Genotype-specific nutrient responses of wheat (*Triticum aestivum* L.), Maize (*Zea mays* l.) and sunflowfer (*Helianthus annuus* l.)

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Abstract. *The long-term experiments were carried out on chernozem soil in eastern part (Hajdúság) of Hungary. Our scientific data proved that the most important parameters for the characterization responses were the followings: natural nutrient utilization ability (yield in control), fertilizer utilization ability (yield surpluses of NPK fertilizers), maximum yield, fertilizer requirement (N_{opt}+PK). The genotypes of wheat, maize and sunflower could be classified into 4 groups: type A = modern genotype (high natural and fertilizer responses); type B = traditional intensive genotype (moderate natural nutrient utilization and excellent yield surplus of NPK fertilizer); type C = traditional extensive genotype (high control yield and low yield increasement by NPK fertilizer); type D = old genotype (bad natural and fertilizer responses). By using of genotype fertilization crop model we can improve the efficiency of natural and fertilizer utilization in wheat, maize and sunflower production.*

Keywords: natural nutrient utilization, fertilizer response, genotype

1. Introduction

Winter wheat has a decisive role in Hungarian crop production. The sowing area of wheat varies between 1.0-1.2 million ha. The national average yield of wheat was 5.0-5.5 t ha^{-1} in the 1980's but nowadays the average yield varies between 3.0-5.0 t ha-1 depending on the climatic factors of the crop year [1].

According to Donohue and Brann [2], wheat varieties different in the utilization of the applied N fertilizer, which was indicated by the different N concentration of the plant tissues. Gricenko [3], Lahky [4], Tiscsenko and Blagovecsenszkaja [5], Moszkov [6], Ivanova and Matveeva [7] Morozov and Morozova [8], Klasen [9], Johnson and Raun [10] also pointed out the different fertilizer requirements of winter wheat varieties in their studies. In the experiments of Anderson [11], the N-response of wheat varieties was dependent upon the soil N content and the water supply.

Pepó [12, 1] differentiated four typical fertilizer response groups of winter wheat varieties in his experiments.

The different winter wheat genotypes utilized the applied fertilizers with different efficacy [13, 14, 15, 16]. Hungarian and foreign research results proved that the N requirements and fertilizer response of the different wheat genotypes greatly differ and the variety-specific fertilization based upon this knowledge is favourable from agronomical, economic and environmental aspects [17, 18, 19, 20, 21, 22].

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The most critical factors determining maize yield are the water and the nitrogen supply [23]. The cropyear and different agrotechnical factors (fertilization, crop rotation, irrigation etc.) could modify the yields of different maize genotypes [24, 25, 26].

Maize requires a balanced NPK fertilization and nitrogen has a determining role from among the macroelements [27]. Uribelarrea et al. [28] 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 [29,30]. According to Azeez [31], the dosage of 90 kg ha^{-1} N significantly increased the maize yield.

Sunflower is a crop which can utilize well the natural nutrient stock of the soil. The effects and efficacy of fertilization are greatly influenced by the agro-ecological (soil, weather) and agrotechnical conditions [32]. Domestic and foreign research results proved that, depending upon the conditions, the fertilization requirements of sunflower ranged within lower (40-60 kg ha^{-1} N+PK) [33, 34, 35] and higher (75-120 kg ha^{-1} +PK) intervals [36, 37]. In contrast to other crops (maize, wheat), there has been only limited research providing relevant data on the hybrid-specific fertilization of sunflower hybrids [38, 39, 40, 41].

2. Materials and methods

Long-term experiments were carried out in 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 experiments were set up in 1983.

The structure of the other experiments was determined in accordance with the experimental objectives.

In the experiments, the same optimal agrotechniques were applied apart from the treatments, which provided an opportunity to compare the effect of the studied agrotechnical factors (fertilization, genotype) and the year.

3. Results

Winter wheat is a good nutrient indicator (mainly nitrogen) field crop which means that the higher or lower fertilizer doses comparing with optimum reduce the yield quantity and quality, too. The nutrient supply and fertilizer response of winter wheat varieties with different genotypes have been studied in a long-term experiment (established in 1983 year) on chernozem soil in Eastern part of Hungary (Hajdúság region).

Results of our long-term experiment carried out for 30 years proved that the fertilizer response of the different winter wheat varieties can be determined by the following parameters:

- Natural nutrient utilization ability
  (indicated by the level of the variety's control yield)
- Fertilizer utilization ability
  (yield surplus of fertilization)
- Realized maximum yield
  (under specific ecological and agrotechnical conditions)
- Fertilizer requirement
  (optimum N+PK dosage of the given variety)

Part of the varieties could utilize less the natural nutrient stock of chernozem soils (Mv Mazurka, GK Öthalom), while others utilized it very effectively (e.g. Mulan, Bitop, GK Csillag) (Figure 1). There were large differences also in the maximum yields of the varieties. In 2009, the difference between the highest (GK Csillag, 9117 kg ha^{-1}) and lowest yield (Lupus, 6800 kg ha^{-1}) was 2317 kg ha^{-1}. The fact that the optimum N+PK dosage of wheat varieties varied between 90-120-150 kg ha^{-1} N+PK also draws the attention to the importance of variety-specific fertilization. This means that the species-specific N+PK optimum value should be determined specifically for each variety.

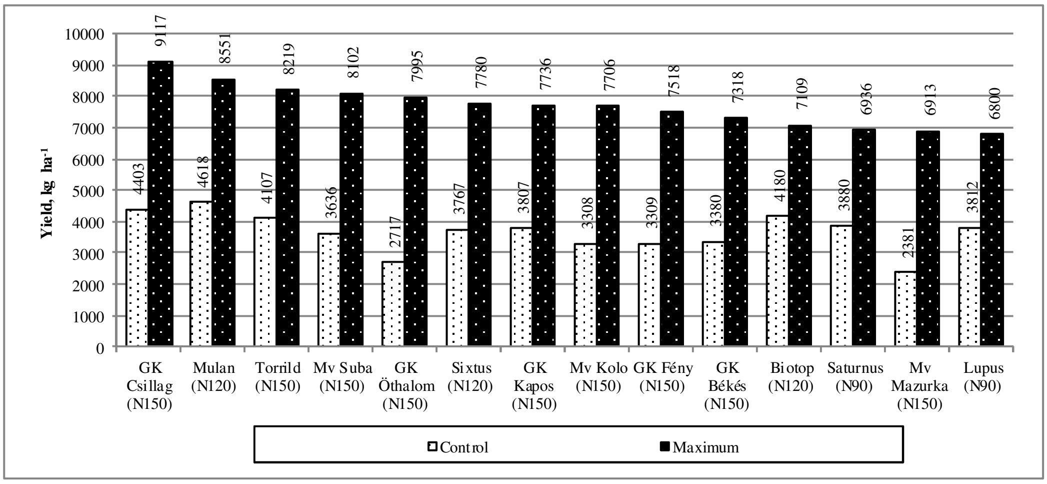

Fig. 1. The control and maximum yields of different winter wheat varieties (Debrecen, 2009)

Based on our long-term experiments of several decades, winter wheat varieties could be classified into four essentially different groups according to their fertilizer response (Figure 2). These 4 groups provide useful assistance in the variety-specific, environmentally-friendly fertilization of winter wheat.

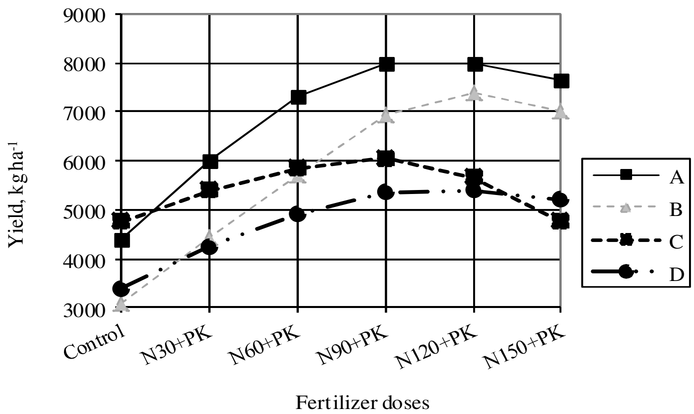

Fig. 2. Fertilizer response of winter wheat varieties (Debrecen)

The types of winter wheat varieties according to their fertilizer response are as follows:

Type A: modern type (combines the advantages of the extensive and intensive types), it has an excellent utilization of both the natural soil nutrient stock and the fertilizers

Type B: intensive type

it has traditionally weak natural nutrient utilizing ability, but high fertilizer response

Type C: extensive type

it has traditionally excellent natural nutrient utilizing ability, but moderate fertilizer response

Type D: unfavourable type

this type cannot utilize effectively either the soil nutrients or the fertilizers

Using different parameters we built up a variety-specific fertilization crop models. This crop model is shown graphically on the Figure 3. The studied 15 different wheat varieties can be classified into 4 groups by using the crop model.

This fertilization crop model gives excellent scientific support for the variety-specific fertilization of winter wheat, it can reduce the harmful environment effects of fertilization.

From among the field crops in Hungary, maize has the widest biological bases. 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 hybrid (in its abiotic and biotic adaptation ability), but also in the responses of the hybrids to the different agrotechnical inputs. From among the agrotechnical responses, one of the most important ones is the fertilizer response of maize hybrids.

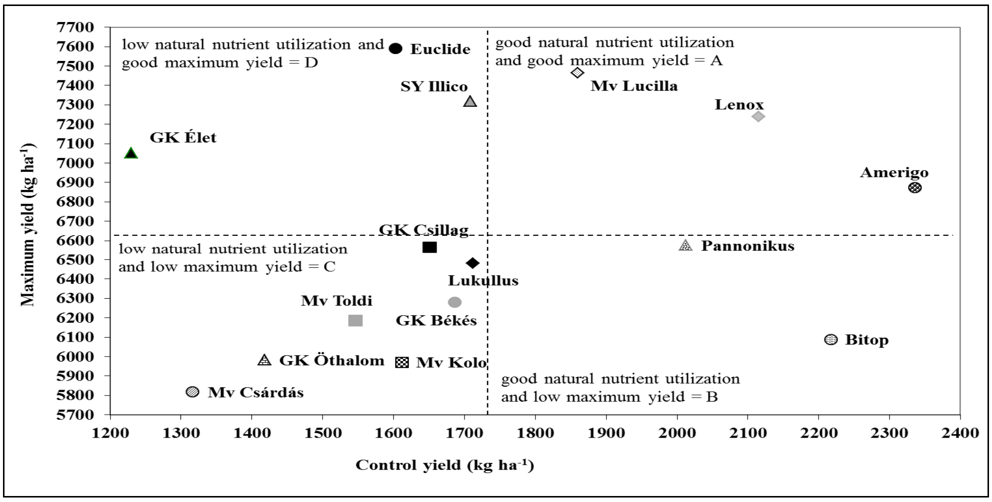

Fig. 3. Variety-specific classification of wheat genotypes nutrient utilization (Debrecen, 2013, chernozem soil)

In the vegetation period of 2013, the fertilizer response of maize hybrids with different genetic backgrounds was studied on chernozem soil in long-term experiments. The yields of the hybrids ranged from 9500 to 18600 kg ha^{-1} depending upon the hybrid and the fertilizer treatment (Table 1). 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 1). The maximum 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}).

Table 1) 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			

When analyzing the efficacy of fertilization and nutrient supply as an average of the ten tested hybrids (Table 2), 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 2), 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}).

Table 2) 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

For the complex evaluation of the fertilizer response of the tested maize hybrids such a graphic method was applied (Figure 4) which is suitable for the joint evaluation of

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

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).

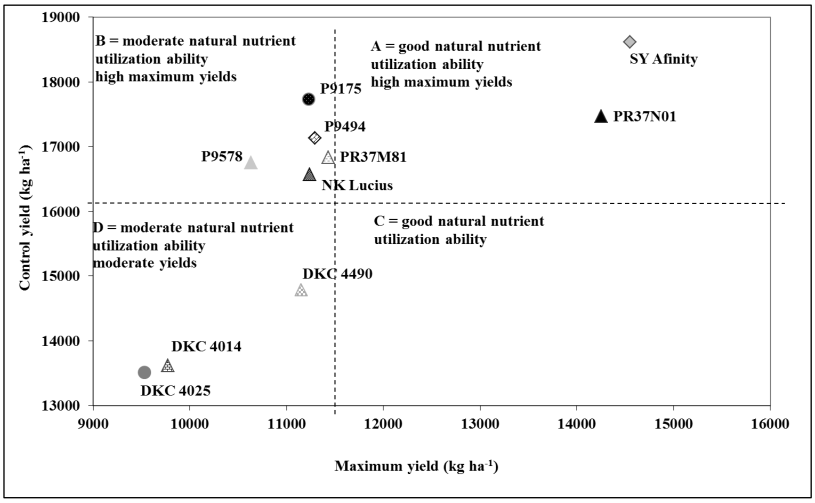

Fig. 4. Complex evaluation of the nutrient response of maize hybrids (Debrecen, 2013)

Our studies have also proved that the fertilizer response of sunflower hybrids can be significantly modified by the cropyear (Figure 5). In a dry year, the sunflower hybrids – due to the low infection level – showed a favourable fertilizer response (results of 2007 year). In years with an average water supply, the yield of the hybrids reduced (from a lower yield level) with increasing fertilization as a result of the increasing fungal infection due to fertilization (results of 2008 year).

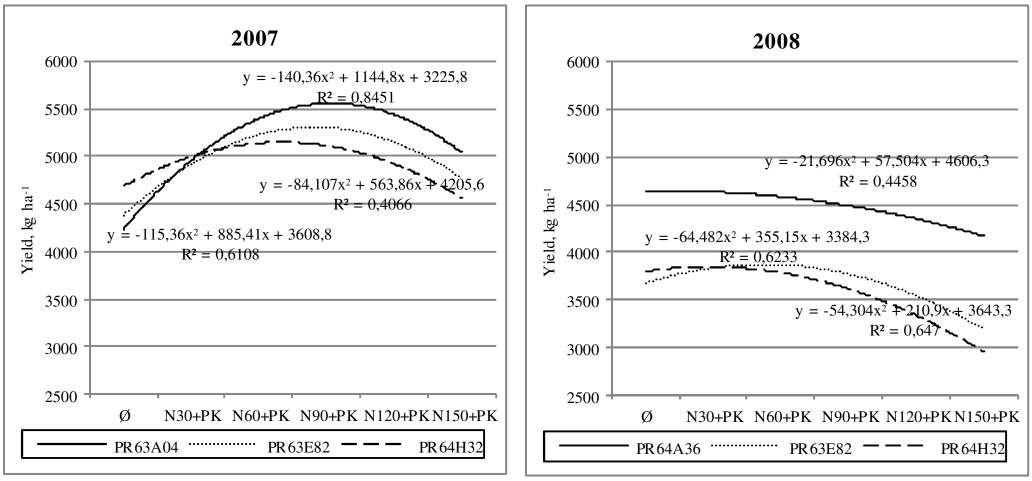

Fig. 5. Fertilizer responses of sunflower genotypes (Debrecen, 2007-2008)

Fertilization had an effect not only on the amount of sunflower yield but also on its quality, that is on oil content (Figure 6). Results of 2009 year showed – as an average of the tested hybrids – that increasing fertilizer dosages reduced the oil content. Thus, the optimum NPK dose for maximum yield and maximum oil content differed.

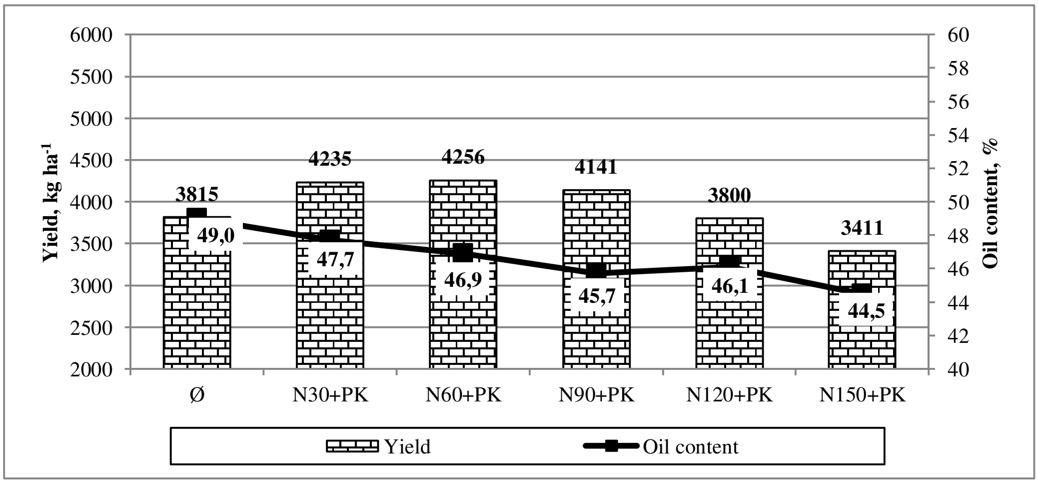

Fig. 6. Effect of fertilization on the yield and oil content of sunflower (Debrecen, 2009) (average of the hybrids)

Conclusions

Results of our long term experiments on chernozem soil proved that the nutrient supply and fertilization had determining importance in winter wheat production even on chernozem soil with excellent water- and nutrient husbandry. According to our experimental results we built up a variety-specific fertilization crop model by using different parameters (natural nutrient utilization, yield surplus of fertilization, maximum yield, optimum N+PK dose, fertilization curve). The winter wheat varieties can be classified into 4 groups by using the fertilization crop model.

Maize is a crop with extremely high productivity. The year and the weather have a significant yield-determining effect in maize production. 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}. 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. Our experimental results proved that the water utilization of the maize hybrids can be improved with a proper nutrient supply and optimum fertilization. Based on their fertilizer response, maize hybrids could be classified into different groups. We proved that 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 results of fertilization.

As compared with other field crops, sunflower has a different response to climate change. This is primarily due to its better adaptation ability and stress tolerance. However, even in the case of sunflower, the further development of the production technology elements and their site- and variety-specific adaptation are of exceptional importance. Among the technological elements, hybrid selection, fertilization had the special importance.

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