extent of differentiation. However, in practice, these population densities are used most often, i.e. we considered their examination justified. As a matter of course, there was a year when the effect of a higher population density was more pronounced, such as the rainy year of 2016, when higher population density resulted in an 8% increase in yields. The average yield was 11.4 t ha^{-1} in the case of 60,000 plants ha^{-1}, and 12.38 t ha^{-1} in the case of 80,000 plants ha^{-1}.

It can be concluded from our results, the increasing population density has the most positive effect in rainy crop years, a population density of 80,000 plants per hectare instead of 60,000 plants per hectare results in a 10% increase in yield. In a dry or average crop year, no significant difference was in the yield of maize between population density values of 60-80 thousand plants per hectare under the examined conditions.

3.12. The effect of nutrient supply on yield

Evaluating the three examined years together, averaged over the different population density values, the average yield of hybrids in the non-fertilised treatment was 7.53 t ha-1. In the case of the N80 + PK treatment, this value was 9.83 t ha-1, while doubling the fertilizer dose resulted in a yield of 10.42 t ha-1. Based on the results of the one-way analysis of variance, the $LSD_{5\%}$ was 0.53 t ha-1, i.e. it can be concluded that all fertilizer doses increased maize yield. Compared to the control treatment, each fertilizer dose resulted in a yield increase of 2.3 t ha-1, and an increase in the fertilizer dose resulted in an additional 0.59 t ha-1 yield surplus (Table 5). The values of the yield surplus expressed as % are shown in Figure 1, where the average yield of the N160 + PK treatment was taken as 100%.

Based on our calculation, fertilization had a 28% effect on yield during the three examined years (Figure 5). This effect is of the same order of magnitude as reported by Győrffy (1976): 26%, Berzsenyi et al. (2011): 30%, Nagy (1996b): 48%, and Pepó - Csajbók (2014): 39%.

When examining the effect of fertilization from the profitability aspect, it can be concluded that no return was realised on the extra financial input of the N160 + PK fertilizer dose, i.e. its application was not economical. However, applying the highest fertilizer dose is not recommended from an environmental point of view either.

Table 5. The effect of nutrient supply on yield, averaged over the different hybrids, population densities and the examined years (Hajdúszoboszló, 2015-2017)

Nutrient supply	Yield ($t\ ha^{-1}$)	Yield surplus ($t\ ha^{-1}$)	Percentage distribution	$LSD_{5\%}$ ($t\ ha^{-1}$)
Control	7,53	-	72%	**0,53**
N80+PK	9,83	+ 2,3	+ 22%	
N160+PK	10,42	+ 0,59	+ 6%	

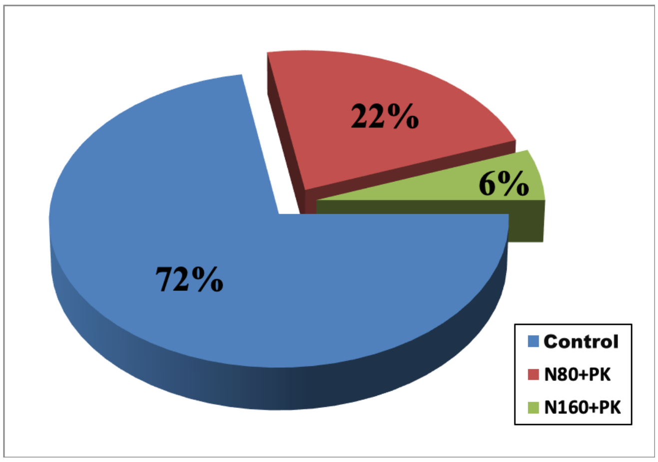

Figure 5. The effect of NPK fertilisation on yield, averaged over the different hybrids and population density values (Hajdúszoboszló, 2015- 2017)

4. NEW SCIENTIFIC RESULTS

1. The leaf area index had a significant effect on yield in a favourable or average crop year. In extremely dry years, this effect cannot be demonstrated. When sufficient rainfall was available for the maize population, the performed regression analysis showed that the effect of leaf area index (LAI) was very significant on yield. There is a strong positive correlation between the two factors (R^2 values: 0.8209 and 0.6968, respectively).
2. The effect of increasing the population density on grain moisture content is minimal, as nutrient supply and hybrids have more pronounced effect.
3. There is a significant difference in the protein content of maize hybrids. Of the examined hybrids, the Kenéz hybrid had the highest protein content, while the DKC4717 hybrid had the lowest protein content. The effect of crop year on the examined hybrids' protein content is significant in the extreme dry year, as it was 1.2–2.5% higher than in the rainy or average crop year. It can be concluded that nutrient supply has a significant effect on the raw protein content of maize, however, the necessary environmental factors (precipitation) are required in order for the positive role of nutrient supply to be effective. There was a significant negative correlation between the relative protein content and relative starch content of maize hybrids. In all three examined years, we found a close, inversely proportional relationship between protein and starch content (r = -0.60; -0.77; -0.83, respectively in the order of the examined years).
4. Of the different yield-forming elements, the nutrient supply had a significant effect on the thousand-grain weight and the number of grains per cob. The number of grains in a row and cob length increased with increasing fertilizer dose and decreased with increasing population density.
5. The height of the examined hybrids increases with the increase of the applied nutrient levels. However, increasing population density (excluding rainy years) reduced plant height, however, this effect is less pronounced than that of nutrient treatments. Significant differences were observed in the height of the examined hybrids. The P9486 hybrid was significantly lower than the other examined hybrids.

6. In maize production, crop year plays the most significant role (about 40%) in determining yield. There may be a difference in yield of up to 5 t ha-1 between dry and rainy crop years, using the same agrotechnics. It can be concluded that the amount of precipitation during the growing season is closely related to yield. Fertilisation has an effect of almost 30%, while increasing the population density has an effect of only 3% on the yield of the examined hybrids.
7. Increasing the population density had the most positive effect in the rainy crop year, realising a 10% increase in yield as a result of using a population density of 80,000 plants ha^{-1} instead of 60,000 plants ha^{-1}. In a dry or average crop year, we could not detect a difference in the yield of population densities between 60-80 thousand plants ha^{-1} under the examined conditions. It can be concluded that, with favourable nutrient supply, the effect of increasing population density was more pronounced.
8. In the dry crop year, the fertiliser dose of N 160 P2O5 120 K2O 140 kg ha^{-1} caused yield decrease on Hajdúság chernozem soil. However, in average and rainy crop years, this dose had a yield-increasing effect in comparison with the N 80 P2O5 60 K2O 70 kg ha^{-1} treatment.

5. SCIENTIFIC RESULTS FOR PRACTICAL APPLICATION

1. It can be concluded from the obtained results that the degree of nutrient supply and the hybrid effect have a significant effect on grain moisture content. As a result of fertilisation treatments, the grain moisture content of hybrids at harvest is 1-2% higher than in non-fertilised plots. In the case of the DKC4717 hybrid, higher values were measured in each examined year in comparison with the P9486 or DA Sonka hybrids.
2. Quality is an increasingly important aspect in maize production. From an animal feed point of view, the protein content of maize is an important factor, while the development of starch content, is especially important in the production of bioethanol and isosugar. In our experiment, the protein content of the Kenéz hybrid was significantly higher in each examined year than that of the other hybrids. The DCK4717 hybrid had the lowest protein content. The effect of crop year on protein content was shown to be significant. In extreme dry years, the protein content of the examined hybrids is 1.2-2.5% higher than in average or rainy crop years. The starch content of the Kenéz hybrid was significantly lower than that of the other examined hybrids in each year, but its oil content was outstanding.
3. The yield potential of the available hybrids is different, i.e. choosing the proper hybrid requires utmost attention. During our experiments, the lowest yields were produced on the chernozem soil in the Hajdúság region by the Kenéz hybrid, i.e. it is not recommended in the examined area. The DA Sonka hybrid is capable of excellent yields in rainy crop years, but it provides poor results the case of average or dry crop years. The stress tolerance and crop safety of this hybrid are unsatisfactory. The safest and highest yield was observed in the case of the P9486 hybrid. In all three years of the experiment, this hybrid was among the 3 best yielding hybrids, thereby showing that it is capable of outstanding yields under both favourable and unfavourable conditions.
4. It is not recommended for the practice to use a lower-than-average (70-72 thousand plants ha^{-1}) population density on chernozem soils with moderately appropriate nutrient supply, as we could not achieve higher yields at lower population density values (60 thousand plants ha^{-1}) even in extremely dry crop years. Higher-than-average population densities (80 thousand plants ha^{-1}) can be

recommended only if the level of nutrient supply is adequate and the prevailing ecological and climatic conditions (precipitation) are ideal for maize. With a favourable supply of nutrients, the effect of increasing population density is more pronounced, the yield increase is more pronounced in rainy crop years, while the extent of yield decrease is lower in drought, which is caused by the high population density (lack of water). The population density response of hybrids also shows a difference, with some hybrids giving a more pronounced response to increasing population density either positively or negatively (e.g., DKC 4717), while other hybrids have a wide optimum interval in terms of population density, i.e. they react more flexibly to changing population densities (e.g. P9486).

5. Based on the results obtained during the years of this experiment, the application of the treatment of N 160 P2O5 120 K2O 140 kg ha-1 or higher fertilizer doses is not recommended on chernozem soil in the Hajdúság region. Compared to the N 80 P2O5 60 K2O 70 kg ha-1 treatment, it does not result in a significant yield surplus which would compensate for the cost of the extra input, while high nutrient supply could even cause yield depression in a dry crop year. In addition, the application of such high fertiliser dose is not recommended from an environmental point of view either. Based on the obtained results, we recommend to apply 80 kg of nitrogen and the related phosphorus and potassium doses. This dose can be increased to 120 kg if required, but the AL-soluble and available nutrient content should also be taken into consideration.

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List of publications related to the dissertation

<u>Hungarian book chapters</u> (3)

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