Ph.D. Thesis

STUDY OF QUALITY AND NUTRIENT REACTION OF DIFFERENT MAIZE HYBRIDS WITH DIFFERENT GENOTYPES ON A CHERNOZEM SOIL TYPE

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1. INTRODUCTION, OBJECTIVES

Cereals are field crops that are produced on the largest area both nation- and worldwide. Their production is of basic importance, because they can be utilized in many different ways (as nutrition, fodder or for industrial processing etc.). Cereals are produced on an area of more than 720 million hectares worldwide. Cropping structure of Hungary is mainly focused on cereals, which means that cereals are produced on 2/3 of the total 4.3 million hectares cropping area. Maize (1.1-1.2 million ha) and wheat (1.0-1.1 million ha) have the highest share of the total cropping area.

Due to the even more occurring weather anomalies – as results of climate change – far more extreme weather and climatic occurrences can be observed than previously. Climate change has the highest impact on agriculture among the main economical branches. However, the safe food-supply for the even increasing population is of vital importance. Maize is one of the most important field crops produced and several agrotechnical factors play determining role in its production technology from the aspect of yield amount and yield safety, as well. According to that the right choice of hybrids and the agrotechnology have become more and more important in maize production, for yield safety can be increased by the optimization of biological basis and agrotechnical factors, one of the key elements of which is nutrient supply. Biological basis of maize production have become significantly developed during the past two decades. Maize hybrids produced commonly show significant differences in their reaction towards different agrotechnical factors. This statement is particularly valid regarding the reaction of hybrids to nutrient supply. The application of mineral fertilizers has become a very important economical and environment protection issue during the past years. Therefore, it is of high importance from both theoretical and practical aspects to determine the reaction of different maize hybrids of various genotypes towards nutrient supply, just as their natural nutrient utilization ability exactly. This is relevant in order to improve the effectivity of fertilizer application that is an expensive agronomical measurement, just as to decrease environmental contamination.

Within the confines of the present research experiment the effect of crop year was analysed on the agronomical, physiological and quality properties of maize hybrids of different genotypes. It was set as an objective to determine the nutrient reaction and nutrient optimum of the maize hybrids involved in the experiment.

The present research work covered following studies and analyses:

- the effect of nutrient supply on the yield amount and quality of the maize hybrids involved in the experiment
- the reaction of different maize genotypes towards nutrient supply
- the effect of nutrient supply and crop year on some plant physiological parameters (relative chlorophyll content, leaf area index, leaf area durability)
- the relationships between nutrient supply, yield and physiological characteristics
- the determination of the nutrient balance of the plant production area for maize production

2. MATERIALS AND METHODS

2.1. Location and soil properties of the experimental field

The research work has been carried out at the Látókép Research Site of the University of Debrecen, Centre for Agricultural Sciences, Farm and Regional Research Institute. The research site is located 15 km far from Debrecen, along the main road nr. 33, in the territory of the Hajdúság loess ridge.

The experimental soil is based on loess, with deep humus layer; it is medium set calcareous chernozem in good agricultural state. Regarding its soil physical properties it can be classified as a loam, its pH is nearly neutral. The phosphorous supply of the soil is medium, while its potassium supply is rather medium-good. Humus content is also medium; the humous soil layer is about 80 cm deep. Water table depth is 3-5 m.

2.2. Experimental settings and arrangement

The field experiment was carried out between March 2012 and October 2014. The experimental treatments were set up in split-plit-plot design with four replications. The size of each plot was 1.5 m x 5 m (7.5 m^2). Two factors (genotype and nutrient supply) were studied in the experiment.

50% of the nitrogen fertilizer, just as 100% of the phosphorous and potassium fertilizer were applied as a Kemira Optima (10:15:18) complex mineral fertilizer, before the execution of autumn plough measurements. The rest 50% of the nitrogen fertilizer was applied as ammounium-nitrate (N 34%) in the springtime, before the preparation of the seedbed. Beside the control treatment a basic dosage (N: 30 kg ha^{-1}, P_2O_5: 22.5 kg ha^{-1}, K_2O: 26.5 kg ha^{-1}), just as its 2-, 3-, 4- and 5-times dosage were applied to the experimental plots.

In the first year of the experiment (2012) four maize hybrids: PR37M81 (FAO 360), PR37N01 (FAO 380), P9494 (FAO 390) and SY Afinity (FAO 470), while in the second (2013) and third (2014) crop years 10-10 hybrids were studied that were the following: P9578 (FAO 320), DKC 4014 (FAO 320), NK Lucius (FAO 330), P9175 (FAO 330), DKC 4025 (FAO 340), PR37M81 (FAO 360), DKC 4490 (FAO 370), PR37N01 (FAO 380), P9494 (FAO 390), just as SY Afinity (FAO 470).

2.3. Weather characters of the studied crop years

The low amount of fallen precipitation in the spring of 2012 has increased soil water stock only in a low extent; however it made the execution of spring agrotechnical works in an adequate quality much easier. After sowing, 71.9 mm precipitation fell during May, and 91.7 mm in June. Parallel to this temperature values were higher than the long-term average (May: 15.8 ˚C; June: 18.7 ˚C), so optimal weather circumstances promoted quick and uniform emergence and early development. Drought period in August (4.1 mm precipitation; temperature: 22.5 ˚C) continued in September too (precipitation: 3.5 mm; temperature: 18.5 ˚C). Dry, drought weather conditions resulted in the quick desiccation of the assimilation area and the sudden loss of leaf area affected grain filling processes negatively.

The extreme high amount of precipitation that fell during March 2013 (136.3 mm) was more than 4-times higher than the long-term average value (33.5 mm). On the one hand it filled the water stock of the chernozem soil significantly, but on the other hand it delayed the right-time execution of spring agrotechnical works. This high amount of precipitation coincided with a lower average temperature (2.9 ˚C) than the long-term average value (5.0 ˚C). Due to the warming period in June and the amount of disposable water content of the soil the vegetative growth of maize populations became intensive. Consequently populations developed adequately until the generative development stage. Due to the dry period in August maize populations lost the most of their leaf area and as a result of that grain filling processes were hindered.

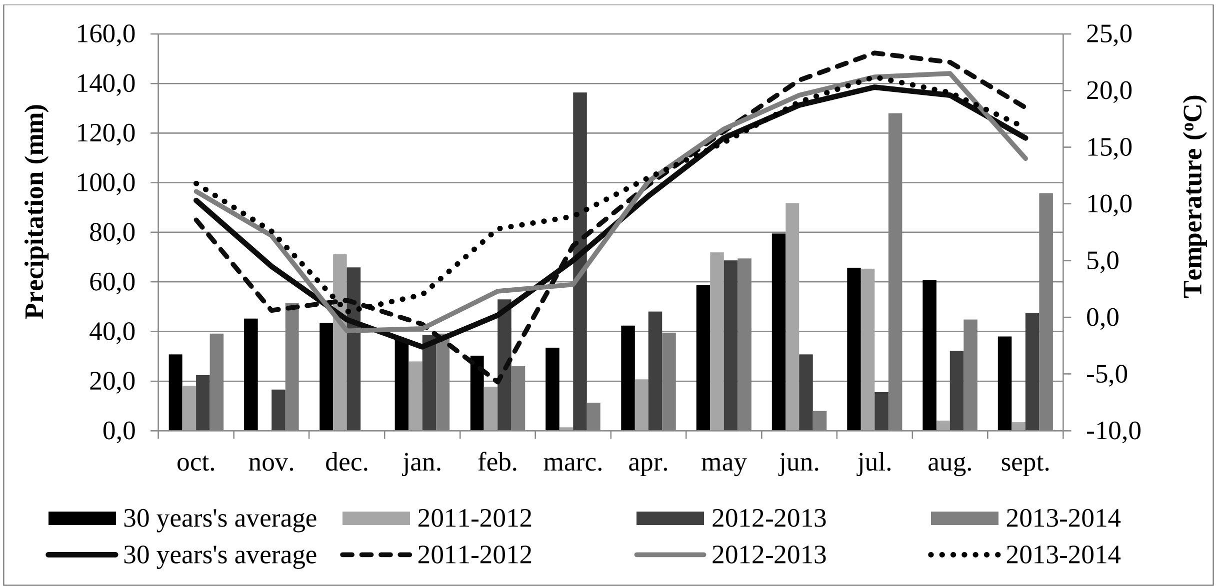

Figure 1. Development of temperature and precipitation data and their comparison with 30-years average values (Debrecen 2011-2014)

Although the amount of precipitation in the first quarter of 2014 was lower than the long-term average, it could ensure the emergence and rapid early development of maize populations, because it fell periodically. Weather conditions turned to be very unfavourable in June, because the total amount of precipitation was 7.9 mm, which was 71.6 mm lower than the long-term average. This low amount of water affected maize populations before the flowering stage negatively. In contrast, the extreme high amount of precipitation in July (128.0 mm), that was almost 2-times higher than the long-term average value (65.7 mm), had favourable effect. This amount of precipitation and the average temperature (21.1 ˚C) higher than the 30-years average, just as the higher humidity affected the generative development phases, the flowering and fertilization, just as the grain filling of maize populations favourably. Two and a half-times higher amount of precipitation fell in September than the long-term average that hindered on the one hand drying processes of maize populations, on the other hand the execution of harvest works (Figure 1.).

2.4. Research methods applied in the experiment

In the present research work relative chlorophyll concentration and leaf area index values of maize hybrids were registered. Relative chlorophyll content of maize hybrids was measured by a SPAD-502 Plus device, while leaf area of plant population on 1 m^2 area (Leaf area index – LAI) was determined by a portable SunScan Canopy Analysis System (SS1) leaf area measurement device. These measurements were carried out in different phenological phases of maize plants (6-8 leaves development, 12-leaves development, flowering (both stamens and stigmata) grain filling). Leaf area durability was determined from the measured LAI values according to the following formula:

$$LAD = \frac{LAI_1 + LAI_2}{2} * (t_2 - t_1)$$

Largest (maximal) height of maize hybrids was determined with a height measurement ruler, for which 5 average developed plants were measured for each plot.

Protein, oil and starch content of maize grain yield were determined under laboratory conditions from grain yield samples collected at harvest. Crude protein content was determined according to the standard ISO 5983-1:2005 using the method of Kjeldahl, while oil (crude fat) content was determined according to the standard MSZ 6830/19-79 by extraction and starch content was determined according the standard MSZ 6830/18-1988 using polarimetry method.

Element content of maize hybrids of different genotypes was determined in the crop years 2013 and 2014. For the determination of the element content plant and cob samples were collected before harvest. Cut vegetative and generative (stamens), just as cob samples were dried in an oven at a temperature of 80 ˚C to constant weight. Phosphorous content was determined according to the standard MSZ ISO 6491:2001 using photometry, while magnesium, calcium, sodium, potassium, copper, zinc, iron and manganese content were determined according to the standard MSZ EN ISO 6869:2001 by atomic adsorption.

The element content of maize stalk was determined using following methods and according to the standards listed:

- Nitrogen content was determined by the method of Kjeldahl according to the standard MSZ-08-1783-6:1983
- Potassium content was determined by flame photometry according to the standard MSZ-08-1783-5:1983
- Calcium content was determined according to the standard MSZ-08-1783-26:1985, while magnesium content acc. to the standard MSZ-08-1783-27:1985, phosphorous content acc. to the standard MSZ-08-1783-23:1985, iron content acc. to the standard MSZ-08-1783-31:1985, manganese content acc. to the standard MSZ-08-1783-32:1985, zinc content according to the standard MSZ-08-1783-33:1985, copper content acc. to the standard MSZ-08-1783-34:1985 and sulphur content was determined according to the standard MSZ-08-1783-38:1985.

At harvest two average sized cobs were selected in case of each hybrid for the treatments without fertilization (control), just as for the nutrient supply levels of N_{90}+PK and N_{150}+PK. Cob length, diameter, thousand grain weight, cob: grain yield ratio were determined for the selected cobs.

2.5. Method for the evaluation of experimental results

Statistical evaluation of the result data was executed using the software Microsoft Excel 2013, just as SPSS for Windows 13.0.2-way analysis of variance was used for the evaluation of the results. For the determination of the relationships between the studied factors Pearson correlation coefficients and Kang's stability analysis, just as regression analysis were calculated. For the quantification of the effect of fertilization and genotype on yield amount the components of variance were partitioned.

3. RESULTS AND DISCUSSION

3.1. The effect of ecological factors and nutrient supply on the physiological parameters of maize hybrids

Relative chlorophyll content

Various SPAD values were measured in the present experiment for different maize hybrids in case of different crop years, nutrient supply levels and measurement times. Regarding the three crop years studied no significant difference was found between the maximal SPAD values. Regarding the average of nutrient supply levels the highest values of relative chlorophyll content varied between 56.2 and 60.9 in 2012; 51.1 and 53.7 in 2013, just as between 58.8 and 61.8 in 2014. Relative chlorophyll content of maize hybrids in the studied crop years increased between the phenological phases of 12-leaves development and fully emerging stigmata, but afterwards during the grain filling phase it decreased. Relative chlorophyll content was increased by nutrient supply in case of all maize hybrids and in all studied crop years; however this statement could not be statistically proven in each case. Depending on the given crop year and hybrid, the highest SPAD values were measured in case of the nutrient supply levels of $N_{60-120-150}$+PK.

Leaf area

Similar to the relative chlorophyll content values, leaf area index values showed different tendencies in case of the studied maize hybrids and regarding the different nutrient supply levels. There were no significant differences found between leaf area index values in the studied three crop years. The highest LAI values of the hybrids were detected in case of the nutrient supply levels of $N_{120-150}$+PK in all three studied crop years. Regarding the average of nutrient supply levels and depending on the given hybrid the highest leaf area index values were measured in the crop year of 2012 (3.3-3.6 m^2 m^{-2}). Similar LAI values were measured in 2014 as well (3.0-3.4 m^2 m^{-2}). Leaf area index values measured in 2013 were lower than that (2.7-3.3 m^2 m^{-2}). In case of all studied maize hybrids and all crop yeas LAI values showed increasing tendency parallel to the phenological development of plants, just as to the increasing nutrient supply levels until the flowering phenological phase

Leaf area durability

Leaf area durability was significantly affected by the given crop year and mineral fertilization: regarding the average of treatments LAD values varied between 226 and 256 days in 2012, 178 and 222 days in 2013 and between 210 and 232 days in 2014 (*Table 1*).

Table 1. Development of leaf area durability (LAD) of different maize hybrids in case of different nutrient supply levels (days) (Debrecen, 2012-2014)

Crop year	Tápanyagszint	P9578	DKC4025	PR37M81	PR37N01	P9494	SY Afinity	**Average**
2012	Control	—	—	229	247	232	204	**228**
	N_{60}+PK			237	257	236	230	**240**
	N_{120}+PK			240	251	242	234	**242**
	N_{150}+PK			245	268	256	237	**252**
	Average			**238**	**256**	**242**	**226**	**240**
$SzD_{5\%}$ Fertilization		25						
$SzD_{5\%}$ Hybrid		13						
$SzD_{5\%}$ Interaction		26						
2013	Control	164	152	150	194	172	164	**166**
	N_{30}+PK	172	165	176	197	193	191	**182**
	N_{60}+PK	180	173	172	218	209	191	**190**
	N_{90}+PK	191	170	181	221	215	193	**195**
	N_{120}+PK	213	201	214	238	220	211	**216**
	N_{150}+PK	214	210	232	263	238	233	**231**
	Average	**189**	**178**	**188**	**222**	**208**	**197**	**197**
$SzD_{5\%}$ Fertilization		31						
$SzD_{5\%}$ Hybrid		11						
$SzD_{5\%}$ Interaction		26						
2014	Control	193	214	213	205	216	209	**208**
	N_{30}+PK	222	215	211	230	219	217	**219**
	N_{60}+PK	210	194	225	231	215	246	**220**
	N_{90}+PK	208	211	221	213	236	231	**220**
	N_{120}+PK	222	197	217	214	236	246	**222**
	N_{150}+PK	224	228	234	234	226	244	**232**
	Avergae	**213**	**210**	**220**	**221**	**225**	**232**	**220**
$SzD_{5\%}$ Fertilization		13						
$SzD_{5\%}$ Hybrid		13						
$SzD_{5\%}$ Interaction		33						

Regarding the studied cropping periods the hybrid PR37N01 (2012: 256 days and 2013: 222 days), just as SY Afinity (2014: 232 days) sustained its active photosynthesising leaf area for the longest period. Regarding the average of the hybrids the lowest LAD values were measured in all studied crop years in case of the unfertilized treatment (2012: 228 days; 2013: 166 days; 2014: 208 days). In contrast, in case of the nutrient supply level of N_{150}+PK significantly higher LAD values were measured (2012: 252 days; 2013: 231 days; 2014: 232 days). The correlation between fertilization and LAD values was weak positive in 2012 and 2014 (2012: r=0.395**, 2014: r=0.313**), while in 2013 it was moderate positive, (r=0.660**). Higher LAD values resulted in the production of more favourable yield amounts in the present experiment. In the crop years of 2012 and 2014 weak positive correlation was found between yield amount and leaf area durability (2012: r=0.310*, 2014: r=0.313**), while in 2013 it was medium positive (r=0.585**) (*Table 1*).

Plant height

Plant height of the studied maize hybrids showed different tendencies during the experimental period. Significant differences were found between plant height values of the three studied crop years. Height values of maize hybrids were the lowest in 2014: according to the measured data and regarding the average of treatments the smallest hybrid was DKC4025 (232.8 cm), while the highest one was SY Afinity (268.1 cm). Plant height was higher in the crop year of 2013 than in 2012. In 2013 the smallest hybrid was DKC4025 (250.6 cm) again, while the highest one was SY Afinity (287.2 cm). The highest maize populations were produced in the crop year of 2012 (regarding the average of nutrient supply levels: PR37M81: 290.0 cm, PR37N01: 296.9 cm, P9494: 292.5 cm, SY Afinity: 308.8 cm). As an effect of fertilization the height of maize hybrids showed increasing tendency (regarding the average of hybrids: 2012: control: 293.2 cm, N_{150}+PK: 300.8 cm, 2013: control: 247.2 cm, N_{150}+PK: 272.2 cm, 2014: control: 244.1 cm, N_{150}+PK: 244.8 cm). Weak positive correlation was found between plant height and yield in 2012 (r=0.337**) and 2014 (r=0.222**), while in 2013 it was strong positive (r=0.700**).

3.2. Generative factors

In the crop year of 2012 cob length varied between 18.7 and 21.5 cm. In contrast, smaller cob length values were measured in 2013 (16.6-20.7 cm) and 2014 (17.5-21.2 cm). Mineral fertilization increased cob length that was statistically proven by the results of the crop years 2012 and 2014. Regarding the average of the treatments the highest cob diameter values were measured in 2013 (4.7-5.2 cm) depending on the given hybrid, while smaller diameters were measured in both 2012 and 2014 for the studied maize hybrids (2012: 4.7-5.0 cm, 2014: 4.2-4.9 cm). Mineral fertilization had the greatest impact on cob diameter in the crop year of 2012: strong positive correlation was found between these factors (r=0.711**). The highest thousand seed weight was measured in 2012. Regarding the average of nutrient supply levels and depending on the given hybrid thousand seed weight values varied between 348.5 and 362.6 g in this crop year. Moderate differences were found regarding the cob: grain yield rates of the three studied crop years. Regarding the average of the treatments cob: grain yield rates of 2014 were similar to those in 2013 (2014: 86.5-90.1%, 2013: 86.6-89.3%). Smaller values were determined in the crop year of 2012 (2012: 84.9-86.5%). Correlation between fertilization and cob: grain yield rate (r=0.474**), just as between yield and cob: grain yield rate (r=0.521**) could be revealed using Pearsons correlation analysis only in the crop year of 2012.

3.3. Effect of ecological factors and nutrient supply on the yield of maize hybrids

Regarding the average of nutrient supply levels and depending on the studied hybrid highest yield amounts were recorded in 2013 among the studied crop years (12,047-16,806 kg ha^{-1}). Lower yield amounts were measured in 2012 and 2014 (2012: 12,116-13,281 kg ha^{-1}, 2014: 11,078-13,922 kg ha^{-1}). The high amount of precipitation that fell before the vegetation period played a determining role in the production of high yield in 2013: it filled the water stock of the soil significantly and thus it could ensure the water amount that was essential for the vegetative development of maize populations and that balanced unfavourable weather conditions of the summer period partly.

In the crop year of 2012 and 2013 SY Afinity produced the highest yield from studied hybrids (2012: N_{90}+PK: 14,972 kg ha^{-1}, 2013: N_{120}+PK: 18,619 kg ha^{-1}), while in 2014 the highest yield amount was measured in case of the hybrid P9175 (2014: N_{90}+PK: 15,189 kg ha $^{-1}$).

The nutrient supply level of N_{90}+PK (14,199 kg ha^{-1}) proved to be optimal in 2012 regarding the average of the studied hybrids, while in 2013 and 2014 it was the level of N_{120}+PK. The highest yield amounts were measured in case of this nutrient treatment regarding the average of the hybrids (2013: 16,011 kg ha^{-1}, 2014: 13,630 kg ha^{-1}). In case of the nutrient level of N_{150}+PK yield decrease was observed in case of most of the studied maize hybrids (except for: 2013: P9175, PR37M01).

3.3.1. Fertilizer utilization of maize hybrids

The extent of yield surplus resulted by 1 kg NPK fertilizer active substance was studied as well in the present research work. In the crop year of 2012 it has been stated that – depending on the nutrient supply level – the amount of yield surplus varied between 6.0 and 18.5 kg kg^{-1} in contrast to the control treatment. The hybrid PR37M81 (18.5 kg kg^{-1}) produced the highest yield surplus in case of the nutrient level of N_{30}+PK, while for all the other nutrient levels it was the hybrid SY Afinity (N_{60}+PK: 17.8 kg kg^{-1}, N_{90}+PK: 17.7 kg kg^{-1}, N_{120}+PK: 10.5 kg kg^{-1}, N_{150}+PK: 8.4 kg kg^{-1}). Regarding the different nutrient supply levels the highest yield surplus for unit fertilizer amount was measured – except for the hybrid

P9494 (N_{60}+PK: 16.4 kg kg^{-1}) – in case of the nutrient supply level of N_{30}+PK (PR37N01: 18.5 kg kg^{-1}, PR37N01: 15.9 kg kg^{-1}, SY Afinity: 18.0 kg kg^{-1}).

In the crop year of 2013 the yield increment for 1 kg NPK fertilizer active substance ranged between 7.3 and 54.2 kg kg^{-1} depending on the nutrient supply level. The highest yield surplus was recorded in case of the hybrid P9578 (54.2 kg kg^{-1}). In case of most of the nutrient supply levels the lowest yield amount for unit fertilizer active substance was measured for the hybrid PR37N01 (except for: N_{90}+PK: 9.6 kg kg^{-1}). Except for the hybrid DKC4490 (N_{60}+PK: 21.8 kg kg^{-1}) maize hybrids produced the highest yield increment for unit fertilizer active substance in case of the nutrient supply level of N_{30}+PK.

In the crop year of 2014 the yield increment for unit fertilizer active substance – in contrast to the control treatment – varied between 2.6 and 33.7 kg kg^{-1} depending on the nutrient supply level. The highest yield increment was measured in case of the hybrid P9578 (33.7 kg kg^{-1}), while the lowest for the hybrid NK Lucius (2.6 kg kg^{-1}). The studied maize populations produced the highest yield surplus for 1 kg NPK fertilizer active substance – except for the hybrid DKC4014 (N_{60}+PK: 13.7 kg kg^{-1}) – at the nutrient supply level of N_{30}+PK (P9578: 33.7 kg kg^{-1}, NK Lucius: 14.8 kg kg^{-1}, P9175: 30.0 kg kg^{-1}, DKC4025: 13.6 kg kg^{-1}, PR37M81: 13.6 kg kg^{-1}, DKC4490: 11.3 kg kg^{-1}, PR37N01: 18.0 kg kg^{-1}, P9494: 31.5 kg kg^{-1}, SY Afinity: 27.0 kg kg^{-1}).

3.3.2. Water utilization of maize hybrids

Studying the yield amount for 1 mm precipitation during the vegetation period it has been stated that this parameter varied between 38.9 and 58.2 kg mm^{-1} depending on the control or the optimal nutrient treatment in 2012. The weakest water utilisation for 1 mm vegetation precipitation was observed in case of the hybrid PR37M81 (control: 38.9 kg mm^{-1}, N_{opt}+PK: 52.1 kg mm^{-1}). Regarding the yield amount for precipitation unit the hybrid PR37N01 (45.0 kg mm^{-1}) produced the highest results in the unfertilized treatment, while in case of the optimal nutrient supply level it was the hybrid SY Afinity (58.1 kg mm^{-1}).

In the crop year of 2013 yield amount for 1 mm precipitation varied between 39.2 and 76.7 kg mm^{-1} at the two selected nutrient supply levels (control and N_{opt}+PK). The best water utilization was found in case of the hybrid SY Afinity (control: 59.9 kg mm^{-1}, NPK optimum: 76.7 kg mm^{-1}) while the weakest in case of the hybrid DKC4025 (control: 39.2 kg mm^{-1}, NPK optimum: 55.6 kg mm^{-1}). Regarding the yield amount per unit precipitation the studied maize hybrids showed higher results in case of both the control and the optimal nutrient supply treatment in the crop year of 2013 than in that of 2012 (PR37M81: control: 43.8 kg mm^{-1}, NPK optimum: 69.1 kg mm^{-1}, PR37N01: control: 58.7 kg mm^{-1}, NPK optimum: 71.9 kg mm^{-1}, P9494: control: 46.5 kg mm^{-1}, NPK optimum: 70.5 kg mm^{-1}, SY Afinity: control: 59.9 kg mm^{-1}, NPK optimum: 76.7 kg mm^{-1}).

Depending on the studied nutrient supply level (control, N_{opt}+PK) the yield amount for unit precipitation varied between 28.2 and 44.0 kg mm^{-1} in 2014. The yield amount per 1 mm precipitation amount ranged between 28.2 and 33.6 kg mm^{-1} in the control treatment. In contrast, water utilization of hybrids was more favourable in case of the optimal nutrient supply level (35.1-44.0 kg mm^{-1}). In case of the unfertilized treatment water utilization of the hybrid DKC4490 (33.6 kg mm^{-1}) proved to be the most effective, while in case of the optimal nutrient supply level it was the hybrid P9175 (44.0 kg mm^{-1}). The weakest water utilization was observed for the hybrid NK Lucius in case of both nutrient supply levels (control: 28.2 kg mm^{-1}, NPK optimum: 35.1 kg mm^{-1}). Highest deviance of yield amounts per 1 mm precipitation between the control and the optimum nutrient supply level was observed in case of the hybrid P9175 (11.5 kg mm^{-1}).

3.3.3. Development of fertilizer optimum values and complex evaluation of nutrient reaction of the studied maize hybrids

The optimal fertilizer level interval of the studied hybrids was determined in the present work. The upper limit of the interval was defined as the fertilizer dosage related to the maximal yield in the trend function. In order to define the fertilizer dosage more precise, the lower limit was determined by subtracting the quarter of the $LSD_{5\%}$-value from the yield maximum value. Based on the shape of the trend function the hybrid SY Afinity showed the best nutrient reaction among the studied four hybrids in the crop year of 2012. In case of the hybrid SY Afinity the nutrient optimum varied between N: 87.0-111.0 kg, P_2O_5: 65.0-83.0 kg and K_2O: 77.0-98.0 kg in the given crop year, parallel to which high yield amounts were recorded. Favourable nutrient reaction was characteristic to the hybrids PR37N01 and P9494; their nutrient optimum values showed similar development (PR37N01: N: 81.0-111.0 kg, P_2O_5: 61.0-83.0 kg, K_2O: 72.0-98.0 kg; P9494: N: 75.0-102.0 kg, P_2O_5: 56.0-77.0 kg, K_2O: 66.0-90.0 kg). According to the fit of the trend function strong correlation could be detected between the applied fertilizer dosages and yield amounts of all four studied hybrids in the experiment (PR37M81: R^2= 0.9726; PR37N01: R^2= 0.9088; P9494: R^2= 0.9704; SY Afinity: R^2= 0.9463).

According to the shape of the trend functions the hybrids P9578 (nutrient optimum: N: 84.0-108.0 kg, P_2O_5: 63.0-81.0 kg, K_2O: 74.0-95.0 kg), P9175 (nutrient optimum: N: 120.0-

150.0 kg, P_2O_5: 90.0-112.5 kg, K_2O: 106.0-132.5 kg) and PR37N01 (nutrient optimum: N: 111.0-150.0 kg, P_2O_5: 83.0-112.5 kg, K_2O: 98.0-132.5 kg) showed good nutrient reaction and higher nutrient optimum values in the crop year of 2013. These hybrids showed significant yield differences in contrast to the hybrids with weaker nutrient reaction and similar nutrient optimum values (DKC4014, DKC4025, DKC4490) already in the unfertilized treatment. According to the fit of the trend function strong correlation was found between the applied fertilizer dosage and yield amount of all studied maize hybrids (R^2=0.8187- 0.9973).

In the crop year of 2014 it has been stated that the hybrid with the most favourable nutrient reaction was P9175: its nutrient optimum was the following: N: 123.0-150.0 kg ha^{-1}, P_2O_5: 92.0-112.5 kg ha^{-1}, K_2O: 108.0-132.5 kg ha^{-1}. The hybrids P9578 (N: 84.0-105.0 kg ha^{-1}, P_2O_5: 63.0-79.0 kg ha^{-1}, K_2O: 74.0-93.0 kg ha^{-1}), just as SY Afinity (N: 96.0-123.0 kg ha^{-1}, P_2O_5: 72.0-92.0 kg ha^{-1}, K_2O: 85.0-109.0 kg ha^{-1}) showed good nutrient reaction and lower nutrient optimum. In contrast to these hybrids weaker nutrient reaction was characteristic to the hybrids NK Lucius, DKC4025 and PR37M81. Similar to the crop years 2012 and 2013, strong correlation was found between the applied fertilizer amount and the produced yield amounts (R^2=0.8555-0.9938).

Regarding yield results of maize hybrids good natural nutrient utilization and good fertilizer reaction were characteristic to the hybrid P9494 (Group A). Although the hybrid SY Afinity produced the highest yield amount at the optimal nutrient supply level, but relatively lower yield was measured in the unfertilized treatment, therefore this maize hybrid showed moderate nutrient utilization ability and good yield maximum (Group B). In the crop year of 2012 the hybrid PR37N01 was characterized by good natural nutrient utilization ability and moderate yield maximum (Group C). In case of both the control treatment and the optimal nutrient supply level the lowest yield amounts were measured for the hybrid PR37M81, therefore this hybrid could be characterized by moderate natural nutrient utilization ability and moderate yield maximum (Group D) (*Figure 2*).

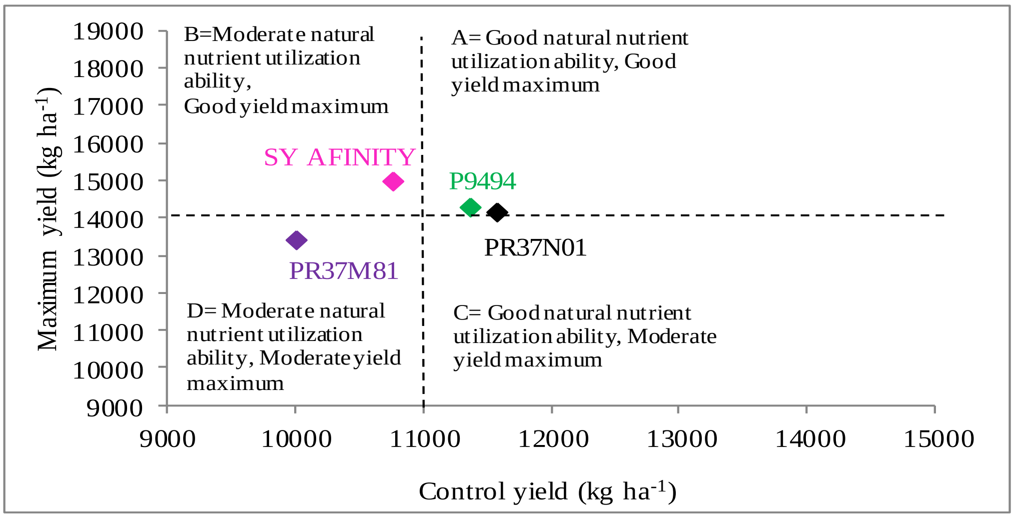

Figure 2: Complex evaluation of nutrient reaction of maize hybrids (Debrecen, 2012)

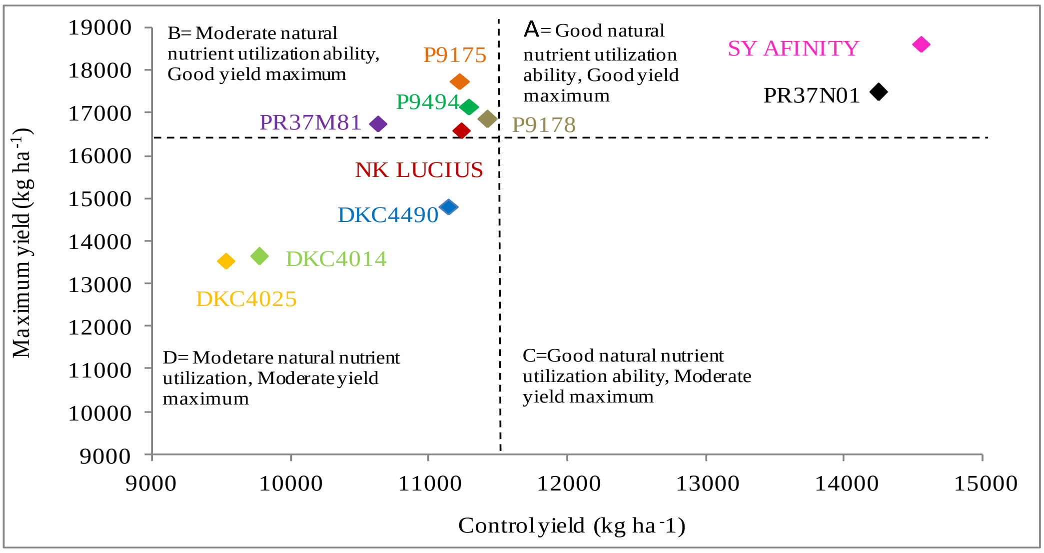

Figure 3: Complex evaluation of nutrient reaction of maize hybrids (Debrecen, 2013)

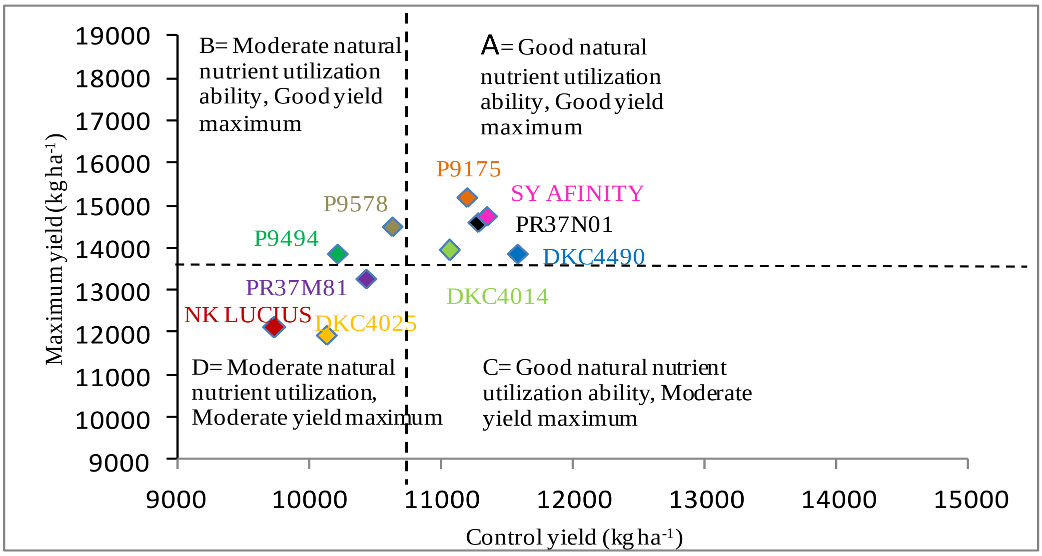

Figure 4: Complex evaluation of nutrient reaction of maize hybrids (Debrecen, 2014)

In the crop year of 2013 good natural nutrient utilization and good yield maximum were characteristic to the hybrids PR37N01 and SY Afinity (Group A). The majority of the studied hybrids belonged to the Group B, that means they were characterized by moderate natural nutrient utilization ability and good yield maximum (NK Lucius, PR37M81, P9578, P9494, P9175). According to the yield results none of the studied hybrids could be classified into the Group C. The hybrids DKC4025, DKC4014 and DKC4490 had moderate natural nutrient utilization ability and moderate yield maximum (Group D) (*Figure 3*).

Regarding the yield results of the crop year 2014 the majority of the hybrids belonged to the Group A, that means they could be characterized by good natural nutrient utilization ability and good yield maximum (DKC4014, DKC4490, PR30N01, SY Afinity, P9175). The hybrids P9494 and P9578belonged to Group B: they had moderate natural nutrient utilization ability, but at an optimal nutrient supply level they produced good maximal yield amounts. The hybrids of the Group D were characterized by moderate natural nutrient utilization ability and moderate yield maximum: the hybrids DKC4025, NK Lucius and PR37M81 belonged to this (*Figure 4*).

3.4. Nutrient intake

On the basis of the nutrient balance it can be stated that under unfertilized conditions the hybrid SY Afinity has utilized more from the nutrients nitrogen (surplus: 2013: 33.0 kg ha^{-1}, 2014: 28.4 kg ha^{-1}), phosphorous (surplus: 2013: 11.0 kg ha^{-1}, 2014: 8.4 kg ha^{-1}) and potassium (surplus: 2013: 20.6 kg ha^{-1}, 2014: 11.1 kg ha^{-1}) than the hybrid P9494 during the studied period. These results confirmed that the hybrid SY Afinity has utilized soil natural nutrient stock more effective than the hybrid P9494. The nutrients NPK were utilized more effective at the nutrient supply level of N_{90}+PK in both studied crop years (2013, 2014) than at the level of N_{150}+PK. This means that parallel to the increasing fertilizer dosages the utilization rate of fertilizers decreased, and consequently the efficiency of fertilization decreased as well (*Table 2*).

Table 2. Nutrient intake of the hybrids P9494 and SY Afinity (Debrecen, 2013-2014)

Year	Hybrid	Nutrient level	Amount of extracted nutrient (kg ha^{-1})			Efficiency %		
			N	P_2O_5	K_2O	N	P_2O_5	K_2O
2013	P9494	Control	122,7	32,9	77,2	—	—	—
		N_{90}+PK	188,5	56,4	120,9	73,1	26,2	48,5
		N_{150}+PK	195,0	51,3	115,1	48,1	12,3	25,3
		Average	**168,7**	**46,9**	**104,4**	—	—	—
	SY Afinity	Control	155,7	43,9	97,8	—	—	—
		N_{90}+PK	231,8	74,8	140,5	84,6	34,3	47,4
		N_{150}+PK	219,9	68,0	135,9	71,4	26,7	42,3
		Average	**202,5**	**62,2**	**124,7**	—	—	—
2014	P9494	Control	107,4	28,2	40,7	—	—	—
		N_{90}+PK	179,5	40,9	70,4	80,1	14,1	33,0
		N_{150}+PK	200,7	47,6	76,9	62,2	12,9	24,1
		Average	**162,5**	**38,9**	**62,7**	—	—	—
	SY Afinity	Control	135,8	36,6	51,8	—	—	—
		N_{90}+PK	203,6	48,0	71,1	75,2	12,6	21,4
		N_{150}+PK	214,1	47,6	79,9	52,1	7,4	18,7
		Average	**184,5**	**44,1**	**67,6**	—	—	—

3.5. Development of yield stability of the studied hybrids

Kang yield stability analysis was run for the hybrids that were produced in all three experimental crop years (PR37M81, PR37N01, P9494, SY Afinity). It has been stated that the most favourable yield stability was characteristic to the hybrid P9494 (b=0.7353) among the studied four hybrids during the three experimental crop years, because the lowest extent of variation in yield amounts was measured in case of this hybrid. Yield stability of hybrids PR37N01 (b=1.1409) and SY Afinity (b=1.3074) – that produced higher yields – was less favourable because changes in the ecological conditions affected their yield amounts more (*Figure 5*).

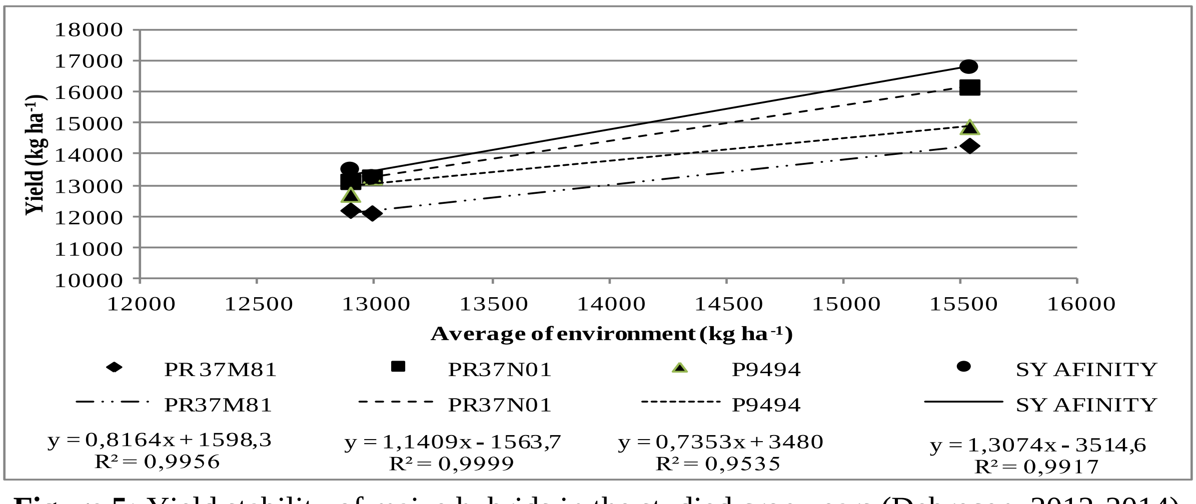

Figure 5: Yield stability of maize hybrids in the studied crop years (Debrecen, 2012-2014)

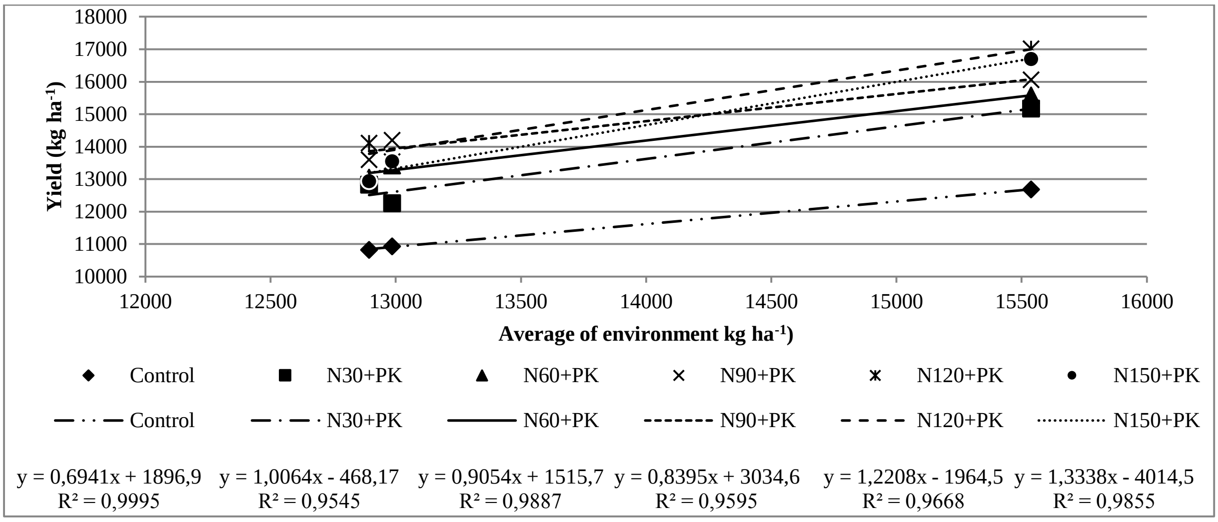

Figure 6: Yield stability of maize hybrids depending on nutrient supply levels (Debrecen, 2012-2014)

Regarding the nutrient supply levels the most favourable yield stability was detected in case of the unfertilized treatment (b= 0.6941). In case of the application of higher nutrient dosages than the control treatment the most favourable stability was observed at the nutrient level of N_{90}+PK (b=0.8395). Parallel to the increasing nutrient dosages the stability of nutrient supply levels decreased. By the application of nutrient supply dosages of N_{120}+PK and N_{150}+PK high yield results could be produced, but environmental conditions affected yield variation significantly (N_{120}+PK: b= 1.2208; N_{150}+PK: b= 1.3338) (Figure 6).

3.6. Complex evaluation of the effect of mineral fertilization, genotype and crop year on maize yield

Partitioning the components of variance the extent of determining effect of mineral fertilization and genotype on yield surplus could be determined compared to the control yield amounts. It has been stated that fertilization had the greatest impact in the crop year of 2014 (84.3%). In contrast, its yield increasing effect was less pronounced in 2012 and 2013 (2012: 70.7 %; 2013: 66.2 %). Genotype played the most pronounced effect in the production of yield surplus in the crop year of 2013 (33.8 %). However, in the crop years 2012 and 2014 it contributed to the production of the maximal yield amounts in a lower extent (2012: 29.3 %; 2014: 15.7 %) (*Figure 7*).

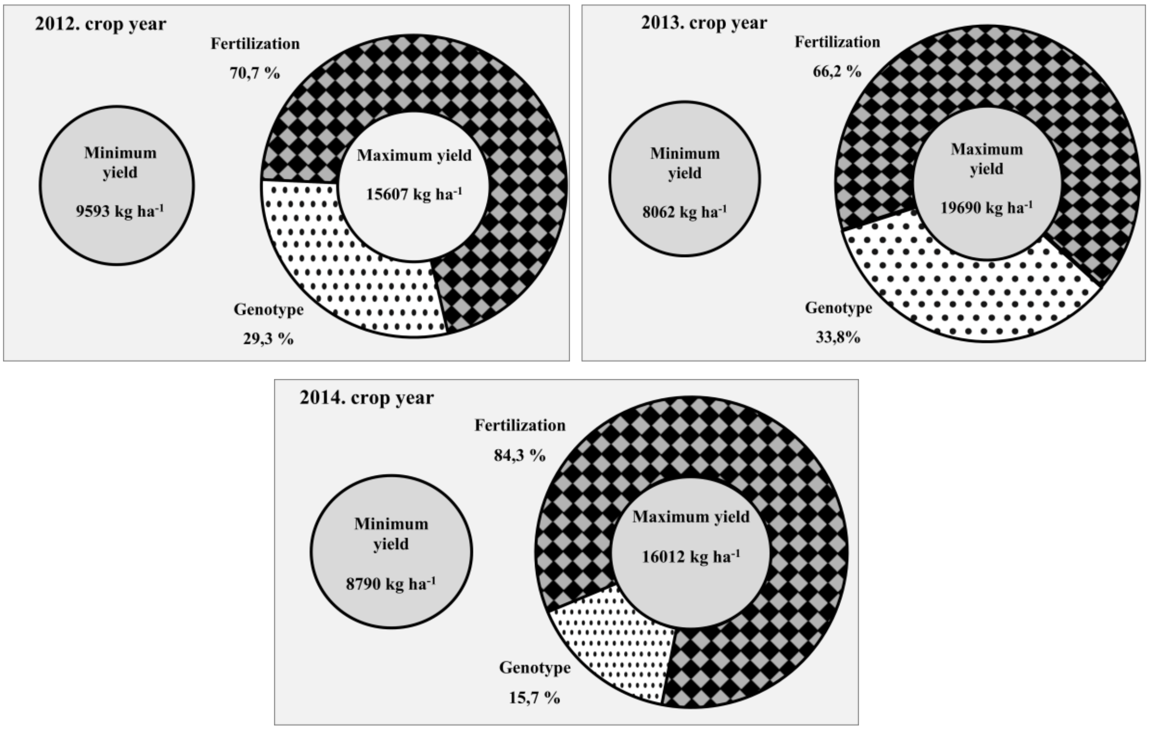

Figure 7. The roles of fertilization and genotype in the yield of mazie (Debrecen, 2012-2014)

Overall comparing the three studied crop years it has been stated that mineral fertilization had the greatest impact on yield amounts: it affected the production of yield surplus compared to the control treatment by 58.3%. Genotype (25.3%) and crop year (16.4%) had rather moderate contribution to the production of yield surplus (*Figure 8*).

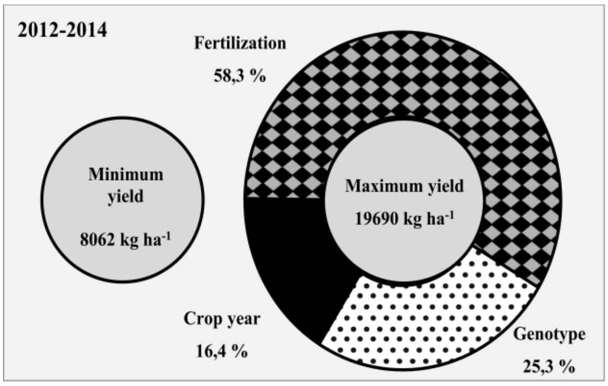

Figure 8. The roles of fertilization, genotype and the crop year in the yield of maize (Debrecen, 2012-2014)

3.7. The effect of crop year, genotype and nutrient supply on the yield quality of maize

In the present research work it has been stated that mineral fertilization has increased protein and oil content, while it decreased the starch content of grain yield. The strong correlation between the studied factors has been statistically confirmed as well. Pearson correlation analysis found strong positive relationship between fertilization and protein content in all three studied crop years (2012: r=0.842**, 2013: r=0.834**, 2014: r=0.913**) (*Table 3*).

Table 3: Correlation analysis between protein, starch and oil content, just as yield amount and fertilization using Pearson correlation analysis (Debrecen, 2012-2014)

Year	Examinated factors	Protein %	Starch %	Oil %
2012	Fertilization	0,842(**)	-0,877(**)	0,481(**)
	Yield	0,624(**)	-0,706(**)	0,446(*)
	Protein %	—	-0,905(**)	0,406(*)
	Starch %	—	—	-0,522(**)
2013	Fertilization	0,834(**)	-0,757(**)	0,929(**)
	Yield	0,570(**)	-0,599(**)	0,715(**)
	Protein %	—	-0,859(**)	0,839(**)
	Starch %	—	—	-0,784(**)
2014	Fertilization	0,913(**)	-0,776(**)	0,745(**)
	Yield	0,377(*)	-0,238^{NS}	0,378(*)
	Protein %	—	-0,844(**)	0,812(**)
	Starch %	—	—	-0,824(**)

Similar conclusion can be drawn regarding the correlation between mineral fertilization and oil content as well (2013: r=0.929**, 2014: r=0.745**) – except for the crop year of 2012. In this year only weak positive correlation was fond between the two factors (2012: r=0.481**). Also strong, but negative correlation was found between starch content and mineral fertilization (2012: r=-0.877**, 2013: r=-0.757**, 2014: r=-0.776**) (*Table 3*).

3.8. Development of primary, secondary and trace element contents

Crop year, genotype and mineral fertilization had significant impact on the development of primary, secondary and trace element amounts. In the crop year of 2013 the studied elements could be detected in the highest rate in the grain yield and vegetative biomass of the two selected maize hybrids at the nutrient supply level of N_{90}+PK (except for: P9494: N: N_{150}+PK: 1.14 m/m %). In contrast, in the crop year of 2014 the nutrient supply level of N_{150}+PK proved to be the optimal regarding the primary, secondary and trace element content, because the studied nutrients showed maximum values at this nutrient supply level (except for: SY Afinity: Mn-content: N_{90}+PK: 110.00 mg kg^{-1}).

4. NOVEL SCIENTIFIC RESULTS

1. Nutrient optimum intervals for maize hybrids of new genotypes were determined in different crop years using parabolic regression analysis (N_{90}-N_{150}+PK). Optimal fertilizer dosage was affected by – beside genotype – the given crop year as well. In case of a dry crop year rather a lower (N_{90}+PK), while in a crop year with more favourable water supply ($N_{120(150)+}$PK) rather higher fertilizer dosages proved to be the agro-ecological nutrient optimum.

2. Productivity of the applied maize hybrids varied between 11 and 17 t ha^{-1} in a small-plot experiment with optimized agrotechnical conditions on a chernozem soil.

3. The results of the present long-term experiment confirm that the utilization of primary-element containing mineral fertilizers was different: it depended on the given crop year, the fertilizer dosage and the applied genotype. Fertilizer dosages higher than the optimum dosage were utilized by maize hybrids with lower efficiency (utilization of nutrients was following: in the treatment of N_{90}+PK N=73-85%, P_2O_5: 13-34%, K_2O: 21-49%; in case of the nutrient supply level of N_{150}+PK N= 48-71%, P_2O_5: 7-27%, K_2O: 19-42%). The nutrient utilization ability of the hybrid SY Afinity was more favourable than that of the hybrid P9494.

4. Using Kang's stability analysis it has been proven that yield stability showed significant differences regarding both maize hybrids and fertilizer treatments. Favourable yield stability was characteristic to the maize hybrids P9494 (b=0.7353) and PR37M81 (b=0.8164), while the hybrids PR37N01 (b=1.1409) and SY Afinity (b=1.3074) showed higher deviances in yield amounts. Regarding the fertilizer treatments it was the control (unfertilized) treatment that proved to be the most stable (b=0.6941) – however parallel to a low yield level. The most stable and balanced yield was measured in case of the nutrient supply level of N_{90}+PK (b=0.8395).

5. Due the fact that the studied crop years could be considered as average and that the chenozem soil had excellent parameters only medium or weak correlations were found between yield amount and some plant physiological parameters (SPAD, LAI, LAD) using Pearson correlation analysis. The relationship between yield and SPAD values (at the phenological phase of flowering and grain filling) was affected by the crop year (in 2012: r=0.651** - 0.736**; in 2013: r=0.355** - 0.435**; in 2014: r=0.294** - 0.526**).

Medium positive correlation was found between yield and LAI values solely in the crop year of 2013 (r=0.351** - 0.633**).

6. Partitioning the components of variance it has been stated that – regarding the average of the studied crop years – fertilization had a contribution to the yield increment production of maize hybrids of 58.3%, while in case of genotype it was 25.3% and for crop year 16.4%.

7. Strong positive correlation was found between fertilization and protein content (r=0.834**-0.913**), while strong negative relationship was determined between fertilization and starch content (r=-0.757**- -0.877**). The strength of correlation between fertilization and oil content was depending on the given crop year (r=0.481**-0.929**).

8. The amount of main primary, secondary and trace elements was significantly determined by the crop year. In the rather dry crop year of 2013 the nutrient level of N_{90}+PK proved to be optimal (except for: P9494 grain: N: N_{150}+PK: 1.14 m/m %,), while in the crop year of 2014 N_{150}+PK could be considered as optimal nutrient supply level. Regarding the two studied maize hybrids and the average of the treatments the hybrid SY Afinity was characterized by higher element content of both grain yield and vegetative plant parts in both 2013 and 2014, than the hybrid P9494 (except for: 2013: P9494: shoot: Fe: 69.33 mg kg^{-1}, Cu: 3.01 mg kg^{-1}, Mn: 67.68 mg kg^{-1}, just as 2014: P9494: grain: K: 3313.50 mg kg^{-1}, Fe: 19.73 mg kg^{-1}, shoot: N: 0.95 m/m%, Fe:176.17 mg kg^{-1}, Cu: 7.11 mg kg^{-1}, Mn:114.62 mg kg^{-1}).

5. RESULTS APPLICABLE IN THE PRACTICE

1. The practically realizable productivity of maize hybrids with new genotypes ranges between 11 and 17 t ha^{-1} in the Hajdúság region under optimized agrotechnical conditions.

2. In order to realize the productivity of maize hybrids the application of hybrid-specific fertilization technology is of basic importance. Water supply of the vegetation period modifies the agro-ecological fertilizer optimum. Yield maximums can be produced with the application of a fertilizer level of $N_{90(120)}$+PK in case of a drier crop year, while in a year with more favourable water supply it is the fertilizer dosage of $N_{120(150)}$+PK.

3. Choosing maize hybrids, yield stability has to be taken into account beside productivity. The hybrids SY Afinity and P9175 had excellent productivity, while the hybrids P9494 and PR37M81 proved to have favourable yield stability.

4. It can be an important criterion for the determination of fertilizer dosages in practice that in case of the application of mineral fertilizer dosages higher than the optimum (N_{90-120}+PK) the nutrient utilization will decrease and that nutrient utilization of different maize genotypes are different as well.

5. Not only higher yield amounts can be produced as an effect of fertilization of maize hybrids, but water utilization of hybrids can be significantly improved with optimal nutrient supply (regarding the average of the hybrids: 2012-2014: WUE: 31.2-47.8 kg mm^{-1} in the control treatment; 2012-2014: WUE: 40.0-67.1 kg mm^{-1} in the optimum fertilizer dosage treatment), thus the adaptation of hybrids to climate change can be improved as well.

6. Fertilization (58.3%) and genotype (25.3%) – among the studied factors – proved to be the main factors that affected the realization of maize productivity.

7. In case of the chernozem soil with excellent nutrient management plant physiological parameters (SPAD, LAI, LAD) can be limited used to forecast yields.

8. Mineral fertilization affected nutritional content parameters of maize hybrids. As an effect of the application of increasing fertilizer dosages, protein and oil content of plants increased, while starch content decreased.

LIST OF PUBLICATIONS

UNIVERSITY OF DEBRECEN
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Registry number: DEENK/207/2015.PL
Subject: Ph.D. List of Publications

Candidate: Lajos Gábor Karancsi
Neptun ID: KRPBUC
Doctoral School: Hankóczy Jenő Doctoral School of Crop Production, Horticulture and Food Sciences
MTMT ID: 10040125

List of publications related to the dissertation

Hungarian book chapter(s) (1)

1. **Karancsi L.G.**: Különböző kukorica hibridek termésének és tápanyag reakciójának vizsgálata eltérő műtrágyakezelések esetén.
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2. **Karancsi, L.G.**: The effect of nutrient supply on the yield and chlorophyll content of corn hybrids.
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24. Pepó P., Dóka L.F., Szabó A., **Karancsi L.G.**, Vad A.: Néhány agrotechnikai tényező hatása a borsó (Pisum sativum L.) termésére.
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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.

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