NEW RESULTS OF NUTRIENT UTILIZATION AND RESPONSE OF MAIZE *(Zea mays* L.*)* HYBRIDS

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Abstract
In a long-term experiment, the fertilizer response of 10 maize hybrids of different genotypes was studied on chernozem soil in a favourable year. The yields of the hybrids varied between 9500 and 18600 kg ha^{-1} depending upon the fertilizer treatment and the genotype. The excellent nutrient and water management of the chernozem soil was proved by the high yield (9500 – 14600 kg ha^{-1}) obtained in the control. Even in such a good soil, the maize hybrids demanded fertilization and responded to it with a high yield increasement (3200 – 6500 kg ha^{-1}). From among the tested hybrids, 8 hybrids gave the highest yield in the N_{120}+PK treatment, while 2 hybrids reached their maximum yield in the N_{150}+PK fertilizer treatment (13500 – 18600 kg ha^{-1} depending upon the hybrid). The water utilization of maize was improved as a result of the optimum fertilization. The water-use efficiency (WUE) was 30.35 kg mm^{-1}, while it increased to 42.22 kg mm^{-1} at the optimum fertilizer dosage (N_{120}+PK). The natural nutrient utilization ability (yield in the control treatment) and the yield obtained at the optimum fertilizer dosage (N_{120}+PK and N_{150}+PK) were used in a special coordinate system.

Keywords: maize, yield, fertilization, water utilization, nutrient efficiency

Introduction

The most critical factors determining maize yield are the water and the nitrogen supply (Moser et al., 2006). Nagy (1996) finds positive correlations between irrigation and fertilization as well as plant population and fertilization. Fertilization, irrigation, soil cultivation and plant population increased the yield by 48 %, 28 %, 18 % and 6 %, respectively. Maize is a plant that demands high amounts of nutrients and also requires and gives good responses professional fertilizer application (Pakurár et al., 2004). The cropyear and different agrotechnical factors (fertilization, crop rotation, irrigation etc) could modify the yields of different maize genotypes (Pepó et al., 2006; Berényi et al., 2007; Karancsi and Pepó, 2012). Széles et al. (2013) proved that the yield was influenced not only by the precipitation of the crop year, but also by the amount of precipitation and temperature during the winter. Results of Kuscu et al. (2013) proved that the better water supply resulted higher yields because the main limitation factor was water deficit. Huang et al. (2010) stated that imbalanced fertilization did not increase the yield of maize in the long run, furthermore, it resulted in soil acidification. Maize requires a balanced NPK fertilization and nitrogen has a determining role from among the macroelements (Kovačevic et al. 2006). Uribelarrea et al. (2007) found that the applied hybrid and the N supply have a great role in the N accumulation and in the efficacy of N uptake in maize. According to their results, the grain yield of maize increased gradually with increasing fertilizer doses up to the N_{160} fertilization level. On chernozem soils with medium-good NPK supply, the dosages above 120 kg ha^{-1} N active ingredient did not increase yields efficiently, furthermore, they even reduced it without irrigation (Zhou et al, 2011). According to Azeez (2009), the dosage of 90 kg/ha N significantly increased the maize yield. As opposed to that, Berenguer et al. (2009) stated that the highest yields were obtained at 96, 153 and 159 kg ha^{-1} N in 2003, 2004 and 2005, respectively. Idikut and Kara (2011) stated that the effect of nitrogen doses was significant for the tasseling period, 1000 grain yield of different maize varieties. Similar results were obtain in silage maize by Budakli Carpici et al. (2010). According to their results the dry matter yield

responded linearly to nitrogen rates with the highest dry matter yield at 300 – 400 kg N ha^{-1}.

Mateials and methods

The experiment was carried out at the experimental farm of the University of Debrecen Centre for Agricultural Sciences, Institute of Crop Sciences at Látókép. The site is located in Eastern-Hungary, 15 km from Debrecen in the Hajdúság loess region and its soil is calcareous chernozem soil (N 47°33', E 21°27'). The experimental soil is of good culture-state, medium-hard loam. Its humus content is medium, 2.8 %, its pH value is almost neutral, pH_{Kcl}=6.4. The soil has good water management characteristics. The long-term experiment was set up in 1983. The hybrids studied in the experiment were 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) and SY Afinity (FAO 470). The hybrids were sown with a seed number of 72.000 plants/ha. Six fertilization treatments were applied (Table 1). Nitrogen was applied in the form of 34% ammonium-nitrate (50% in the spring), the nitrogen 50% and the phosphorus and potassium fertilizers were applied in full dosage (100%) in the autumn as a 10:15:18 special complex fertilizer. The forecrop was winter wheat. The major meteorological data are presented in Table 2.

Results

From among the field crops in Hungary, maize has the widest biological bases. Currently, the number of state registered hybrids is almost four hundred (390 hybrids on the variety list of 2013). There are great differences among the maize hybrids of different genetic background. The differences are manifested not only in the yield potential and yield stability of the given hybrid (in its abiotic and biotic adaptation ability), but also in the responses of the hybrids to the different agrotechnical inputs. The responses to the agrotechnical inputs have a great influence on the biological, agronomical and economic efficiency of maize production technology. From among the agrotechnical responses, one of the most important ones is the fertilizer response of maize hybrids, on the one hand, because fertilizer represent a very high cost, on the other hand, because overfertilization is not only ineffective from the economic point of view, but it can also indicate severe environmental problems.

In the vegetation period of 2013, the fertilizer response of maize hybrids with different genetic

Table 1. Fertilizer doses of long-term experiment (Debrecen, chernozem soil)

Treatment	N	P_2O_5 kg ha^{-1}	K_2O
Control	0	0	0
1	30	22.5	26.5
2	60	45	53
3	90	67.5	79.5
4	120	90	106
5	150	112.5	132.5

Table 2. Some important meteorological data (Debrecen)

Precipitation (mm)	Oct-Feb.	March.	Apr.	May.	June	July	Aug.	Total
2012/2013	196.4	136.3	48.0	68.7	30.8	15.6	32.2	528.0
30 years average	186.7	33.5	42.4	58.8	79.5	65.7	60.7	527.3
Temperature (°C)	Oct-Feb.	March.	Apr.	May.	June	July	Aug.	Average
2012/2013	3.7	2.9	12.0	16.6	19.6	21.2	21.5	13.9
30 years average	2.4	5.0	10.7	15.8	18.7	20.3	19.6	13.2

Table 3. The effect of fertilization on the yield of maize hybrids (kg ha^{-1}) (Debrecen, chernozem soil, 2013)

Hybrids	Control	N_{30}+PK	N_{60}+PK	N_{90}+PK	N_{120}+PK	N_{150}+PK
P9578	11428	15710	15869	16105	16838	16475
DKC 4014	9774	11846	12349	12437	13622	13011
NK LUCIUS	11237	14392	15112	15017	16572	15553
P9175	11226	14880	15851	16311	16713	17736
DKC 4025	9530	11011	12982	12299	13514	12943
PR37M81	10630	14123	14611	14757	14838	16754
DKC 4490	11148	12741	13790	14364	14789	14414
PR37N01	14250	15641	15965	16519	17476	17127
P9494	11293	14388	15092	16263	17132	15206
SY AFINITY	14550	16570	16643	16736	18619	17718
$LSD_{5\%}$ (Hybrid)			1230			
$LSD_{5\%}$ (Nutrient level)			408			

backgrounds was studied on chernozem soil in a long-term experiment started 30 years ago. The weather of 2013 was favourable for the vegetative and generative development and yield formation of maize. As a joint effect of the favourable crop rotation (wheat – sunflower - wheat – maize), careful agrotechnique and favourable weather, the tested maize hybrids could realize a significant ratio of their yield potential. The yields of the hybrids ranged from 9500 to 18600 kg ha^{-1} depending upon the hybrid and the fertilizer treatment (Table 3). The favourable physical, chemical and biological characteristics of the chernozem soil and its excellent water and nutrient management are well indicated by the high yields of the hybrids obtained in the control (non-fertilized) treatment. The yields of the hybrids varied between 9500 and 14600 kg ha^{-1} in the control treatment. This means a difference of 5100 kg ha^{-1} between the tested genotypes in 2013, which illustrates that there are huge differences between maize hybrids in their natural nutrient utilization ability. In 2013, the hybrids DKC 4025, DKC 4014, PR37M81 gave a relatively moderate yield in the control treatment (9500 – 10600 kg ha^{-1}). These hybrids had different FAO numbers, which indicates that the natural nutrient utilization ability of hybrids is primarily determined by the genotype. The hybrids PR37N01 and SY Afinity gave outstandingly high yields (14200 – 14500 kg ha^{-1}) in the control treatment in 2013, these hybrids also differed in their vegetation season-length.

In the season of 2013, the maximum yields of the hybrids varied within a very favourable range between 13500 and 18600 kg ha^{-1} (Table 3). The yield maximum of the hybrids DKC 4025, DKC 4014 and DKC 4490 was relatively lower than the average (between 13500 and 14800 kg ha^{-1}). Outstandingly high yields were obtained in the case of the hybrids SY Afinity, P9175, PR37N01, and P9494 (between 17100 and 18600 kg ha^{-1}).

The evaluation of the nutrient utilization of the tested maize hybrids is included in Table 4. As

Table 4. Parameters of maize hybrids nutrient utilization (Debrecen, chernozem soil, 2013)

	Average of 10 hybrids	The minimum and maximum yield of hybrids
Control yield (kg ha^{-1})	11507	9530 – 14550
Maximum yield (kg ha^{-1})	16305	13514 – 18619
The yield surplus of fertilization (kg ha^{-1})	4798	3226 – 6510
Optimum N +PK (kg ha^{-1})	126 N+ PK	120 N+PK - 150 N+PK

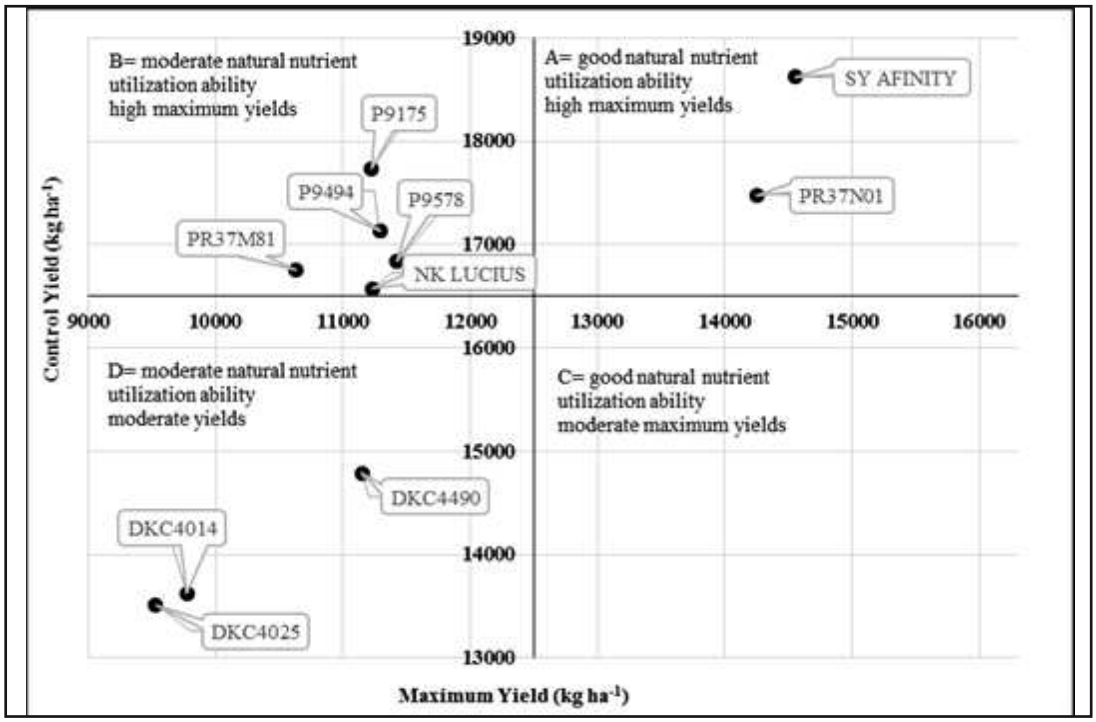
Table 5. Study of nutrient efficiency of different maize genotypes (Average of ten hybrids) (Debrecen, chernozem soil, 2013)

	Control	N_{30}+PK	N_{60}+PK	N_{90}+PK	N_{120}+PK	N_{150}+PK
Average yield (kg ha^{-1})	11507	14130	14826	15081	16011	15694
Absolute yield surplus of fertilization (kg ha^{-1})	-	2623	696	255	930	-317
Relative yield surplus of fertilization (kg 1 kg NPK^{-1})	-	33,20	8,81	3,23	11,77	-4,01
WUE (kg mm^{-1}(Rainfall March – Sept.)	30,25	37,26	39,10	39,77	42,22	41,39

an average of the tested 10 hybrids, the control and the maximum yields were 11507 kg ha^{-1} and 16305 kg ha^{-1}, respectively. The minimum and maximum values of the hybrids in control treatment and maximum yields represent well the natural nutrient utilization ability and realized yield potential of the different genotypes. As an average of the 10 tested hybrids, the yield increasement due to fertilization was 4798 kg ha^{-1}. The differences in the fertilizer response of the hybrids were proved by the minimum and maximum values of the yield increasement due to fertilization (3226 and 6510 kg ha^{-1}). The different fertilizer request was also proved by the optimum N + PK fertilizer dosage. In 2013, the N_{120}+PK fertilizer dosage was the optimal (the maximum yield was obtained at this dosage) for most of the hybrids, however, the highest yield was obtained at the dosage of N_{150}+PK in the case of two hybrids (P9175 and PR37M81). As for the latter, the importance of the genotype should be highlighted, that is the hybrids with different vegetation season length can be characterized by the same optimum fertilizer dosage. It should also be emphasized that the newest (P9175) and the old (PR37M81) genotypes also had the same optimum fertilizer dosage. Based on our experimental results, however, a trend could be observed that the more modern maize genotypes gave higher yields at the same or lower N_{opt} +PK dosage in general, that is the fertilizer utilization ability of the hybrids was improved as a result of breeding.

When analysing the efficacy of fertilization and nutrient supply as an average of the ten tested hybrids (Table 5), it was found that the absolute yield increasement due to fertilization was the highest between the control and the N_{30}+PK treatment (2623 kg ha^{-1}). In the fertilization treatments of higher dosage, the fertilization resulted in a more modest yield increment (696, 255 and 930 kg ha^{-1} as an average of the hybrids), moreover, a small yield reduction (-317 kg ha^{-1}) was observed in the N_{150}+PK treatment. The relative yield increasement due to fertilization was also calculated as an average of the hybrids (Table 5), this index represents the maize yield increasement due to 1 kg NPK fertilizer. As regards the relative yield increment due to fertilization, the most favourable value (33.20 kg 1 kg NPK^{-1}) was also obtained between the control and the N_{30}+PK treatment, with increasing dosages, these valued were reduced (8.81, 3.23 and 11.77 kg 1 kg NPK^{-1}) and then became negative (-4.01 kg 1 kg NPK^{-1}).

Figure 1. Complex evaluation of the nutrient response of maize hybrids (Debrecen, 2013)



Results of our long-term experiments proved that there is a strong correlation between the nutrient and water supply of maize. A more favourable nutrient supply improved the water utilization of the maize hybrids (Table 5). As an average of the ten tested hybrids, the amount of yield per 1 mm precipitation from March 2013 until September 2013 was determined in the different fertilizer treatments. Our experimental results proved that a more favourable nutrient supply resulted in the improvement of water utilization by maize hybrids that is they could produce more yield from 1 mm precipitation. While the water use efficiency (WUE) was 30.25 kg mm^{-1} in the control treatment as an average of the tested hybrids, it increased to 42.22 kg mm^{-1} in the N_{120}+PK fertilizer treatment.

For the complex evaluation of the fertilizer response of the tested maize hybrids such a graphic method was applied (Figure 1) which is suitable for the joint evaluation of

- the natural nutrient utilization ability (yield in the control treatment)
- the maximum yield due to fertilization (yield in the N_{opt} +PK treatment).

For this evaluation, such a coordinate system was used in which the maximum yields and the control yields were presented in the ordinate (vertical) axis and the abscissa (horizontal) axis, respectively. In this way, such a coordinate system was created in which the hybrids with a different fertilizer response could be illustrated in the different quarters. Based on this, the tested maize hybrids could be classified into the following four fertilizer response groups:

A = hybrids which have a good natural nutrient utilization ability and give high maximum yields as a result of fertilization (SY Afinity, PR 37N01).

B = hybrids which have a moderate natural nutrient utilization ability and give high maximum yields as a result of fertilization (P 9175, P 9494, PR 37M81, P 9578, NK Lucius).

C = hybrids which have a good natural nutrient utilization ability and give moderate maximum yields as a result of fertilization (-).

D = hybrids which have a moderate natural nutrient utilization ability and give moderate yields as a result of fertilization (DKC 4014, DKC 4025, DKC 4490).

Those hybrids are the best for the production, which can utilize well both the natural nutrient stock of the soil and the applied fertilizers (group A). Those hybrids can also be favourable, which can significantly increase their relatively lower control yield as a result of fertilization (group B) (Figure 1).

Discussion

The results of our long-term experiment on chernozem soil in 2013 proved that fertilization is a very important agrotechnical element of maize production technology. Maize has extremely high productivity. The year and the weather have a significant yield-determining effect in maize production. In the experiment, the yields of the ten tested maize hybrids varied between 9500 and 18600 kg ha^{-1} depending upon the fertilizer treatment. Very favourable yields were obtained also in the control, non-fertilized treatment (9500 – 14600 kg ha^{-1}), which proved the excellent qualities and the good water and nutrient management of the chernozem soil. Fertilization had a yield-increasing effect even in spite of these high control yields. The maximum yield of the maize hybrids varied between 13500 and 18600 kg ha^{-1} in 2013. The yield-increasing effect of fertilization was 4798 kg ha^{-1} as an average of the hybrids, ranging from 3226 to 6510 kg ha^{-1} depending upon the genotype. As an average of the hybrids, the optimum fertilizer dosage was the N_{126}+PK. Berényi et al. (2007) proved that the maize had very good fertilizer response on chernozem soil.

The absolute yield increment due to fertilization was the highest between the control and the N_{30}+PK treatment (2623 kg ha^{-1} as an average of the hybrids), then it decreased with increasing fertilizer dosages. A similar statement can be made for the relative yield-increment due to fertilization (the relative yield-increment between the control and the N_{30}+PK treatment was 33.20 -kg 1 kg NPK^{-1} (Kovacevic et al., 2006, Karancsi and Pepó, 2012).

Our experimental results proved that the water utilization of the maize hybrids can be improved with a proper nutrient supply and optimum fertilization. As an average of the hybrids, the WUE was 30.35 kg mm^{-1} in the control treatment, while it increased to 42.22 kg mm^{-1} in the optimum fertilization treatment.

Based on their fertilizer response, maize hybrids could be classified into different groups. Pepó (2006) proved the significance of hybrid-specific fertilization and the different nutrient utilization of maize hybrids based on their experimental results. For this classification, the nutrient utilization of the hybrids (yield in the control treatment), and the maximum yield due to fertilization (yield in the N_{opt}+PK treatment) were used. Based on that, the tested hybrids can be classified into four different groups. As regards the nutrient utilization, those hybrids are the most valuable, which can significantly increase their good control yield as a result of fertilization. Our research results can successfully contribute to a better knowledge of maize genotypes, to the exploration of their traits and to a rational, environment-friendly application of fertilizers adapted to the given hybrid.

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