

## Long-term experiments on chernozem soil in the University of Debrecen

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### Summary

The impact of agrotechnical management practices (nutrient and water supply, crop rotation, crop protection, genotype) on the yields of winter wheat and maize and on the soil water and nutrient cycles was studied in long-term experiments set up in 1983 in Eastern Hungary on chernozem soil. The long-term experiments have shown that nitrogen fertilizer rates exceeding the N-optimum of winter wheat resulted in the accumulation of  $\text{NO}_3\text{-N}$  in the soil. Winter wheat varieties can be classified into four groups based on their natural nutrient utilization and their fertilizer response. The fertilizer responses of wheat varieties depended on crop year (6.5–8.9 t ha<sup>-1</sup> maximum yields in 2011–2015 years) and the genotypes (in 2012 the difference was ~3 t ha<sup>-1</sup> among varieties). The optimum N(+PK) doses varied between 30–150 kg ha<sup>-1</sup> in different crop years. In maize production fertilization, irrigation and crop rotation have decision role on the yields. The efficiency of fertilization modified by cropyear (in dry 891–1315 kg ha<sup>-1</sup>, in average 1927–4042 kg ha<sup>-1</sup>, in rainy cropyear 2051–4473 kg ha<sup>-1</sup> yield surpluses of maize, respectively) and crop rotation (in monoculture 1315–4473 kg ha<sup>-1</sup>, in biculture 924–2727 kg ha<sup>-1</sup> and triculture 891–2291 kg ha<sup>-1</sup> yield surpluses of maize, respectively). The optimum fertilization could improve the water use efficiency in maize production.

Our long-term experiments gave important ecological and agronomic information to guide regional development of sustainable cropping systems.

**Keywords:** long-term experiments, chernozem soil, crop year, agrotechnical elements, wheat, maize

### Introduction

Plant growth, yield and yield stability in field crop production are determined by a complex interaction of environmental, biological and agrotechnical management factors. The impacts and interactions between these factors can be studied most effectively in long-term experiments.

The oldest long-term experiments were set up 130–175 years ago (Rothamsted, 1843; Grignon, 1875; Illinois, 1876; Halle, 1878 etc.). Such long-term experiments provide valuable data on the effects of agrotechnical management practices on the yield of the given crop, on the

associated changes in the soil properties, the impact of environmental factors (climate) and any resulting environmental impacts/risks (Johnston, 1997; Körschens, 2006; Hejzman and Kunzová, 2010; Pepó, 2015).

The increasing demands of the world for food, feed, industrial raw materials, biofuels etc., means that more crop production products, in terms of quantity and quality, are also required. In the last half century, the land area of the world covered by arable production has not changed dramatically (it is ~10.5%, FAO, 2017) and it is expected to remain at the same level in the future. The increasing demands can be fulfilled only by intensification of crop production. In parallel, intensive crop production also has to meet the demands of sustainability and environmental protection. Within a given environment, the most important farmer-controlled factors of wheat yield are genotype, crop management (Bell et al., 1995; Duvick and Cassmann, 1999) and their interaction (Pepó, 2005).

Long-term experiments are essential tools to assess and develop effective management practices for sustainable production and environmental impact (Rasmussen et al., 1998; Richter et al., 2007). In the sustainable intensification of crop production, yields are increased without adverse environmental impacts and without the cultivation of more land (Baulcombe et al., 2009). Godfray et al. (2010) have focused on the importance of reducing the “yield gap” – this is the difference between realised productivity and the best that can be achieved using current genetic material and available technologies and management.

Traditional cereal production uses a lot of external inputs to achieve high yields (Hole et al., 2005). Hungarian crop production is cereal-oriented one. Proportion of cereals (small grains and maize) takes about 70% of Hungarian arable land. In sustainable cereal production nutrient supply, fertilization is a key agrotechnical element (Jordan et al., 1997; Oehl et al., 2004; Keller et al., 2012), but the crop rotation, irrigation, plant density, weed control (Berzsenyi et al., 2000; Vad et al., 2007; Pepó, 2017) have important role, too. The yield-losses and yield fluctuation of cereals caused by crop year (climate change) depended on soil conditions, the stress-tolerance of genotypes and the agrotechniques.

The long-term experiments set up at Látókép Experimental Station, near Debrecen, Hungary, more than 30 years ago provide an opportunity to determine the individual and interactive effects of the different agrotechnical management treatments on the vegetative and generative development of the major cereal crops (wheat, maize) and the consequent yield and crop quality. From the data of these long-term experiments, cause and effect relationships leading to changes in the yield and crop quality of yields can also be determined under varying weather conditions. The experimental results also enable the study of the

environmental impacts arising from crop production, thereby creating a basis for the development of sustainable crop models. The aim of our research was to study the effects of the major agrotechnical management factors (nutrient and water supply, crop rotation, plant density, crop protection) on winter wheat and maize (growth parameters, yield, crop quality) and on soil nutrient (N, P, K) and water cycles.

### Material and methods

The long-term experimental site, within the Látókép Experimental Station, is located in Eastern-Hungary (region Hajdúság), 15 km from Debrecen (N 47°33' E 21°27'). The long-term experimental site is characterized by continental climatic conditions. The average total annual precipitation is 565 mm and average annual yearly mean temperature is 9.84 °C.

The soil is a calcareous chernozem with a specific plasticity index ( $K_A$ ) of 43, and nearly neutral pH ( $pH_{KCl}=6.46$ ). When the long-term experiments were set up the humus content of the topsoil was 2.76% (0–0.2 m upper soil layer) and the total depth of the humus-enriched horizon was about 0.8 m. The phosphorus and potassium supplies can be regarded as medium (AL- $P_2O_5$  133 mg  $kg^{-1}$ ) and good (AL- $K_2O$  240 mg  $kg^{-1}$ ), respectively. Water holding properties of the soil are very favourable for crop production. Total water storage capacity is 808 mm in the 0–2 m layer with an available water of 513 mm in the 0–2 m layer of which 342 mm is readily available. The water table is at 8–10 meters depth.

Two long-term experiments were set up in 1983.

#### *Long-term experiment No.1 – Wheat variety fertilizer response testing*

The treatments are as follows:

- fertilization;
- crop rotation;
- genotypes.

The plots are 10 m<sup>2</sup> and the experiment design is a split-split-plot with 4 replications. The total area of the experiment is ~3 ha.

#### *Long-term experiment No.2 – Polyfactorial experiment for different crop models*

The treatments are as follows:

- crop rotation;
- fertilization;
- water supply;
- specific agronomic factors.

The plots are 46 m<sup>2</sup> and the experiment design is a split-split-plot with 4 replications. The total area of the experiment is ~10.5 ha.

## Results and discussion

Our long-term experimental results proved that weather conditions (mainly the rainfall quantity and its distribution) strongly modified the yields of winter wheat genotypes even on chernozem soil characterized by excellent water- and nutrient husbandry. In the average of wheat varieties and crop years the yield was 7631 kg ha<sup>-1</sup> but the yields varied depending on the crop years (Table 1). The minimum yield was in 2013 (6514 kg ha<sup>-1</sup>) and we got the maximum yield in 2015 (8921 kg ha<sup>-1</sup>). The winter wheat genotypes could differently adapt to the crop year. According to our long-term experimental data we could state that the differences among the varieties were about 3 t ha<sup>-1</sup> in the same agrotechnical conditions (in 2012 the yields varied between 6075–8919 kg ha<sup>-1</sup>). The crop year (mainly the water supply during the vegetation period) can modify the optimum N+PK doses, too. In crop year characterized by average water supply the optimum N+PK doses varied between N=90–150 kg ha<sup>-1</sup>+PK and in crop year after very mild winter the N<sub>opt</sub>+PK dropped down to N=30–60 kg ha<sup>-1</sup>+PK (because of very high mineralization of organic matter in the chernozem soil).

Table 1. Fertilizer response of winter wheat genotypes in different crop years (Debrecen, chernozem soil, 2011–2015)

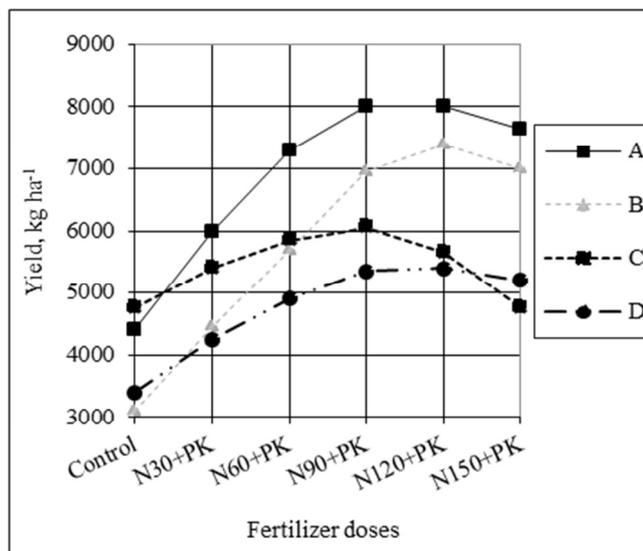
Variety	2011 (N <sub>opt</sub> )	2012 (N <sub>opt</sub> )	2013 (N <sub>opt</sub> )	2014 (N <sub>opt</sub> )	2015 (N <sub>opt</sub> )	Average
GK Öthalom	6819 <sup>(150)</sup>	6175 <sup>(150)</sup>	5983 <sup>(150)</sup>	8713 <sup>(30)</sup>	8862 <sup>(150)</sup>	7310
Pannonikus	8123 <sup>(90)</sup>	8139 <sup>(150)</sup>	6576 <sup>(150)</sup>	7996 <sup>(30)</sup>	8864 <sup>(90)</sup>	7940
Euclide	9586 <sup>(150)</sup>	8919 <sup>(150)</sup>	7590 <sup>(150)</sup>	-	-	8698
GK Csillag	-	7263 <sup>(150)</sup>	6562 <sup>(150)</sup>	8350 <sup>(60)</sup>	9150 <sup>(150)</sup>	7831
Bitop	-	6075 <sup>(150)</sup>	6089 <sup>(120)</sup>	6663 <sup>(30)</sup>	-	6276
GK Békés	-	7917 <sup>(150)</sup>	6281 <sup>(120)</sup>	7915 <sup>(30)</sup>	8809 <sup>(90)</sup>	7731
Average	8176	7415	6514	7927	8921	7631
Yield interval (t ha <sup>-1</sup> )	6.8–9.6	6.1–8.9	6.0–7.6	6.7–8.4	8.8–9.2	6.3–8.7
Min–Max (%)	83–117	82–120	92–117	84–105	99–103	82–114
Interval of yield fluctuation (%)	34	38	25	21	4	32
Interval of N <sub>opt</sub> (kg ha <sup>-1</sup> )	90–150	120–150	120–150	30–60	90–150	90–128
LSD <sub>5%</sub>	457	355	600	674	614	-

Results of our long-term experiment carried out for 30 years proved that the fertilizer response of the different winter wheat varieties (Figure 1) 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).

Figure 1. 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.

Our long-term experimental data proved that the fertilization of wheat resulted good yield surpluses on chernozem soil characterized by excellent natural nutrient stock (Table 2). The yield surpluses of wheat varied between 2659 kg ha<sup>-1</sup> (2013/2014 crop year) and 6020 kg ha<sup>-1</sup> (2015/2016 crop year). The yields of control treatment proved the excellent natural nutrient availability of chernozem soil (1816 kg ha<sup>-1</sup> and 5897 kg ha<sup>-1</sup>). The other meteorological parameters could modify the yield surplus of wheat genotypes (in 2013 the strong and long frosting period in March decreased the yields; in 2014 the very mild winter period accelerated the N-mineralization in chernozem soil).

Table 2. Effect of crop year on the control and maximum yield of winter wheat (average of varieties, Debrecen, 2010–2017)

Crop year	Control yield kg ha <sup>-1</sup>	Maximum yield kg ha <sup>-1</sup>	Yield-surplus kg ha <sup>-1</sup>	Rainfall in veg. period (mm)	Rainfall deviation from 30 year average (mm)	N <sub>opt</sub> (+PK) kg ha <sup>-1</sup>
2010/2011	4023	8043	4020	340.9	-60.0	133
2011/2012	3906	7303	3397	320.7	-80.2	144
2012/2013	1816	6674	4858	480.2	+79.3	145
2013/2014	5897	8556	2659	284.0	-116.9	49
2014/2015	4662	9024	4362	350.9	-50.0	110
2015/2016	3927	9947	6020	561.7	+160.81	115
2016/2017	5226	8028	2802	379.6	-21.3	133

Wheat is a sensitive arable crop to agroecological and agrotechnical factors. Our multifactorial long-term experimental data (between 1986 and 2017) proved that the effects of fertilization were different depending on the crop rotation and the weather of crop year. In Eastern Hungary characterized by continental climate the precipitation quantity and its distribution are the decisive agroecological factor on chernozem soil. The effects of crop year were significant on the yields of wheat in different (bi- and triculture) crop rotation (Table 3).

Table 3. Effect of crop year, crop rotation and fertilization on the yield of wheat in long-term experiment (Debrecen, chernozem soil, 1986–2017)

Crop rotation	Yield (kg ha <sup>-1</sup> )					
	Dry crop year 9 years (28%)		Average crop year 18 years (56%)		Rainy crop year 5 years (16%)	
<b>Biculture (after maize)</b>						
Control	1892 f	3698*	2516 ef	5513*	3162 e	2257*
N <sub>opt</sub> +PK**	5590 cd		8029 ab		5419 cd	
<b>Triculture (after peas)</b>						
Control	4426 de	2853*	5763 cd	2837*	4885 cd	1305*
N <sub>opt</sub> +PK***	7279 b		8600 a		6190 a	

Note: \* yield surplus of fertilization (kg ha<sup>-1</sup>) and a, b, c, d, e, f letters are significantly different at P≤0.05 level; \*\* N<sub>opt</sub>+PK=150–200 kg ha<sup>-1</sup>+PK in biculture; \*\*\* N<sub>opt</sub>+PK=50–100 kg ha<sup>-1</sup>+PK in triculture.

We obtained the strongest effect of crop year in biculture (the yields of wheat varied between 1892–3162 kg ha<sup>-1</sup> in control and 5419–8029 kg ha<sup>-1</sup> in N<sub>opt</sub>+PK, respectively). In diversified crop rotation (triculture) the yield-fluctuations of wheat were less (in control 4426–5763 kg ha<sup>-1</sup>, in N<sub>opt</sub>+PK 6190–8600 kg ha<sup>-1</sup>, respectively). The efficiency of fertilization was modified by crop year and crop rotation. The highest yield surpluses of wheat were obtained in average crop year in different crop rotation, but the efficiency of nutrient supply was much higher in biculture (5513 kg ha<sup>-1</sup>) comparing with triculture (2837 kg ha<sup>-1</sup>). The optimum N(+PK)

doses were much lower ( $N_{opt}=50\text{--}100\text{ kg ha}^{-1}+\text{PK}$ ) in triculture than in biculture ( $N_{opt}=150\text{--}200\text{ kg ha}^{-1}+\text{PK}$ ) because of peas forecrop.

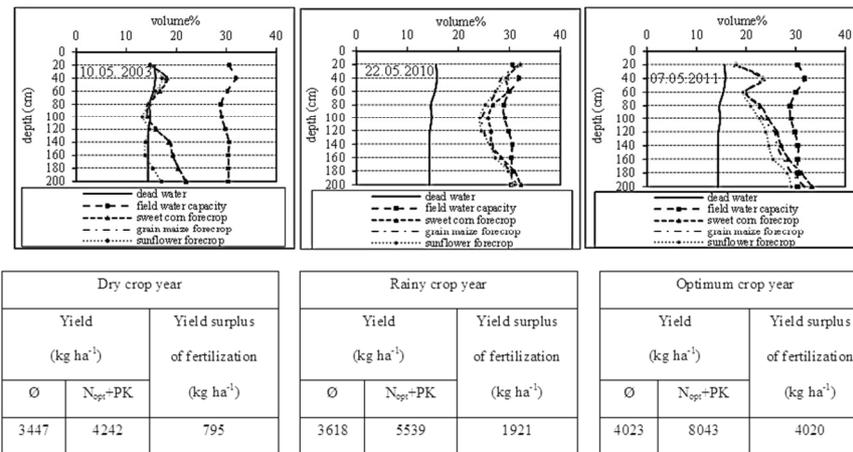
The results of the polyfactorial long-term experiment showed (Table 4) that increasing the intensity of plant protection resulted in the decrease of the values of infection with leaf, stem and ear diseases. Averaged over 2013–2016, the increase of fertiliser doses significantly increased infection level. At the same time, in the case of crop rotation, there was no difference between the infection values of biculture and triculture. In the case of the various plant protection technologies, compared to extensive technology, average plant protection significantly decreased infection, while there was a moderate difference between average and intensive plant protection technologies in both crop rotations.

Table 4. Effects of crop rotation, fertilization and crop protection on the infections (%) of winter wheat (Debrecen, chernozem soil, non irrigated, 2013–2016)

Crop protect. Fert.	Biculture			
	Powdery mildew	Helminthosporium	Leaf rust	Yellow rust
Extensive				
Ø	4	9	2	6
$N_{opt}+\text{PK}$	14	25	12	26
Average				
Ø	3	6	2	5
$N_{opt}+\text{PK}$	11	19	9	13
Intensive				
Ø	2	4	1	1
$N_{opt}+\text{PK}$	6	13	5	4
LSD <sub>5%</sub>	2	4	3	5
Triculture				
Extensive				
Ø	8	13	6	10
$N_{opt}+\text{PK}$	16	23	12	15
Average				
Ø	5	8	4	5
$N_{opt}+\text{PK}$	13	20	10	11
Intensive				
Ø	3	6	2	2
$N_{opt}+\text{PK}$	7	13	6	5
LSD <sub>5%</sub>	3	5	2	4

The longer duration of these experiments enable the study of the most important material processes (water and nutrient cycle) in the crop production space. In the course of testing the fertilizer response of winter wheat varieties, the dynamics of the chernozem soil's water stock during the vegetation period of winter wheat is determined. The yield of winter wheat was strongly determined by the soil's water stock and the amount of available water in the soil during the phenophases (earing-flowering) critical for the yield formation of winter wheat (Figure 2).

Figure 2. Effect of crop year and crop rotation on the water-husbandry of chernozem soil and the yields of winter wheat in long-term experiment (Debrecen, Hungary)



Our long-term experimental results proved (Figure 3) that N fertilization exceeding the agro-ecological demand of winter wheat increases the NO<sub>3</sub>-N content of the soil. This NO<sub>3</sub>-N accumulation layer increased with time (100 mg kg<sup>-1</sup> in 1995 and 275 mg kg<sup>-1</sup> in 2000), and even under continental climate conditions (prone to draught) it shifted gradually to the bottom soil layers (0.8–1.4 m in 1995 and 1.2–2.2 m in 2000).

Maize is a sensitive field crop to agroecological and agrotechnical factors.

Especially important key-elements are the nutrient- and water supply and crop rotation in sustainable maize production. Our polyfactorial long-term experimental data proved that the effects of fertilization were different depending on the crop rotation and the weather of crop year.

The effects of crop year were significant on the yields of maize in every crop rotation (Table 5). The yields of control (non fertilized), varied between 3743–7279 kg ha<sup>-1</sup> in dry crop years, 6305–9577 kg ha<sup>-1</sup> in average crop years and 7538–10 221 kg ha<sup>-1</sup> in rainy crop years, respectively. The maize yields were in optimum fertilizer treatments in the same crop year types between 5058–8203 kg ha<sup>-1</sup>, 10 457–12 168 kg ha<sup>-1</sup> and 12 521–13 014 kg ha<sup>-1</sup>, respectively. We obtained the strongest effect of crop year in monoculture. The efficiency of fertilization was modified by crop year and crop rotation. The biggest fertilization effects were in monoculture and lowest ones were in triculture. So the appropriate crop rotation can reduce the N<sub>opt</sub>+PK fertilizer doses (in mono- N<sub>180</sub>+PK, in bi- N<sub>120</sub>+PK, in triculture N<sub>60</sub>+PK).

Figure 3. Effect of N-fertilization on the NO<sub>3</sub>-N accumulation of chernozem soil in long-term experiment (Debrecen, Hungary)

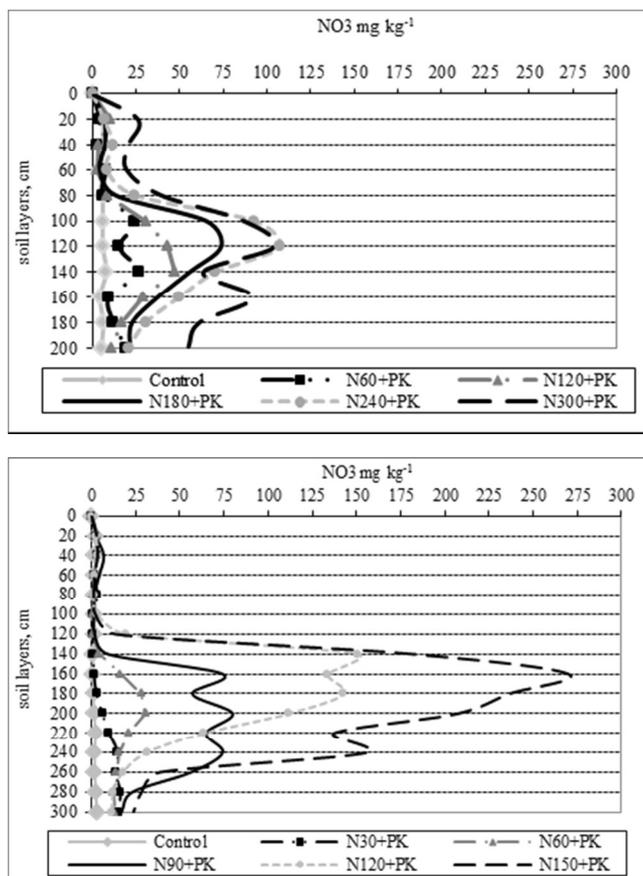


Table 5. Effect of crop year, crop rotation and fertilization on the yield of maize in long-term experiment (Debrecen, chernozem soil, 1986-2017)

Crop rotation	Yield (kg ha <sup>-1</sup> )					
	Dry cropyear 12 years (38%)		Average cropyear 14 years (44%)		Rainy cropyear 6 years (18%)	
Monoculture						
Control	3743 i	1315*	6305 g	4152*	7538 ef	5476*
N <sub>opt</sub> +Pk	5058 h		10457 c		13014 a	
Biculture						
Control	7279 f	924*	9315 d	2853*	10209 cd	2312*
N <sub>opt</sub> +PK	8203 e		12168 ab		12521 ab	
Triculture						
Control	6708 fg	891*	9577 cd	1938*	10221 cd	2574*
N <sub>opt</sub> +PK	7599 ef		11515 b		12795 ab	

Note: \* yield surplus of fertilization.

## Conclusions

Our long-term experiments proved that we have to harmonize the ecological, biological and agrotechnical factors to increase the nutrient- and water-use efficiency and decrease the harmful environmental effects in wheat production. According to our findings there were huge differences among the maximum yields and the optimum N+PK doses of winter wheat genotypes. The wheat varieties differently responded to the N+PK fertilizer doses and they differently utilized the natural nutrient sources of chernozem soil. The yields of wheat varieties varied between 6075–9586 kg ha<sup>-1</sup> and the N<sub>opt</sub>+PK doses fluctuated between N=30–150 kg ha<sup>-1</sup>+PK depending the crop year (mainly water supply) and genotypes. So under climatic change the optimum fertilization is a key-element to change the conventional wheat production into a sustainable one (Austin, 1999; Pepó, 2007; Maye et al., 2015; Bala and Sikder, 2017).

Monitoring the sustainability of wheat production needs different indicators (Barrios and Sarte 2008). The nutrient- and water-use efficiency were modified by crop year, crop rotation and fertilization. We obtained the highest yield surpluses of wheat in average crop year, in diversified crop rotation with using less N<sub>opt</sub>+PK doses (N=50–100 kg ha<sup>-1</sup>+PK) comparing with the dry and rainy crop years, simplified crop rotation (biculture) similarly to Dobermann (2005), Noureldin et al. (2013) and Khatri et al. (2017).

In maize production fertilization, irrigation and crop rotation have decision role on the yields. The efficiency of fertilization modified by crop year (in dry 891–1315 kg ha<sup>-1</sup>, in average 1938–4152 kg ha<sup>-1</sup>, in rainy crop year 2312–5476 kg ha<sup>-1</sup> yield surpluses of maize, respectively) and crop rotation (in monoculture 1315–5476 kg ha<sup>-1</sup>, in biculture 924–2853 kg ha<sup>-1</sup> and triculture 891–2574 kg ha<sup>-1</sup> yield surpluses of maize, respectively). The optimum fertilization could improve the water use efficiency in maize production.

In the long-term winter wheat fertilization experiment, the excellent nutrient supplying capacity of the chernozem soil was proved even 30 years after starting the experiment (Berzsenyi et al., 2000; Babulicová, 2008) and also the differences between the wheat genotypes in their fertilizer responses were verified. Based on the fertilizer response, the winter wheat varieties were classified into four groups. In a polyfactorial long-term experiment, the significant effect of the year (mainly that of water supply) was found both in winter wheat and in maize. In contrast with other long-term experiments (Schellberg and Hüging, 1997; Yang et al., 2014), a high level of yield was obtained even in the control treatment on the chernozem soil in our experiment (winter wheat: 1892–4885 kg ha<sup>-1</sup>, maize: 2685–9602 kg ha<sup>-1</sup>). The yield-increasing effect of fertilization was

influenced both by the year and the crop rotation. Maximum yields of winter wheat and maize varied from 7.3 to 8.6 t ha<sup>-1</sup> and from 10.0 to 13.0 t ha<sup>-1</sup>, respectively.

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