Theses of the PhD dissertation

THE EFFECTS OF NPK FERTILIZATION, IRRIGATION AND CROP ROTATION ON THE YIELD OF THE MAIZE HYBRID RESEDA ON CALCAREOUS CHERNOZEM SOIL IN THE HAJDÚSÁG REGION

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1. INTRODUCTION, PRELIMINARY RESEARCH

Cereals have a determining role in global crop production. It is proven by the fact that cereals are grown on about half of the total arable land, among which maize has the second largest sowing area of 161 million hectares (*FAO data, 2008*). The leading countries in maize production are the USA, Brazil and China, these three countries account for 50 % of the global sowing area and for 65% of the global maize yield. In Europe, France had the leading role as regards the produced amount, while Romania and Ukraine are of determining importance as regards their sowing area.

Bioethanol production, as an alternative fuel, has become a new direction of maize utilization for the last decade. Bioethanol production for use as fuel was 73.9 million m^3 in 2009. The most significant increase in production was achieved by the USA with 12 %, which means the processing of over 100 million tons of maize, while bioethanol production stagnated in South America and Brazil. According to the preliminary estimation of the international cereal council, the European Union increased its production by 9 % in 2009, to achieve this the Union used 7.6 million tons of cereals, which was 40 % more than that used in the previous year. The five largest bioethanol producers of the EU are France, Germany, Spain, Poland and Hungary.

In Hungary, wheat and maize are grown on about 50 % (4.5 million hectares) of the total arable land. The sowing area of maize has exceeded 1 million hectares since the 1920s, which is due to the fact that maize has provided the most important feed basis for animal husbandry.

The efficacy of crop production is basically determined by the ecological, biological and agrotechnical factors combined. Ecological factors are circumstances, the successful adaptation to which can be the key to a biologically, agronomically and economically effective production. In recent years, there have been extremities in climatic factors, which highlight the importance of adaptation. This is supported by the fact that the degree of yield fluctuation significantly increased (30-50%) in the past two decades. In addition to the fluctuation in the amount of the annual precipitation, the extreme distribution during the vegetation period was also intensified.

It is necessary to weigh the production technology factors according to their impact on the yield. Based on this, so-called critical production technology elements can be differentiated. Critical production technology elements decisively determine the yield, therefore, it is essential to ensure an optimum level of these factors. In maize production, such critical production technology elements are the crop rotation, irrigation and fertilization. However, the effects of these factors are not asserted individually but via their interactions.

Research results have proven that the plant produce is decisively determined by the amount of water available for the plant. In Hungary, the index calculated from the amount of precipitation, the evapotranspiration of plants and the surface evaporation is negative in most years, therefore, the water necessary for a proper yield volume should be supplemented. A further problem is that not only the amount but also the distribution of the precipitation is unfavourable for crop production. However, the irrigated area in Hungary does not reach 200 000 hectares and on most of this area, vegetables are produced. Irrigation is an excellent tool for the mitigation of the harmful effects of the extreme weather in recent years (mainly drought). Irrigation has especially high cost requirements, therefore, it is important to have a better knowledge of the ecological, biological and agrotechnical factors influencing the efficacy of irrigation.

In addition to water, the bases of plant life are the different nutrients. The volume of fertilizer use in Hungary has gone through significant changes for the past half century. After World War II, fertilization became more significant with the development of the profession and the technology. Before 1960, the use of artificial fertilizers was very low in Hungary which was accompanied by low yields of 2 t ha^{-1}. After this period, an intensive growth started as regards the amount of active ingredients used, which continued up to the mid-1970s. During and after this period, the soils were filled up with nutrients, due to which the yields also increased (6 t ha^{-1}). After the permanent, high-dosage fertilization (280 kg ha^{-1}) of the period between 1975 and 1985, a slightly decreasing trend could be observed in fertilizer use (230 kg ha^{-1}) between 1985 and 1990. After the change of the regime, the amount of the applied fertilizers dramatically decreased to 30-40 kg ha^{-1}. The impact of this was manifested in yields, mainly in the increase in yield fluctuation and in the dependence of the yield upon the year. A slight increase can be observed in fertilizer use since the change of the regime, but the amount of yield is determined primarily by the year. The current fertilization practice is characterized by a prevalence of nitrogen fertilization.

Among the agrotechnical factors, crop rotation is undoubtedly the cheapest, but it is one of the most decisive elements. The forecrop has an influence on the development of the succeeding crop in several ways. The harvest of the forecrop determines the quality of soil cultivation and the soil processes. The amount and quality of trash and crop residues also influence the nutrient and organic matter content of the soil in addition to the above mentioned factors. From a phytopathological aspect, the forecrop also determines the quantity of the common pathogens, pests and weeds and the degree of damage caused by them. Due to the extreme distribution of precipitation in recent years, the impact of the forecrop on the soil water stock has also become more important. Via a purposeful selection of the crop sequence, we can have a direct impact on the input efficacy.

2. RESEARCH OBJECTIVES

The objectives of the research were to study the effect of the year on maize yield and to give a complex evaluation of the role of crop rotation, NPK fertilization and irrigation in maize production. The complex evaluation of the above factors and the quantification of their interactions and the quantification of the impact of the different studied production technology elements on yield were also among our objectives. A set task of the dissertation was to work out a fertilization recommendation adapted to the regional circumstances based on the data analysis. Our research results are of great importance in improving the efficacy of maize production in the region, in determining the proper NPK fertilization and irrigation and in the specification of the critical production technology parameters.

3. MATERIALS AND METHODS

3.1. Experimental site, soil conditions

The experiments were carried out at the Látókép Experimental Farm of the University of Debrecen Centre for Agricultural Sciences and Engineering, Farm and Regional Research Institute between 2004 and 2009 in the long-term field experiment set up by †Dr. László Ruzsányi.

The experimental soil was calcareous chernozem with a deep humus layer formed on loess. The soil was of good culture state, it was medium-hard (plasticity according to Arany: 38-40), which could be classified as medium-hard loam soil. The width of the humus layer ranged from 80 to 90 cm. The average humus content of the humus layer with uniform humus content was 2.8 %.

Based on the soil test results (KÁTAI, 2006), it can be concluded that both the pH in water and in KCl (0.7-0.8) significantly decreased with increasing fertilizer dosages. In the control treatment without irrigation, the pH values both in water and in KCl were almost the same for mono- and triculture. Under irrigated conditions however, the measured values in the control and in the different fertilizer treatments pH values in water and in KCl showed a reduction of 0.2-0.4 as compared to non-irrigated conditions both in mono- and triculture. The pH value of the experimental soil in water and in KCl ranged from 5.6 to 6.8 and from 4.7 to 5.9, respectively.

Based on the measurements performed in 2000 by the Regional Central Laboratory under the direction of Dr. Zoltán Győri, it can be stated that as a result of fertilization, a significant accumulation zone was formed in the 200-300 cm layer of the experimental soil under non-irrigated conditions in the treatment with the largest fertilizer dosage (*Figure 1*). In biculture, similar trends can be observed, but the nitrate content of the accumulation zone is much lower, than in monoculture, in the winter wheat-maize crop rotation, the roots of the two crops use available nitrogen from different depths of the soil, therefore, nitrogen accumulation in the same soil layer is less probable. In both crop rotation models, it is obvious, that no accumulation zone was formed in the irrigated treatments, not even in the high-dosage treatments, which is probably due to the fact that the nitrate accumulation is located under the studied soil profile due to the strong vertical water movement caused by the irrigation. Nevertheless, the lack of an accumulation zone can also be caused by the fact that less nutrients remain in the soil due to the more intensive nutrient uptake induced by the irrigation (*Figure 2*).

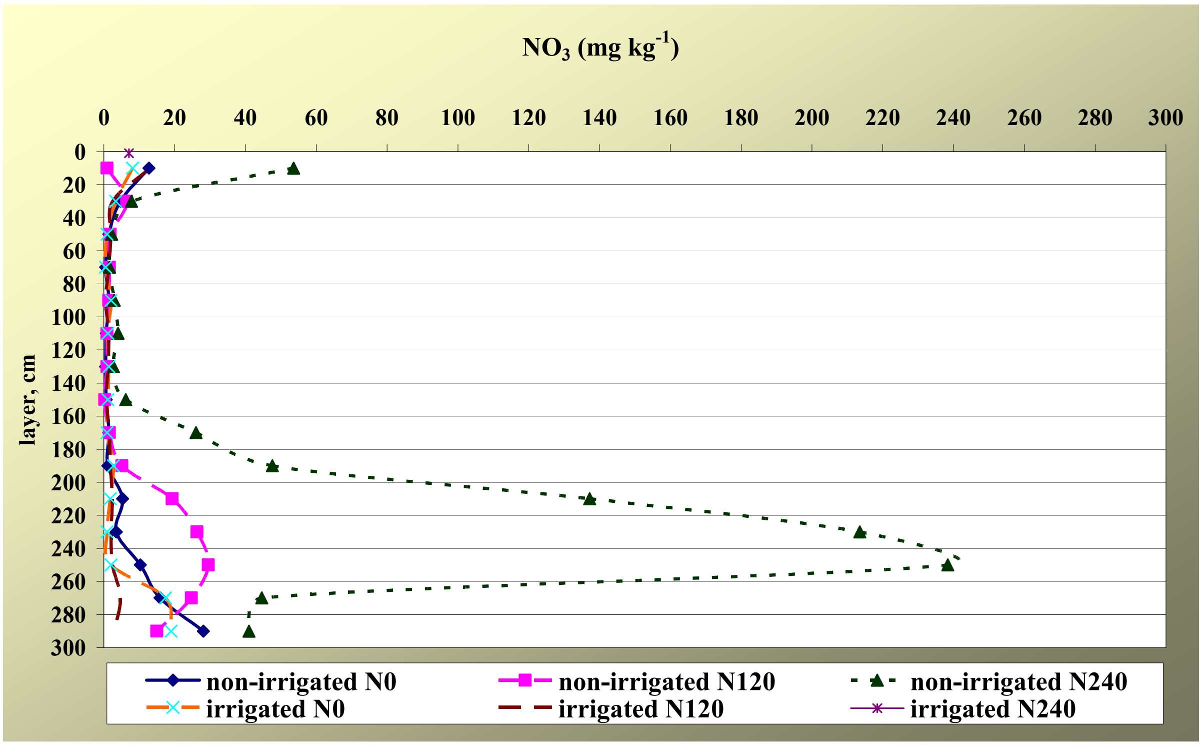


Figure 1. The **impact of artificial fertilization on the NO_3 nitrogen content of the soil in monoculture**

(Debrecen-Látókép, 2000)

(Source: based on the data of Z. Győri)

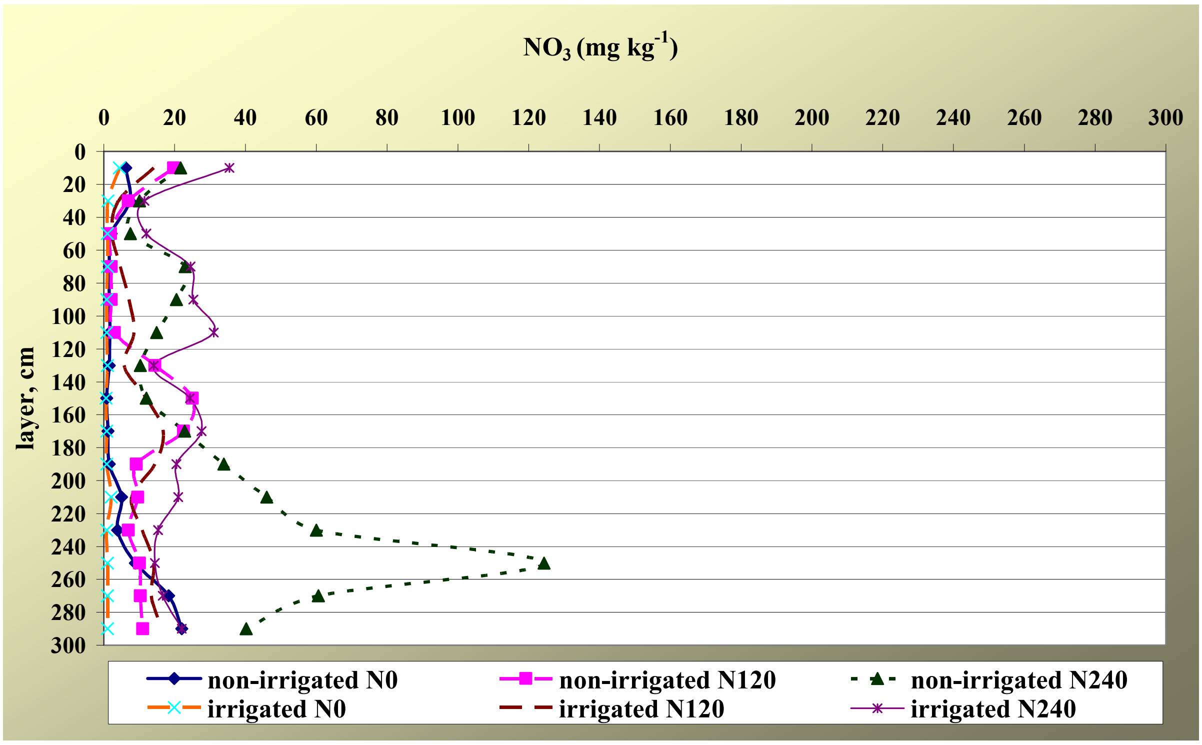


Figure 2. **The impact of artificial fertilization on the NO_3 nitrogen content of the soil in biculture**

(Debrecen-Látókép, 2000)

(Source: based on the data of Z. Győri)

In monoculture, a smaller change was observed in the Al-soluble P_2O_5 content as a result of the different fertilizer treatments both under irrigated and non-irrigated conditions as regards the 60-300 cm layer of the soil. However, in the cultivated layer of 0-40 cm, a significant increase can be observed in the P_2O_5 content with the increasing fertilizer dosages. In high-dosage fertilizer treatments, values higher than 200 mg/kg were measured both under irrigated and non-irrigated conditions. In both irrigation treatments, the P_2O_5 content of the soil was drastically reduced under the 40 cm layer, which indicates that the nutrient is accumulated in the cultivated layer.

In the case of potassium, similarly to phosphorus, a significant accumulation (320-420 mg/kg) could be detected in the upper cultivated soil layer (0-40 cm) as a result of the fertilizer treatments. However, the changes are stronger in the bottom layers of the soil (average of the 60-300 cm layers) than in the case of phosphorus. A significant accumulation could be detected in the largest dosage NPK treatment, values twice higher than those of the control were measured. This phenomenon indicates that an accumulation zone similar to that of nitrogen, but of much lower degree is formed in the lower soil layers as a result of the fertilizer treatments. Meanwhile, it is important to note, that this increase in potassium content is probably primarily due to the fact that cracks are formed in the soil in the periods of drought and in this way the potassium absorbed by the soil colloids can be leached from the mentioned layer as a result of a sudden heavy rain (*Table 1*).

Table 1. **The impact of NPK fertilization on the Al-soluble P_2O_5 and K_2O content of the soil in maize monoculture (mg/kg)**
(Debrecen-Látókép, 2000)

Monoculture						
P_2O_5	**Non-irrigated**			**Irrigated**		
	$N_0P_0K_0$	**$N_{120}P_{90}K_{90}$**	**$N_{240}P_{180}K_{180}$**	**$N_0P_0K_0$**	**$N_{120}P_{90}K_{90}$**	**$N_{240}P_{180}K_{180}$**
0-20 cm	**186.5**	**166.8**	**278.6**	**85.1**	**133.1**	**206.1**
20-40 cm	**96.4**	**85.1**	**278.6**	**71.0**	**106.1**	**194.9**
40-60 cm	**36.9**	**42.6**	**45.4**	**36.9**	**31.2**	**48.3**
average of 60-300 cm	***72.3***	***69.4***	***106.8***	***83.0***	***101.1***	***120.2***
K_2O						
0-20 cm	**226.1**	**247.3**	**323.7**	**234.0**	**317.8**	**423.0**
20-40 cm	**191.0**	**169.5**	**365.7**	**232.7**	**350.8**	**373.5**
40-60 cm	**152.6**	**111.7**	**171.8**	**171.2**	**178.8**	**209.3**
average of 60-300 cm	***137.4***	***127.5***	***224.4***	***130.6***	***174.1***	***225.0***

Source: based on the data of Z. Győri

Similar trends can be observed in biculture as in monoculture, the difference being that the absolute nutrient content values of the soil are lower, primarily in the case of phosphorus (*Table 2*).

Table 2. **The impact of NPK fertilization on the Al-soluble P_2O_5 and K_2O content of the soil in maize biculture (mg/kg)**
(Debrecen-Látókép, 2000)

Biculture						
P_2O_5	**Non-irrigated**			**Irrigated**		
	$N_0P_0K_0$	**$N_{120}P_{90}K_{90}$**	**$N_{240}P_{180}K_{180}$**	**$N_0P_0K_0$**	**$N_{120}P_{90}K_{90}$**	**$N_{240}P_{180}K_{180}$**
0-20 cm	**84.0**	**147.4**	**72.5**	**46.6**	**187.6**	**284.9**
20-40 cm	**58.1**	**84.0**	**267.8**	**37.9**	**63.9**	**153.1**
40-60 cm	**40.8**	**43.7**	**184.7**	**35.0**	**40.8**	**43.7**
60-300 cm	***100.5***	***103.0***	***135.4***	***89.0***	***130.0***	***151.5***
K_2O						
0-20 cm	**193.8**	**272.5**	**322.4**	**180.1**	**316.5**	**333.4**
20-40 cm	**173.7**	**174.1**	**228.6**	**133.6**	**154.8**	**310.4**
40-60 cm	**116.7**	**115.6**	**145.9**	**117.7**	**110.6**	**116.7**
60-300 cm	***109.7***	***134.3***	***193.9***	***91.4***	***143.5***	***199.1***

Source: based on the data of Z. Győri

3.2. Experimental setup

The treatments set up in the long-term experiment enable the study of the effect and interaction of three critical production technology elements. The first production technology element is crop rotation, three models of which were studied [monoculture, biculture (wheat, maize), triculture (pea, wheat, maize)].

Five different fertilization treatments were set up. The first was the unfertilized control, the further treatments were multiple dosages of N60, P_2O_5 45, K_2O 45 kg ha^{-1} up to the level $N_{240}P_{180}K_{180}$. In the autumn, 50 % of the nitrogen and the total amount of P and K were applied, while the remaining 50 % of the N was applied before the seedbed preparation in the spring.

The third studied production technology element was the irrigation. The amount of irrigation water in one irrigation cycle was 50 mm, applied in two parts in order to reduce losses due to run-off. The date of irrigation was determined by the cumulated water deficiency values and the acute water deficiency values caused by the extreme dry hot days. The applied irrigation method was sprinkling irrigation by a linear move irrigation system.

3.3. Agrotechnique applied in the experiment

Regarding soil cultivation procedures applied in the experiment, conventional operations were preferred and we strived to perform these operations at the optimal time without unnecessary damaging of the soil structure. The soil cultivation performed was as follows:

- skim ploughing
- ploughing down of the artificial fertilizers applied in the autumn
- deep ploughing in the autumn
- harrowing and levelling in the spring
- seedbed preparation

The tested hybrid was the same in all years, *PR37M81 (Reseda)* with a plant density of 60 000 plants/ha. Sowing was performed around 20 April with respect to the optimal soil conditions.

In the different crop rotations, the applied crop protection treatments were uniform, except for soil disinfection which was applied only in the monoculture simultaneously with sowing in order to prevent damage caused by the larvae of Western corn rootworm (*Diabrotica virgifera virgifera* LeConte). Herbicides most fitting to the weed flora were selected for use in the experiment and were used in pre- and postemergent applications to achieve a good weed killing effect.

3.4. Evaluation methods

The statistical evaluation of the data was performed using the programmes *Microsoft Excel®* and *SPSS for Windows 13.0*. For the statistical evaluation of the results, two-way analísis of variance was applied. The effects of fertilization and irrigation on yield were evaluated using regression analysis. The correlations between the different dependent and independent variables were calculated using the Pearson's correlation. Quantification of the effects of agrotechnical factors on the yield was performed by partitioning variance components.

3.5. Description of weather in the experimental years

Weather in the cropyear of 2004 was near optimal for the development of maize stands. After favourable weather in the autumn, in the winter and in early spring, the drought in May and the cold weather only slightly hindered the development. The period of determining importance in vegetative and generative development (June-July-August) provided almost optimal conditions for yield formation. Weather in September was favourable for grain filling. As a result of the favourable weather, good yields were obtained in this year.

Weather in the cropyear of 2005 was favourable for the vegetative and generative development of maize. Water supply was especially favourable, practically optimal during the whole vegetation period. Temperatures were also around the average. The year was characterized by a late and slow drying of leaves which increased the assimilation capacity of stands. The unfavourable weather effects were limited to tight periods of the season (rainy weather in the second half of April, cold weather at the beginning of May and June). The favourable weather conditions enabled high yields. Due to the favourable precipitation conditions, no irrigation was applied in the experiment in this year.

Regarding weather in 2006, it can be stated that basically it was favourable for the vegetative and generative development of maize except for short unfavourable periods (late spring, a fall in temperature at the beginning of May and June, hot days in July) enabling good yield results.

The dry and warm weather of autumn in 2006 continued also in the winter, in the spring and in the summer. The drought, the hotness and strong sunshine during flowering and grain filling were especially unfavourable for yield formation and accordingly, the yields were significantly reduced. The unfavourable effects of dry weather were only partially compensated by the water management characteristics of the soil. The cold, rainy weather at the end of the season (second half of August, September) could not really influence grain filling and yields in the maize stands being in the last phenophases of the vegetation due to the accelerated development. The extreme, dry weather of 2007 strongly probed the adaptation ability of maize.

Weather in 2008 was basically favourable for the vegetative and generative development and yield formation in maize. Though the cold weather was not favourable for early development, but the weather factors were optimal from mid-May assisting the development of maize stands in June and fertilization and early grain filling in July. Accordingly, a large vegetative mass was formed in this year. The effect of dry, warm weather in August was moderated by the soil water stock. Hot weather in the first half of September resulted in a quick drying of the assimilation surface and in unfavourable grain filling processes. The cold, rainy weather of the second half of September did not have a significant effect on grain filling, the physiological maturation was already over. Due to the favourable water supply, no irrigation was applied in the experiment.

Weather in the cropyear of 2009 was unfavourable for the vegetative and generative development and yield formation of maize. These unfavourable effects could be compensated only partially by the water and nutrient management characteristics of the soil. The hot weather in April-May, July-August and the almost absolute lack of precipitation were unfavourable for the vegetative development of maize. A larger yield reduction was prevented by the abundant precipitation in June (*Table 3*). Due to the unfavourable weather conditions, moderate yields were obtained in 2009.

Table 3. **Changes in the amount of precipitation, deviations from the average of many years**

(Debrecen-Látókép, 2004-2009)

	Precipitation (mm)						
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**30-year average (1968-1997)**
Off-season (X-III)	**210.9**	**205.4**	**248.8**	**128.2**	**214.8**	**203.2**	**220.2**
Deviation from the 30-year average	-9.3	-14.8	28.6	-92.0	-5.4	-17.0	
In the season							
IV.	40.0	74.9	92.3	3.6	74.9	9.9	42.4
V.	17.0	75.8	58.3	54.0	47.6	20.3	58.8
VI.	61.7	54.3	77.1	22.8	140.1	96.6	79.5
VII.	142.2	99.7	30.8	39.7	144.9	9.2	65.7
VIII.	50.2	135.7	62.4	77.6	34.2	11.3	60.7
IX.	31.3	61.7	5.3	86.1	42.2	21.7	38.0
Total	**342.4**	**502.1**	**326.2**	**283.8**	**483.9**	**169.0**	**345.1**
Deviation from the 30-year average	-2.7	157.0	-18.9	-61.2	138.8	-176.1	
Precipitation in the season of maize (X-IX.)	**553.3**	**707.5**	**575.0**	**412.0**	**698.7**	**372.2**	**565.3**
Deviation from the 30-year average	-12.0	142.2	9.7	-153.3	133.4	-193.1	

4. RESULTS AND DISCUSSION

4.1. Analysis of the results per year

In our study, the studied yield-influencing factors were analysed separately for each year and combined for the 6 years by curve fitting and statistical methods to be described below.

In 2004, the differences between the different fertilization levels in monoculture were significant up to the level $N_{120}P_{90}K_{90}$, above this dosage yield increments were still measured, but were not significant. Under irrigated conditions, the fertilizer response showed similar values with slightly higher yields. As a result of fertilizer treatments, yields were more than twice higher, 14347 kg ha^{-1} than in the control (7157 kg ha^{-1}). When analysing the impact of irrigation, the yield-increasing effect of irrigation was relatively low in this crop rotation (7.1 %), which was probably mainly due to the favourable effect of the good water supply of the year.

The fertilizer response in biculture was considerably lower than in monoculture. A basic difference was that the yield of the control was more than 2500 kg ha^{-1} higher than in monoculture. Under non-irrigated conditions, the relative yield increment due to fertilization was much lower varying between 13.9-38.3 %. As a result of irrigation, the yield increment due to fertilization considerably decreased, regarding both its absolute and relative values (6.4-13.0 %). The effect of irrigation was peculiar in this crop rotation model. Both in the control and in the $N_{60}P_{45}K_{45}$ treatment, significant (2049 and 1453 kg ha^{-1}) yield increments were obtained. However, the yield increment was not significant at the fertilization level of $N_{120}P_{90}K_{90}$ and at higher fertilizer dosages a yield reduction of non-reliable degree was observed.

Yields varied between 10 404 and 13 179 kg ha^{-1} in triculture without irrigation. In this crop rotation and irrigation combination, the fertilizer response was peculiar. All fertilizer treatments resulted in a significant yield increment, however, the degree of difference was reliable only between the control and the $N_{60}P_{45}K_{45}$ treatment. Under non-irrigated conditions, the highest yield was measured in the $N_{120}P_{90}K_{90}$ treatment. As a result of irrigation, the difference between fertilizer treatments was slightly different. All fertilizer treatments resulted in a significant yield increment as compared to the control and the differences between the fertilizer treatments were also significant up to the dosage $N_{180}P_{135}K_{135}$. The differences between irrigated and non-irrigated treatments were not significant at either fertilization level, which was primarily due to the good water supply of the year. Summing up, it can be concluded that the favourable weather conditions of 2004 significantly modified the irrigation effect and the crop rotation system was also of great modifying effect in addition to the year in the case of the fertilization treatments.

Due to the favourable precipitation in 2005, irrigation was not necessary. The yield of the control was 8 403 kg ha^{-1} in monoculture without irrigation. The effect of fertilizer treatments was similar to that of 2004, that is all fertilization treatments resulted in a significant yield increment. The highest yield (13 685 kg ha^{-1}) was measured in the highest-dosage fertilizer treatment of $N_{240}P_{180}K_{180}$.

In biculture, a higher control yield was obtained (11 006 kg ha^{-1}) than in the previous year and the yield increment of 2 603 kg ha^{-1} was significant as compared to monoculture. The highest absolute yield was also obtained at this fertilization level (12 976 kg ha^{-1}), at higher fertilizer dosages a non-significant yield reduction was detected.

In triculture, the highest yield was obtained in the $N_{60}P_{45}K_{45}$ treatment, however, the relative variation in yield ranged within a tight interval (12.0-16.8 %). All fertilization levels resulted in a significant yield increment, but a yield reduction was observed at all fertilization levels as compared to the treatment $N_{60}P_{45}K_{45}$ which was significant in the case of the control and the $N_{240}P_{180}K_{180}$ treatment.

In 2006, the yields in monoculture were lower than in the previous years. The yield maximum was obtained in the $N_{180}P_{135}K_{135}$ treatment (9 403 kg ha^{-1}), however, this was not significantly higher than the yield of the treatment $N_{120}P_{90}K_{90}$. Under irrigated conditions, similar trends were observed, however, the fertilizer response was much stronger, which is supported also by the relative yield variation interval (37.9-73.5 %). As a result of irrigation, a significant yield increment was observed in all treatments except for the control and the $N_{60}P_{45}K_{45}$ treatment, the relative values of which varied within a relatively tight interval (-5.2-19.5 %).

In biculture, the yield of the non-irrigated control (8 284 kg ha^{-1}) was considerably higher than that of monoculture (6 575 kg ha^{-1}). All treatments resulted in a significant yield increment, the maximum yield was measured in the $N_{120}P_{90}K_{90}$ treatment (11 813 kg ha^{-1}). Under irrigated conditions, the yield of the control (9 428 kg ha^{-1}) was higher than that in monoculture and all fertilizer treatments resulted in a significant yield increment. Among the tested treatments, the highest yield was obtained in the $N_{120}P_{90}K_{90}$ treatment, the fertilizer dosages higher than that resulted in a significant yield reduction. A positive irrigation effect was observed in all treatments, which was significant for the control and the $N_{120}P_{90}K_{90}$ and $N_{240}P_{180}K_{180}$ treatments. The relative yield increment in triculture (16.3-24.8 %) as compared to the other two crop rotations was much lower, which is mainly due to the high yield of the non-irrigated control (9 770 kg ha^{-1}). The highest amount of yield was obtained in the $N_{120}P_{90}K_{90}$ treatment. Under irrigated conditions, the relative variation in yield (31.2-36.1%) was higher than under non-irrigated conditions although the absolute values of the yields werew almost the same at the different fertilization levels. However, this interval was greatly reduced as a result of the irrigation. The irrigation effect in triculture in 2006 was special. In several treatments (control, $N_{120}P_{90}K_{90}$, $N_{180}P_{135}K_{135}$), a yield reduction was observed in irrigated plots, however, it was significant only in the case of the control.

The lowest yields during the experiment were obtained in non-irrigated monoculture in 2007. This is illustrated by the yield of the control (2 685 kg ha^{-1}) and the yield obtained in the $N_{240}P_{180}K_{180}$ treatment (2 487 kg ha^{-1}) which was even, though not significantly, lower than the control yield. From among the treatments, only the $N_{60}P_{45}K_{45}$ and $N_{120}P_{90}K_{90}$ treatments resulted in a significant yield increment, higher dosages resulted in a significantly lower yield as compared to the $N_{120}P_{90}K_{90}$ level. On the contrary, fertilization caused only in yield increase under irrigated conditions. All fertilization treatments resulted in a significant yield increment as compared to the control, the highest yield was obtained at the $N_{180}P_{135}K_{135}$ level, at the highest fertilizer dosage ($N_{240}P_{180}K_{180}$) a significant yield reduction was observed. The relative yield variation varied between 36.4 and 68.8 % representing a very positive fertilizer response. The yield-increasing effect of irrigation was outstandingly high (94.0-222.0%) due to the extreme dry year. The largest yield-increment as a result of irrigation was 5 898 kg ha^{-1} which accentuates the determinative role of irrigation in dry years. The smallest yield increment due to irrigation (2 525 kg ha^{-1}) was measured in the control treatment.

As opposed to monoculture, none of the fertilizer treatments resulted in a yield reduction in non-irrigated biculture. The yield-increasing effect of the fertilizer treatments ranged within a relatively tight interval (9.1-23.1 %), the maximum yield was measured in the $N_{120}P_{90}K_{90}$ treatment (7 706 kg ha^{-1}). Under irrigated conditions, the yield of the control was much higher (8 413 kg ha^{-1}) and all fertilizer treatments resulted in a significant yield increment as compared to that. As a result of irrigation, a yield increment was observed at all fertilization levels, the degree of which was several times higher than the significance level, which demonstrates well the importance of irrigation under dry conditions. The largest irrigation effect (3 274 kg ha^{-1}) was obtained in the optimum treatment of $N_{120}P_{90}K_{90}$.

The highest non-irrigated control yield among the three crop rotation systems was measured in triculture (6 716 kg ha^{-1}). The maximum yield was obtained in the smallest fertilization treatment of $N_{60}P_{45}K_{45}$, all fertilizer treatments resulted in a significantly lower yield than that.

Under irrigated conditions, the yield of the control was similarly high as that of the winter wheat-maize crop rotation. The highest yield was measured in the $N_{120}P_{90}K_{90}$ treatment which was significantly higher than that of all the other treatments. The effect of irrigation was strong, as a significant yield increment was observed for all fertilization treatments, similarly to the other two crop rotation models. The largest yield increment due to irrigation was measured in the treatment $N_{120}P_{90}K_{90}$ which gave the maximum yield.

Due to the favourable precipitation, no irrigation was applied in the experiment in 2008. An outstanding control yield was measured even in monoculture (9 154 kg ha^{-1}). This high yield level was significantly increased as a result of fertilization. The yield increment as compared to the control reached 4 633 kg ha^{-1}, which was obtained in the $N_{180}P_{135}K_{135}$ treatment giving the maximum yield. In biculture, the highest control yield of the six years was measured (11 613 kg ha^{-1}). The peculiar nature of this year is demonstrated by the fact that no significant differences were observed between the different fertilization levels. Similar statements can be made for the triculture also. Similarly to the biculture, an outstanding control yield was measured (11 291 kg ha^{-1}) and fertilization resulted in higher than 2 t yield increments at all fertilization levels. The maximum yield (13 987 kg ha^{-1}) was measured in the $N_{120}P_{90}K_{90}$ treatment and the yield variation ranged within a very tight interval (18.0-23.9 %) similarly to that of biculture.

In 2009, the yield of the control in monoculture was 6 106 kg ha^{-1}. A significant yield increment was measured at all fertilization levels, the interval of which was 2 545-3 304 kg ha^{-1}. The maximum yield (9 410 kg ha^{-1}) was obtained at the $N_{180}P_{135}K_{135}$ level. The yield increasing effect of fertilization significantly increased as a result of irrigation. The effect of irrigation in this crop rotation model was relatively moderate. Irrigation resulted in a significant yield increment in all fertilization treatments. The degree of this was the smallest in the control (527 kg ha^{-1}), while the largest irrigation effect (2 475 kg ha^{-1}) was measured at the $N_{240}P_{180}K_{180}$ fertilization level.

In biculture, a significant yield increment was measured at all fertilization levels as compared to the control; the maximum yield was obtained in the $N_{120}P_{90}K_{90}$ treatment. The yields showed a similar pattern under irrigated conditions, the only difference being that the absolute values of the increase were much higher (2 301-3 524 kg ha^{-1}). The yield increment due to irrigation was significant for the treatments $N_{60}P_{45}K_{45}$, $N_{120}P_{90}K_{90}$, and $N_{240}P_{180}K_{180}$.

The yield-increasing effect of irrigation was low (being 333 kg ha^{-1} for the control while the highest value was only 1 647 kg ha^{-1}).

In triculture, a relatively high control yield was measured (8 689 kg ha^{-1}). All fertilization treatments significantly increased the yield, however, the efficacy of fertilization was decreasing starting with the $N_{60}P_{45}K_{45}$ level. These results were greatly changed as a result of irrigation, since in spite of the high control yield (9 385 kg ha^{-1}), high yield increments were observed in the different fertilization treatments (1 824-3 480 kg ha^{-1}). The effect of irrigation was significant in all treatments except for the control and the highest values among the three crop rotation models were measured in triculture (696-2 952 kg ha^{-1}).

4.2.Statistical evaluation of the experimental years combined

4.2.1. Evaluation of the interactive effect of crop rotation, fertilization and irrigation

The values taken as an average of the six years proved the significant effect of fertilization in all crop rotation systems as compared to the control (*Table 4*). Under non-irrigated conditions, the yield of the control was 6 677 kg ha^{-1} as an average of the experimental years. The yield increment due to fertilization varied between 2 206 and 3 590 kg ha^{-1}. The highest yield (10 267 kg ha^{-1}) was obtained at the $N_{180}P_{90}K_{90}$ fertilization level, but the yields of the treatments $N_{120}P_{90}K_{90}$ and $N_{240}P_{180}K_{180}$ were not significantly lower than that. The relative variation in yield as an average of the six years varied within a relatively wide interval (33-53.8 %).

Table 4. **The effect of crop rotation and fertilization on the yield and yield increments of maize under irrigated and non-irrigated conditions (as an average of the studied years)**
(Debrecen-Látókép, 2004-2009)

Fertilization treatment (B)		Monoculture		Biculture			Triculture		
		Yield (kg ha^{-1})	Deviation fert. (kg ha^{-1})	Yield (kg ha^{-1})	Deviation fert. (kg ha^{-1})	*Deviation mono.* *(kg ha^{-1})*	Yield (kg ha^{-1})	Deviation fert. (kg ha^{-1})	*Deviation mono.* *(kg ha^{-1})*
Non-irrigated (A)	**$N_0P_0K_0$**	6677	**0**	9487	**0**	***2810***	9700	**0**	***3023***
	$N_{60}P_{45}K_{45}$	8883	**2206**	11071	**1584**	***2188***	11532	**1832**	***2649***
	$N_{120}P_{90}K_{90}$	10157	**3480**	11947	**2460**	***1790***	11540	**1840**	***1383***
	$N_{180}P_{135}K_{135}$	10267	**3590**	11732	**2245**	***1465***	11242	**1542**	***975***
	$N_{240}P_{180}K_{180}$	10046	**3369**	11257	**1770**	***1211***	11158	**1458**	***1112***
Irrigated (A)	**$N_0P_0K_0$**	6946	**0**	10574	**0**	***3628***	9758	**0**	***2812***
	$N_{60}P_{45}K_{45}$	9550	**2604**	12065	**1491**	***2515***	12171	**2413**	***2621***
	$N_{120}P_{90}K_{90}$	11186	**4239**	12994	**2420**	***1808***	12683	**2925**	***1497***
	$N_{180}P_{135}K_{135}$	11866	**4920**	12395	**1821**	***529***	12445	**2687**	***579***
	$N_{240}P_{180}K_{180}$	11789	**4843**	12059	**1485**	***270***	12232	**2474**	***443***
$SD_{5\%}$ (A)		1447		850			1018		
$SD_{5\%}$ (B)		356		259			243		
$SD_{5\%}$ (AxB)		504		366			344		

In biculture, a considerably higher yield (9 487 kg ha^{-1}) was obtained than in monoculture. All fertilizer treatments resulted in a significant yield increment, the maximum yield was obtained in the $N_{120}P_{90}K_{90}$ treatment (11 947 kg ha^{-1}). However, the yield of the $N_{180}P_{135}K_{135}$ treatment was not significantly different from the maximum yield. As compared to the control yield of monoculture, the absolute yield increment in this crop rotation was significant (2 810-5 270 kg ha^{-1}). The relative yield variation as compared to the control ranged within a tighter interval than in the case of monoculture (16.7-25.9 %).

In triculture, the yield of the control (9 700 kg ha^{-1}) was higher than that of biculture and the effect of crop rotation in the control as compared to monoculture was 3 023 kg ha^{-1}. The effect of fertilizer treatments was balanced in this crop rotation, there were small differences between the different fertilization levels. The maximum yield (11 540 kg ha^{-1}) was measured in the $N_{120}P_{90}K_{90}$ treatment, but the yield in the $N_{60}P_{45}K_{45}$ treatment was not significantly different from that. The interval of the relative yield variation was very tight (45) due to the high control yield and the small differences between the different fertilization levels.

Under irrigation, the control yield of monoculture was 6 946 kg ha^{-1}. The yield-increasing effect of fertilization was reliable for all fertilization treatments. The largest yield increment was obtained at the $N_{180}P_{135}K_{135}$ fertilization level (4 920 kg ha^{-1}), however, the yield of the $N_{240}P_{180}K_{180}$ treatment was not significantly lower than that (11 789 kg ha^{-1}). The relative variation in yield ranged between the widest boundaries (37.5-70.8 %) among the studied treatment combinations, which proves the outstanding importance of fertilization under irrigated conditions. This treatment combination showed almost similar fertilization response results, excepr for the $N_{60}P_{45}K_{45}$ level to those obtained in non-irrigated bi- and triculture systems.

In non-irrigated biculture, the yield of the control was outstandingly higher than that of monoculture (10 574 kg ha^{-1}) even compared to the other treatment combinations. All fertilization levels significantly increased the yield in spite of the high control yield, but the differences between the different fertilization levels were moderate. Among the treatments, the $N_{120}P_{90}K_{90}$ fertilization level gave the highest yield, all other fertilization treatments resulted in significantly lower yields. Due to the high control yield, the relative variation in yield as a result of fertilization ranged from 14.0 to 22.9 %.

In triculture, the yield of the control was also high and the fertilizer response as an average of the studied years showed a very similar pattern to that of biculture. The maximum yield (12 683 kg ha^{-1}) was measured in the $N_{120}P_{90}K_{90}$ treatment, however, the yield in the

$N_{180}P_{135}K_{135}$ treatment (12 445 kg ha^{-1}) was not significantly different from that. The relative yield variation ranged between 24.7 and 30.0 %.

Irrigation had a relatively moderate effect considered as an average of six years. The largest yield-increasing effect was measured in monoculture (269-1 743 kg ha^{-1}), which represented a yield increment of 4.0-17.3 % as compared to the non-irrigated treatments. In biculture, a much lower irrigation effect could be detected between the different fertilization levels than in monoculture. The interval of yield increase due to irrigation was between 663 and 1 087 kg ha^{-1} and due to the small differences between the different fertilization levels, the relative variation in yield ranged from 5.7 to 11.5 %. The relative yield increment interval was even smaller in triculture ranging between 0.6 and 10.7 %. Irrigation had the largest impact on yield at the higher fertilization levels (1 074-1 203 kg ha^{-1} yield increment), howeverm the yield increment in the control was negligible (58 kg ha^{-1}) (*Table 5*).

Table 5. **The effects of irrigation and fertilization on the relative and absolute yield increment of maize in different crop rotation systems (as an average of the studied years)**
(Debrecen-Látókép, 2004-2009)

Fertilization treatment	Non-irrigated		Irrigated		Irrigation effect	
	deviation kg ha^{-1}	deviation %	deviation kg ha^{-1}	deviation %	deviation kg ha^{-1}	deviation %
MONOCULTURE						
$N_0P_0K_0$	0	100.0	0	100.0	269	104.0
$N_{60}P_{45}K_{45}$	2206	133.0	2604	137.5	667	107.5
$N_{120}P_{90}K_{90}$	3480	152.1	4239	161.0	1028	110.1
$N_{180}P_{135}K_{135}$	3590	153.8	4920	170.8	1599	115.6
$N_{240}P_{180}K_{180}$	3369	150.5	4843	169.7	1743	117.3
BICULTURE						
$N_0P_0K_0$	0	100.0	0	100.0	1087	111.5
$N_{60}P_{45}K_{45}$	1584	116.7	1491	114.1	994	109.0
$N_{120}P_{90}K_{90}$	2460	125.9	2421	122.9	1047	108.8
$N_{180}P_{135}K_{135}$	2245	123.7	1821	117.2	663	105.7
$N_{240}P_{180}K_{180}$	1770	118.7	1485	114.0	802	107.1
TRICULTURE						
$N_0P_0K_0$	0	100.0	0	100.0	58	100.6
$N_{60}P_{45}K_{45}$	1832	118.9	2413	124.7	640	105.5
$N_{120}P_{90}K_{90}$	1840	119.0	2925	130.0	1143	109.9
$N_{180}P_{135}K_{135}$	1542	115.9	2687	127.5	1203	110.7
$N_{240}P_{180}K_{180}$	1458	115.0	2474	125.4	1074	109.6

4.2.2. Determination of optimum fertilizer dosages and dosage intervals

The optimum fertilizer dosage interval values calculated by *regression analysis* from the six-year results varied greatly under non-irrigated conditions as a result of the applied crop rotation system. The highest fertilizer optimum was observed for monoculture ($N_{174}P_{130}K_{130}$). When determining the optimum fertilizer dosage interval, the fertilizer dosage belonging to the maximum yield and the fertilizer dosage reduced by half of the significant yield difference were taken into consideration. In monoculture, these values were 36 kg N, 27 kg P and 27 kg K (*Figure 3*).

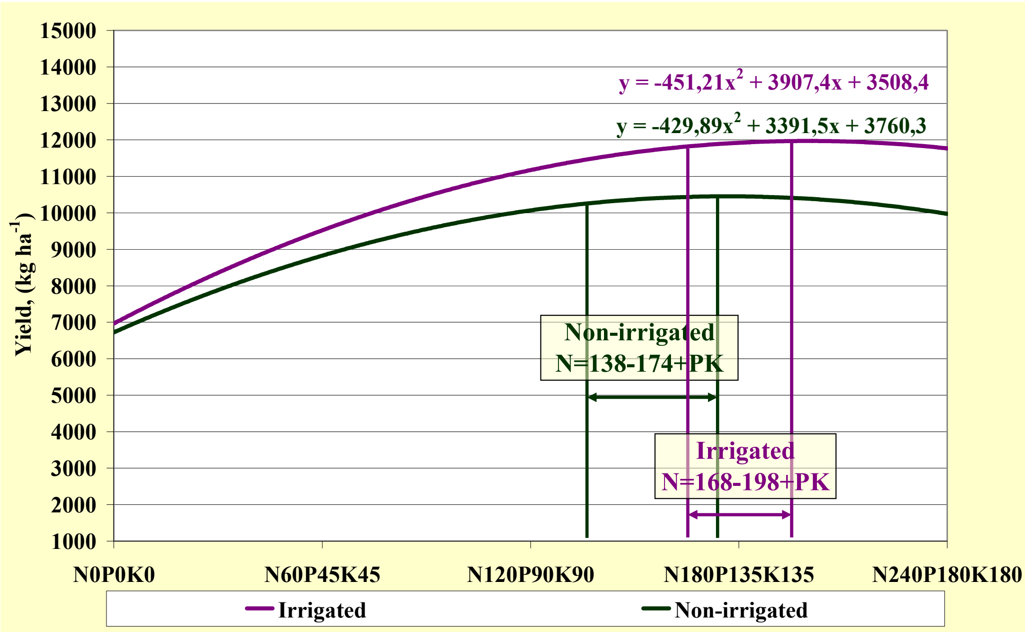


Figure 3. **The effect of fertilization on maize yield and changes in the optimum fertilizer dosage intervals under irrigated and non-irrigated conditions in monoculture**
(Debrecen-Látókép, 2004-2009)

In biculture, the range of the interval did not change (36 kg), however, it was lower by 18 kg N, 13 kg P and 13 kg K active ingredient. In triculture, both the interval and the extreme values were reduced. The N level belonging to the maximum yield is 30 kg lower in triculture and the optimum fertilizer dosage interval was also reduced (30 kg N, 23 kg P and 23 kg K).

As a result of irrigation, a significant increase was observed in optimum fertilizer dosage in monoculture (168-198 kg ha^{-1} N, 126-148 kg ha^{-1} P and 126-148 kg ha^{-1} K). The range of the interval was 30 kg ha^{-1} N, 22 kg ha^{-1} P and 22 kg ha^{-1} K in irrigated monoculture. Th fertilizer dosages were much smaller in irrigated biculture (114-144 kg ha^{-1} N, 85-108 kg ha^{-1} P and 85-108 kg ha^{-1} K). As a result of irrigation, a small reduction occurred in biculture as compared to non-irrigated biculture. In triculture, the extreme values of N optimum increased by 12 kg ha^{-1} (126-156 kg ha^{-1}) as a result of irrigation, while the increment for P and K was 9 kg ha^{-1}.

The extremely dry year of 2007 had a special effect on the extreme values and width of the optimum fertilizer dosage interval. In monoculture, the size of the optimum fertilizer dosage interval did not change (30 kg ha^{-1} N), however, the optimum interval was 60 kg ha^{-1} higher, which is an excellent illustration of the strong irrigation x fertilization interaction in monoculture. The intervals were 78-108 kg ha^{-1} N, 58-81 kg ha^{-1} P and 58-81 kg ha^{-1} K in non-irrigated monoculture (*Figure 4*).

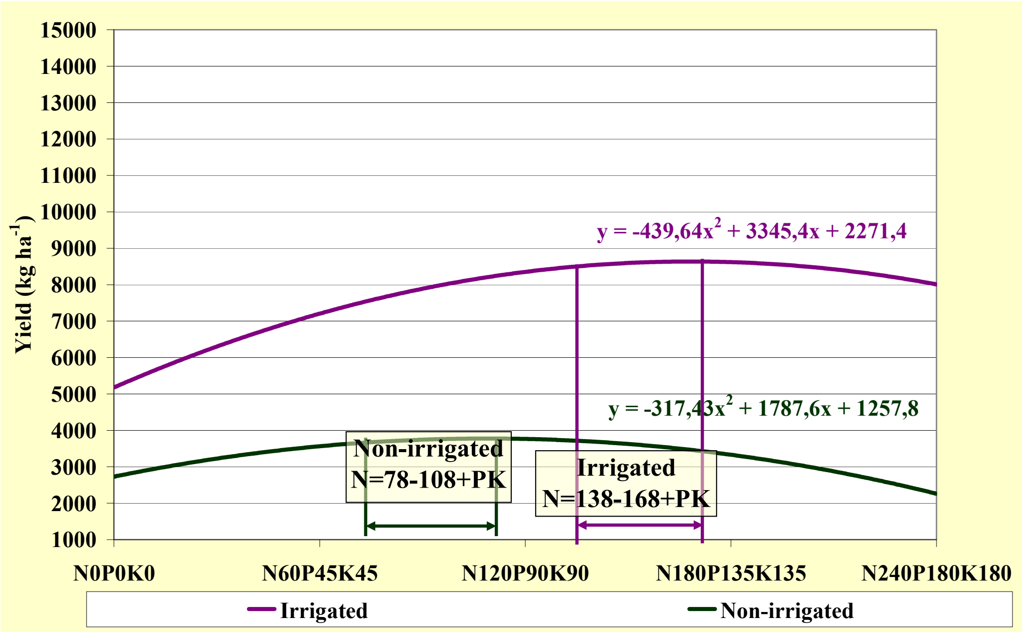


Figure 4. **The effect of fertilization on maize yield and changes in the optimum fertilizer dosage intervals under irrigated and non-irrigated conditions in monoculture**
(Debrecen-Látókép, 2007)

Compared to the values of monoculture, a significant increase was observed in the extreme values and in the interval in biculture (84-138 kg ha^{-1} N, 63-103 kg ha^{-1} P and 63-103 kg ha^{-1} K). The optimum fertilizer dosage interval in triculture can be described by similar trends as above, the difference being that the extreme values were much lower as compared to the other two crop rotation models (36-96 kg ha^{-1} N, 27-72 kg ha^{-1} P and 27-72 kg ha^{-1} K).

In the rainy year of 2008, relatively high fertilizer optimums were measured in all crop rotation models. This interval was 144-180 kg ha^{-1} N, 126-148 kg ha^{-1} P and 126-148 kg ha^{-1}K for monoculture. In biculture, the interval was wider, but the fertilizer optimum for N was 24 kg ha^{-1} lower than in monoculture. A similar trend could be observed in triculture with a small increase in the lower value of the optimum fertilizer dosage interval (*Figure 5*).

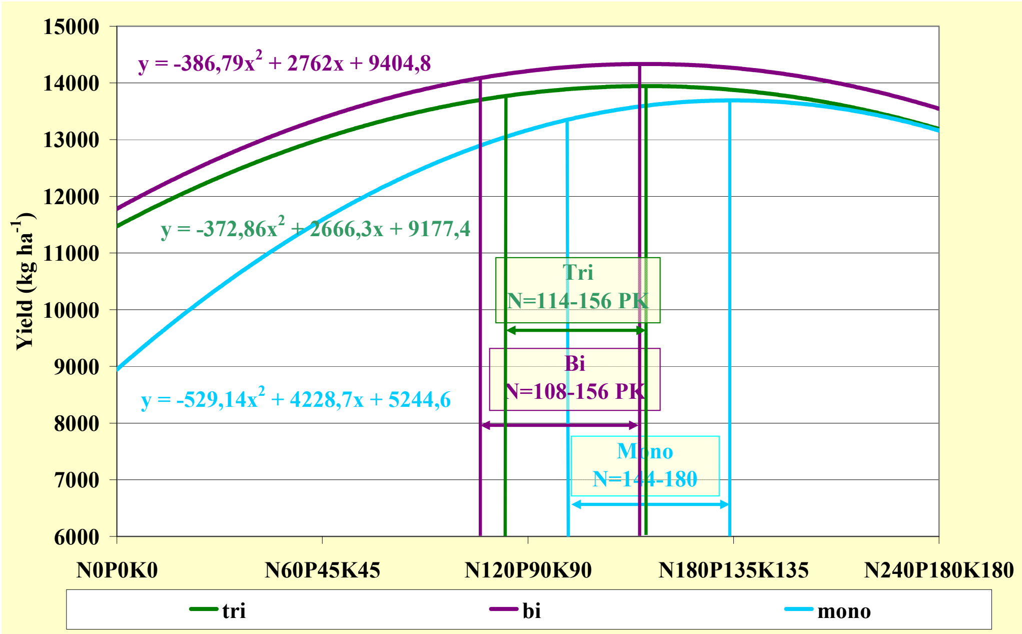


Figure 5. **The effect of fertilization on maize yield and changes in the optimum fertilizer dosage intervals**

(Debrecen-Látókép, 2008)

4.2.3. Study of the effect of direct and indirect factors on yield by correlation analysis

The effect of irrigation and fertilization on yield was studied by *Pearson's correlation analysis*. When analysing the studied years separately, it can be concluded that the effect of fertilization was mainly determined by the forecrop, while in the case of irrigation, the year had a major influence in our experiment. This is supported by the *r* values calculated for monoculture, which showed a tight positive correlation (0.7357-0.9357) in almost all years except for the extremely dry year of 2007. The highest *r* values were obtained in years with a good water supply, in 2004, 2005 and 2008. This fact demonstrates well the fertilization x water supply interaction. The irrigation impact was the highest in the dry year of 2007 (0.9051) and a medium-level irrigation impact was observed in 2009 which could be characterized by an extreme distribution of precipitation.

Fewer tight correlations (above 0.7) were observed in biculture than in monoculture. As regards fertilization, a tight correlation (0.7189) was found in the year of 2004 with good water supply, while both in 2005 and 2008, a medium positive correlation was found. Irrigation had a strong effect (0.8738) on yields in the dry year of 2007. Similar relationships were observed in triculture as in biculture regarding both the direction and strength of the correlation. Accordingly, the largest fertilizer response was observed in 2004, while in all the other years, except for the dry year of 2007, the correlation was positive but only of medium strength. The irrigation impact showed a tight correlation (0.8755) only in 2007.

Based on the six-year results, the effect of irrigation on the degree and direction of the yield x fertilization interaction was studied by Pearson's correlation. In monoculture, a very tight correlation was found both under irrigated and non-irrigated conditions. Under non-irrigated conditions, a tight positive correlation was found (0.7636-0.9471) except for the years 2006 and 2007. In 2006, only a medium correlation was found, while in 2007, the correlation was negative and weak. Irrigation had a spectacular impact on the *r* values of the fertilization x yield interaction. In all studied years, a strong positive correlation was found and this value was higher in the majority of the years than under non-irrigated conditions (0.7944-0.9388). The greatest change was observed in 2007, when the negative value (-0.2354) calculated under non-irrigated condition was transformed into a strong positive interaction (0.7944) as a result of irrigation.

In biculture, a tight correlation was found only in 2004 in the non-irrigated treatment (0.9163). In all the other years, except for 2007 and 2009, the positive correlation was of only medium strength. In triculture, the *r* value of the yield x fertilization interaction significantly decreased as compared to monoculture in all years. Under non-irrigated conditions, a medium positive correlation was determined (0.4362-0.6833) in all years except for 2007 and 2009. In the dry year of 2007, the weak negative correlation found under non-irrigated conditions changed into a medium positive *r* value as a result of irrigation (*Table 6*).

Table 6. **The *r* values of the irrigation and fertilization impact on yields in different crop rotation models calculated by correlation analysis**
(Debrecen-Látókép, 2004-2009)

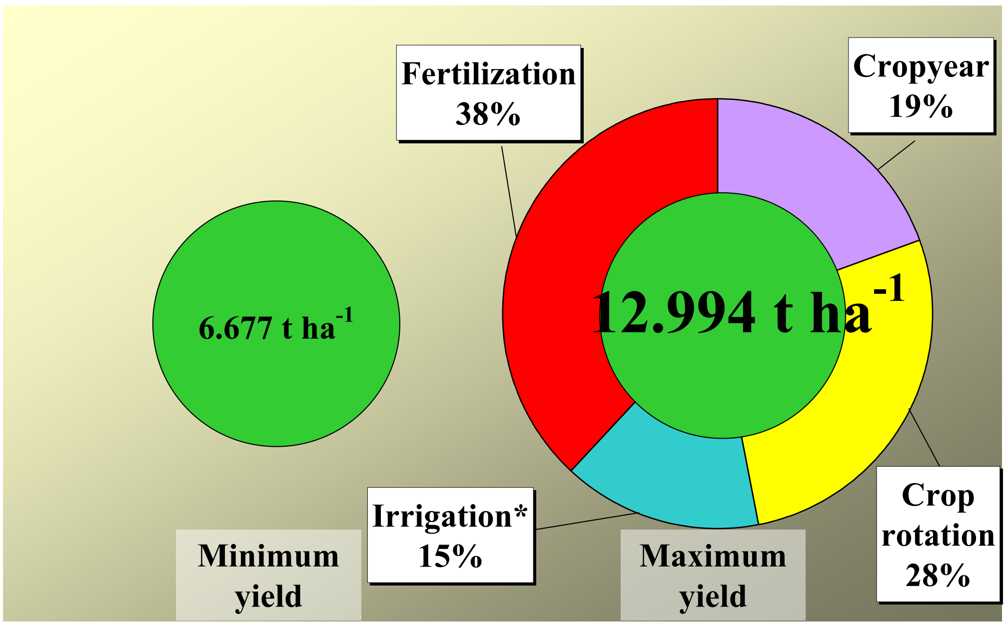
		Monoculture	Biculture	Triculture
2004	fertilization x yield	0.8754	0.7189	0.7261
	irrigation x yield	0.0924	0.2774	0.2320
2005	fertilization x yield	0.9357	0.5344	0.4890
	irrigation after-effect x yield	-0.1235	-0.0508	-0.1045
2006	fertilization x yield	0.7357	0.4877	0.6819
	irrigation x yield	0.2544	0.3174	-0.0402
2007	fertilization x yield	0.1741	0.1390	0.0758
	irrigation x yield	0.9051	0.8738	0.8755
2008	fertilization x yield	0.8550	0.5583	0.6020
	irrigation after-effect x yield	-0.0444	0.0501	0.0315
2009	fertilization x yield	0.7444	0.3771	0.2279
	irrigation x yield	0.4321	0.4860	0.6220

The correlations for the average of the six years were positive but moderate both for irrigation and fertilization. For fertilization, a medium positive correlation (0.4585) was found for monoculture, while a positive but weak correlation was calculated for bi- and triculture. For irrigation, no tight correlation could be found for the average of the six years, which was probably mainly due to the fact that average or higher precipitation fell in four of the studied years. In the same period, only 2007 and 2009 were dry years.

In addition to agrotechnical factors, the interactions of different meteorological parameters and yield were also analysed. Among the studied weather parameters, both precipitation and temperature had a significant effect on yields. Precipitation in the winter and the summer months showed a medium positive correlation in all crop rotation models. From the precipitation during the months of the vegetation period, the precipitation in June and July had the largest impact on yields, a medium positive correlation was found in all crop rotation models. When studying the correlations between temperature parameters and yield, it can be concluded that for all temperature parameters a negative correlation could be found.

4.2.4. Quantification of the yield-influencing effect of the different direct and indirect factors by partitioning variance components

In our experiment, we quantified the yield-determining role of the studied agrotechnical elements based on partitioning the variance components. When determining the role of the studied agrotechnical factors, the yield of the non-irrigated control in monoculture was considered as a basis and the yield increment belonging to the maximum yield obtained by the combination of these factors was partitioned between the studied agrotechnical parameters. Taking the six-year results as a basis, it can be stated that the average yield of the



* in the combined evaluation, the data of the six-year period are included, therefore, due to the justified omission of irrigation in two years, only the irrigation after-effect could be taken into consideration

Figure 6. **The role of yield-determining factors in maize yield development**
(Debrecen-Látókép, 2004-2009)

control was 6.677 t ha^{-1}, which increased to 12.994 t ha^{-1} as a result of the agrotechnical factors applied in the experiments. Among the studied factors, fertilization had the largest effect (38 %=2.398 t ha^{-1}) taken as an average of the six years. This was followed by crop rotation, the yield-determining role of which was 28 % (1.742 t ha^{-1}). The next important factor was the year (19 %), which contributed to the yield increment with 1.230 t ha^{-1}. Among the studied factors, irrigation had the weakest effect (0.947 t ha^{-1}) with a weight of 15% (*Figure 6*).

When evaluating the role of factors separately for each year, it can be seen that the year significantly changed the weight of the different factors (*Figure 7*). In 2004, the yield of the control (in monocukture under non-irrigated conditions) was 7.139 t ha^{-1}, which increased to 14.394 t ha^{-1} due to the effect of the applied agrotechnical factors. Fertilization had the largest weight (70 %=5.117 t ha^{-1}). The relatively low effect of irrigation and crop rotation (11 % =0.790 t ha^{-1} and 19 %=1.348 t ha^{-1}) was primarily due to the fact that the water supply was balanced in 2004, which could significantly increase the efficacy of fertilization. In 2005, the control yield was 8.403 t ha^{-1}, which increased to 13.153 t ha^{-1} as a result of the most favourable factor combinations. Due to the similar weather conditions, fertilization had a prevailing effect also in this year (65 %=3.098 t ha^{-1}). The role of crop rotation increased in this year (28 %=1.345 t ha^{-1}) and an irrigation impact of 7 % (0.307 t ha^{-1}) was determined, in spite of the fact, that no irrigation was applied, nevertheless, the yields of the plots marked as irrigated in the experiment were included in the statistical evaluation. This can be regarded as an irrigation after-effect, since these plots were irrigated in the previous year. In 2006, the control yield was 6.575 t ha^{-1} and the maximum yield of the experiment was 12.882 t ha^{-1}. Among the studied factors, crop rotation (48 %=2.994 t ha^{-1}) and fertilization (43 %=2.731 t ha^{-1}) were of similar significance. The role of irrigation was moderate in this year (9 %=0.582 t ha^{-1}), which was due to the fact that a large amount of precipitation fell shortly after finishing the irrigation, which greatly reduced the role of irrigation. In 2007, the effect of the studied factors on yield was peculiar due to the extremely dry conditions. The control yield was 2.685 t ha^{-1}, which increased to 10.970 t ha^{-1} in the most favourable treatment. As opposed to the above, fertilization had the smallest role (10 %=0.826 t ha^{-1}), while irrigation and crop rotation could be described by similar values (46 %=3.810 t ha^{-1} and 44 %=3.648 t ha^{-1}). These values draw attention to the significance of the reduction in the efficacy of the applied fertilizers due to the lack of water and to the appreciation of crop rotation under stress conditions. In 2008, which can be characterized by an excellent water supply, a very high control yield was measured (9.154 t ha^{-1}), which increased to 14.180 t ha^{-1} in the optimum treatment combination. Due to the favourable water supply, no irrigation was applied and only a minimum impact was demonstrated by the statistical evaluation (0.002 t ha^{-1}). Fertilization had the largest role (71 %=3.553 t ha^{-1}), while the role of crop rotation was moderate (29 %=1.470 t ha^{-1}). In 2009, the control yield was 6.106 t ha^{-1}, while the maximum yield was 13.942 t ha^{-1}. The role of irrigation was revealed also in this year of contradictory water supply situation (31 %=2.405 t ha^{-1}). Although fertilization had the largest role (40 %=3.181 t ha^{-1}), the crop rotation effect was only slightly weaker (29 %=2.250 t ha^{-1}).

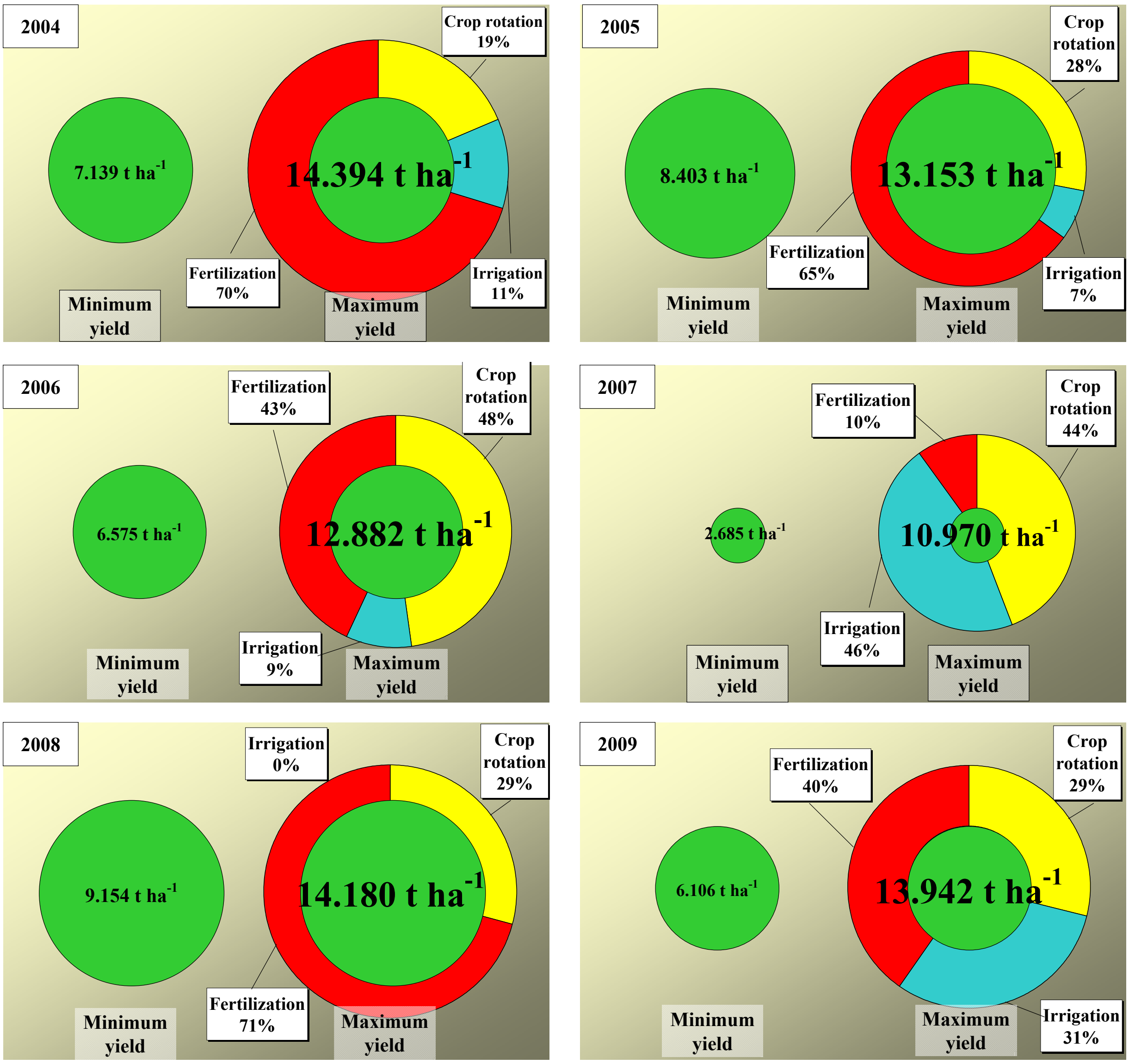


Figure 7. **Analysis of the impact of the different factors on the yield per year by partitioning the variance components**
(Debrecen-Látókép, 2004-2009)

5. NEW SCIENTIFIC RESULTS

1. The absolute (2.2-4.9 t ha^{-1}) and relative (33-71 %) yield increments due to increasing fertilizer dosages were the highest in monoculture both under irrigated and non-irrigated conditions. A considerably lower fertilizer response could be observed in bi- and triculture.
2. For professional irrigation, the water supply conditions of the cropyear should be known. The effect of irrigation is significantly influenced by the growing method. The largest irrigation effect was obtained in a dry year in monoculture (5.9 t ha^{-1} and 222 % yield increment).
3. The agroecological fertilizer optimum interval increased in monoculture as a result of irrigation. A moderate reduction was observed in bi- and triculture.
4. Results of the long-term experiments prove that the fertilizer response is determined mainly by crop rotation, while the irrigation effect is determined primarily by the year.
5. Irrigation had a strong impact on the correlation between fertilization and the amount of yield, especially in dry years (r=-0.2354 in the non-irrigated treatment, r=0.7944 in the irrigated treatment in 2007).
6. Weather conditions have direct and indirect effects on maize yield. The strongest positive correlation was found between precipitation in June-July and yield. Based on the Pearson's correlation analysis, a negative correlation was found between maize yield and the temperature values of the vegetation period.
7. The long-term experiments proved the input-increasing effect and the negative effect of monoculture on maize yield. In the studied period, the role of fertilization, crop rotation, year and irrigation in determining the maize yield was 38 %, 28 %, 19 % and 15 %, respectively, according to the partitioning of the variance components. The yield of the control (6.7 t ha^{-1}) could almost be doubled (13.0 t ha^{-1}) by the optimization of the agrotechnical factors.

6. PRACTICAL APPLICABILITY OF THE SCIENTIFIC RESULTS

1. Crop rotation is an essential agrotechnical factor in the practice. The maximum yields of maize taken as an average of the six years were 9.2-10.3 t ha^{-1} in monoculture, 11.1-12.0 t ha^{-1} in biculture and 11.0-11.9 t ha^{-1} in triculture (non-irrigated, irrigated). By applying a proper crop rotation, the use of inputs can be moderated.
2. The agroecological fertilizer optimum of maize on chernozem soil under non-irrigated conditions was $N_{150}P_{120}K_{120}$ in monoculture, $N_{140}P_{100}K_{100}$ in biculture and $N_{130}P_{100}K_{100}$ in triculture. Irrigation had modified the fertilizer optimum ($N_{180}P_{140}K_{140}$, $N_{130}P_{100}K_{100}$, $N_{140}P_{110}K_{110}$).
3. The results of the experiment have proven the unfavourable effect of monoculture maize production. The yield-increasing effect of irrigation and fertilization was considerably higher in monoculture, applied because of the pressure of the circumstances, than in bi- and triculture.
4. Maize is an ecologically sensitive crop, precipitation and temperature have a significant influence on the amount of yield. In dry years, the average yield of the fertilization treatments and crop rotation models was 5.7 t ha^{-1} without irrigation, while it increased to 9.0 t ha^{-1} under irrigated conditions. The average of the different crop rotation models was 12.9 t ha^{-1} in a year with favourable water supply.
5. By applying an intensive technology (optimum crop rotation, fertilization, irrigation), a high level of maize yield (11-14 t ha^{-1}) can be sustained on chernozem soil. A lower than optimal level of any agrotechnical element can result in a significant yield reduction, the degree of which can be greatly influenced by the given year.

List of the major publications relevant to the topic of the dissertation

<u>Scientific papers in foreign, peer-reviewed journals in foreign language:</u>

1. PEPÓ, P. - ZSOMBIK, L. - **VAD, A.** - BERÉNYI, S. - DÓKA, L. (2007): Agroecological and management factors with impact on the yield and yield stability of maize (*Zea mays* L.) in different crop rotation. Analele Universitatii Oradea, Facultatea de Pretectia Mediului. XIII. 181-187.

<u>Scientific papers in Hungarian peer-reviewed journals in foreign language:</u>

1. PEPÓ, P. - **VAD, A. -** BERÉNYI, S. (2006): Effect of some agrotechnical elements ont he yield of maize on chernozem soil. Cereal Research Communications. 34. 1. 621-624.
2. BERÉNYI, S. - **VAD, A. -** DÓKA, L. - PEPÓ, P. (2007): Effects of fertilization and cropyears on maize (Zea mays L.) yields in different crop rotations. Cereal Research Communications. 35. 2. 241-244.
3. **VAD, A.** - ZSOMBIK, L. - SZABÓ, A - PEPÓ, P. (2007): Critical crop management factors in sustainable maize (*Zea mays* L.) production. Cereal Research Communications. 35. 2. 1253-1256.
4. PEPÓ, P. - **VAD, A.** - BERÉNYI, S (2008): Effects of irrigation on yields of maiza (Zea mays L.) in different crop rotations. Cereal Research Communications. 36. 3. 735-738.
5. **VAD, A. -** DÓKA, L. (2009): Cropyear as abiotics stress effect on the yields of maize (Zea mays L.) in different crop rotations. Cereal Research Communications. 37. 253-256.

<u>Scientific papers in peer-reviewed journals in Hungarian:</u>

1. PEPÓ P. - **VAD A.** - BERÉNYI S. (2005): Agrotechnikai tényezők hatása a kukorica termésére monokultúrás termesztésben. Növénytermelés. 54. 4, 317-326.
2. PEPÓ P. - DÓKA L. - BERÉNYI S. - **VAD A.** (2008): Az öntözés hatása a kukorica (*Zea mays* L.) termésére száraz évjáratban csernozjom talajon. Növénytermelés. 57. 2. 171-180.

Scientific papers in Hungarian non-reviewed journals:

1. PEPÓ P. - **VAD A.** -BERÉNYI S. (2006): Néhány agrotechnikai tényező hatása a kukorica termésmennyiségére. Gyakorlati Agrofórum. Extra 13.. 33-35.
2. PEPÓ P. - ZSOMBIK L. - **VAD A.** - BERÉNYI S. (2007): A kritikus agrotechnikai tényezők elemzése a kukoricatermesztésben. Agrofórum Extra 17.. 5-6.

Conference proceedings in foreign language:

1. PEPÓ, P. - ZSOMBIK, L. - SZABÓ, A. - **VAD, A.** - HORNOK, M. - BALOGH Á. (2006): New agronomic management models in wheat (Triticum aestivum L.) production. The 4th International Symposium „Natural Resources and Sustainable Development”. Oradea, 33-40.

Conference proceedings in Hungarian:

1. **VAD A. -** BERÉNYI S. - PEPÓ P. (2005): A trágyázás, öntözés és tőszám vizsgálata monokultúrás kukorica termesztésben. XI. ITF. Keszthely. 14.
2. **VAD A.** - PEPÓ P. (2009): Agrotechnikai tényezők hatása a kukorica termésére és termésbiztonságára. V. Növénytermesztési Tudományos Nap. Növénytermesztés: Gazdálkodás-Klímaváltozás-Társadalom, Keszthely. Akadémiai Kiadó, 245-248.

Publications not directly related to the research topic

Scientific papers in Hungarian non-reviewed journals:

1. PEPÓ P. - ZSOMBIK L. - **VAD A.** -SZABÓ A. (2005): Újabb adatok a kukorica hibridspecifikus gyomirtási technológiájához. Gyakorlati Agrofórum. Extra 12. 35-37.