University Doctoral (PhD) Dissertation Theses

THE EFFECTS OF WEATHER STRESS FACTORS AND APPLIED AGROTECHNIQUE ON MAIZE YIELD

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1. INTRODUCTION

The number of world population will exceed 9 billion by 2050, and in order to cover its demand, food production shall be doubled (OECD and FAO 2011). The highest growth in population may be expected in Asia and Africa, nearly 86% of the world population will live in these areas in 2050, whereas in Europe the number of population will decrease (ENSZ 2011).

The cultivation area per capita value worldwide was 0.44 hectare in 1961, which is expected to be 0.15 hectare by 2050. This means agriculture has the task to produce the yearly food demand of a person in a decreasing area. Therefore agriculture is facing a huge task as the present 1.2% yearly increase in corn production is considerably less than the 1.5% growth in population (Heszky 2009).

Cultivation of plants worldwide happens in an arable land area of 1,400 million hectares, out of this maize is grown on 176 million hectares.

Maize originates from the present South Brasilia, North Eastern Brasilia and Paraguay Geisler (1980), Galinat (1979) and other researchers consider Mexico its primary gene centre as an 80,000-year-old maize pollen was found in Mexico City during excavations. Its growth started in Peru and Mexico, then it became widespread in Central America, South America, and finally it appeared in North America as well. It arrived in Europe in 1493 through Columbus, and it get into Hungary from Italy through Dalmatia, and from Turkey through Transylvania, the earliest written notes about its growth are from 1590. Aborigines named it "mahiz", the word "mays" originates therefrom, and Linné used the latter one for the name of the maize species whereas he gave the name "Zea" to the genus, this comes from the Greek word "zooin" (to live).

Maize (*Zea mays* L.) is the most important corn plant in the world in addition to wheat and rice. It is grown in almost all parts of the world (in nearly 200 countries). The maize production of the world was 872 tons in 2012, contrary to the 670 million tons of wheat and 719 million tons of rice (FAOSTAT 2012). The USA is far the greatest producer with 273 million tons, and it is followed by China (208 million tons), Brasilia (71 million tons), Argentina and India (21–21 million tons). France is in the 15th place (15 million tons), whereas in this year Hungary lost the distinguished 13th place of the previous years and did not get into the group of the 20 greatest producers.

Approximately 100–110 million tons of maize is exported yearly. The greatest exporter of the world is the United States, in 2011 it gave 42% of the export. It was followed by Argentina with 14.4% and Brasilia with 8.7%. Other significant exporters are Ukraine (7.1%), France (5.6%), and India (3.6%). Hungary was the second greatest exporter of Europe (and the seventh most important exporter of the world) (3.3%) in 2011. In comparison to the year 2010, America decreased its export by 11%, whereas Europe increased it by 29.7%, Asia by 45.7% and Africa by 120% in 2011 (FAOSTAT 2011).

Out of the countries in the EU, France is in the first place with 6.2 million tons. The second greatest exporter is Hungary with 3.6 million tons, and it is followed by Romania (2.3 million tons), Bulgaria (0.93), Austria (0.36), and the Czech Republic (0.33).

The maize export of the world exceeded 100 million tons in 2007, 2010 and 2011 as well. In 2011 the continent Asia was an outstanding importer as it accounted for almost the 50% of the total import worldwide (108 million tons). Within this Japan is a dominant importer (15 million tons) although its import decreased by 5.6% compared to 2010. The second greatest receiving country is Mexico (9.5 million tons) and South Korea is in the third place (7.8 million tons). Egypt also belongs to the greatest purchasers with its 7.0 million tons. The EU also supplemented its demand with maize imported from a third country. In this year 4.8 million tons of maize arrived in Spain, whereas the Netherlands accepted 3.5, Italy 2.7, and Germany 1.9 million tons of maize among others (FAOSTAT 2011).

World trade has significantly changed in the recent years, for example China became an importing country instead of an exporting country, the importing regions of the ex-soviet member countries became exporting ones, and the EU formed an internal market to itself.

A considerable part, 90% of maize is used for animal forage, food, whereas the remaining 10% is used as bio fuel and other substances.

Out of corn grains, maize is the most valuable forage, and it has the highest energy content due to the high (60–70%) starch content. Its raw protein content is low (7–9%), which mainly consists of zein, its oil content is 3–5%. Its raw fat content in the germ part is 4–5%, whose nearly 50% is linoleic acid of high biological value. Further internal content of the maize is: sugar 1.4%, pentozanes 6.0%, raw fibre 2.0%, minerals 1.2%.

In developing countries (94 countries) maize is consumed as direct food more often as together with the rice and wheat it provides 30% of the calorie intake. According to forecasts, due to the vital role of maize in nutrition, the demand for it in the developing countries will really doubled by 2050.

The versatile nature of maize is evidenced by the fact that several products are made from it such as maize oil, snack foods and morning cereals, grits, flour, maize starch, maize syrup due to its high fructose content (which sweetens bread, muesli, muesli bars, chocolate, etc.), dextrose (pharmaceutical industry), maize gluten (animal forage). Furthermore it is used in distilling industry (for beer type drinks, vodka types and whisky), in ethanol industry, and for the preparation of plastics, paper and textiles.

2. RAISING THE TOPIC

The population of Hungary in 2011 was 9 million 982 thousand persons, which was by 2.1% less than it was at the time of the national census in 2001. The population of the country has been decreasing since 1981, and the extent of decrease showed a varying tendency during this period. The population of the country is expected to be 9 million 200 thousand by 2050 (Hungarian Central Statistical Office (KSH) 1970–2011).

Climate factors and extreme weather phenomena considerably affect the yield of the cultivation of plants in Hungary as well, compared to the past 100 years temperature has increased by 1°C, and a further 2.6°C increase is expected by 2050. The quantity of precipitation considerably decreased, from yearly 640 mm to 560 mm, furthermore its temporal distribution is uneven as well. Temperature change will affect the Great Hungarian Plain (Alföld) to the greatest extent (Láng et al. 2007).

The arable land area of Hungary has decreased by 500,000 hectares in the past 15 years. Agriculture has to provide the production for the increase in food demand caused by the improving life standard on an ever-decreasing area (Heszky 2009).

Maize is the arable land culture that has been grown in the greatest area for years in Hungary. Its sowing area is stable, between 2000 and 2012 it was 1.181 million hectares on average, with extremities represented by the droughty year 2007 (1.079 million hectares) and the year 2001 (1.258 million hectares). In the same period, the average quantity of the harvested maize was 6.873 million tons, with the following extreme years: 2005 (9.050 million tons) and 2007 (4.027 million tons). In 2007, 3.7 t ha^{-1} was one of the weakest national average yield. Due to the favourable weather, in 2008 the average yield per hectare (7.4 t ha^{-1}) doubled. In 2012, again a very little quantity, only 4.763 million tons of crop was harvested into the warehouses from the 1.191 million hectares of the maize growing area. By analysing the maize production of Hungary between 1981 and 2012, it can be assessed that the national average yield of 5.6 t ha^{-1} in this period was exceeded in 20 years, however, in 12 years the values were well below the average.

In my doctoral (PhD) dissertation I summarized my research work carried out at the Látókép Experimental Site of the University of Debrecen in chernozem with lime coating in the complex soil cultivation experiment founded by János Nagy university professor in 1989, as well as my research work done between 2007 and 2012 in the flood meadow soil formed on the alluvial cone of Sebes-Körös in Nagykereki belonging to the Bihari plane small region.

The aim of the thesis was to analyse the correlation system of the weather changes and maize growth according to the following aspects:

- the effects of the different environment factors on the maize yield,
- the disclosure of the effects of soil cultivation, sowing date, fertilization, number of plants, and irrigation exercised on yield,
- the analysis of the interaction between soil temperature and sowing date,
- the analysis of the role of sowing date to influence grain moisture,
- the evaluation of sowing date as a factor to modify starch content,
- the complex analysis of the factors and the quantification of their interactions.

3. MATERIAL AND METHOD

3.1. The complex long-term soil cultivation experiment in Debrecen

We carried out the tests at the Látókép Experimental Site of the Centre for Agricultural Sciences of the University of Debrecen in medium-hard chernozem with lime coating in the period between 2002 and 2006.

The long-term experiment is of a split-split-plot arrangement, the main plots include the soil cultivation and irrigation variations without repetition. The primary sub-plots include maize hybrids in a stem number of 30-50-70-90 thousand, whereas the secondary sub-plots include randomized fertilization treatment in four repetitions. One soil cultivation block of the experiment is 8064 m^2. The size of a main plot set with one hybrid is 2688 m^2, each plot of fertilization treatment is 336 m^2 in four repetitions (*Figure 1*).

Figure 1 Multifactorial long-term experiment, Debrecen
(soil cultivation x fertilization x irrigation x number of plants x genotype)

(Source: Dobos 2006)

The subjects of analysis in my thesis are the effects exercised on the yield by the two variations of soil cultivation, the three treatments of fertilization, and the treatments with and without irrigation of two hybrids with different genotypes and growing seasons, as well as of two numbers of plants. The experiment included the same genotypes in all five years. In the irrigated main variation we used 100 mm irrigation water in 2002, 85 mm in 2003, 75 mm in 2004, 30 mm in 2005 and 50 mm in 2006. The harvested grain yield is given with 14% moisture content.

The treatments of the experiment:

Soil cultivation variation:

T_1= spring ploughing (23 cm)
T_2= spring shallow cultivation by means of disc tilling (12 cm)

Fertilization treatment:

1. N 0 kg ha^{-1} P_2O_5 0 kg ha^{-1} K_2O 0 kg ha^{-1}
2. N 120 kg ha^{-1} P_2O_5 90 kg ha^{-1} K_2O 106 kg ha^{-1}
3. N 240 kg ha^{-1} P_2O_5 180 kg ha^{-1} K_2O 212 kg ha^{-1}

Irrigation variation:

T_1= irrigated
T_2= non-irrigated

Number of plants in the treatment:

1. 50 thousand stem ha^{-1}
2. 70 thousand stem ha^{-1}

FAO treatment:

1. FAO 300
2. FAO 400

The applied agrotechnique: The agrotechnique applied in the experiment was identical in each year. The green crop of the experiment was maize. Following the harvest of the green crop, after the crushing of the stalks, the whole quantity of fertilizer doses was supplied then immediately worked into the soil by means of IH 10770 type heavy disc.

Spring ploughing happened immediately before sowing in a depth of 23 cm, with alternating plough. Seed bed preparation happened with the use of Kongskilde Germinator. In the first two years of the experiment, the maize sown with Wintersteiger suspended plot sowing machine and later with Gaspardo sowing machine at the end of April was closed with ringed cylinder after the sowing.

Spring shallow cultivation by means of disc tilling (12 cm) also happened immediately before sowing by means of disc tilling done three times. Seed bed preparation happened with the use of Kongskilde Germinátor. After sowing ringed cylinder was used.

Weed control method was double spacing cultivation and Titus Plus 383 g/ha postemergent treatment. Harvest happened with Sampo 2010 plot combine harvester.

Soil: The average pHKCl value of the soil is 6.6, the Arany-type compactness number is 39 in the upper 20 cm layer. The total quantity of water-soluble salts is 0.04%. Carbonated lime content in the upper 80 cm of the soil is around 0% (lime deficient), but it is 12% from 100 cm (medium limy). Organic material content is 2.3% in the upper 20 cm layer of the soil, and it does not exceed 1.00% at a depth of 120 cm. Potassium supply of the soil is good, its P-supply is average.

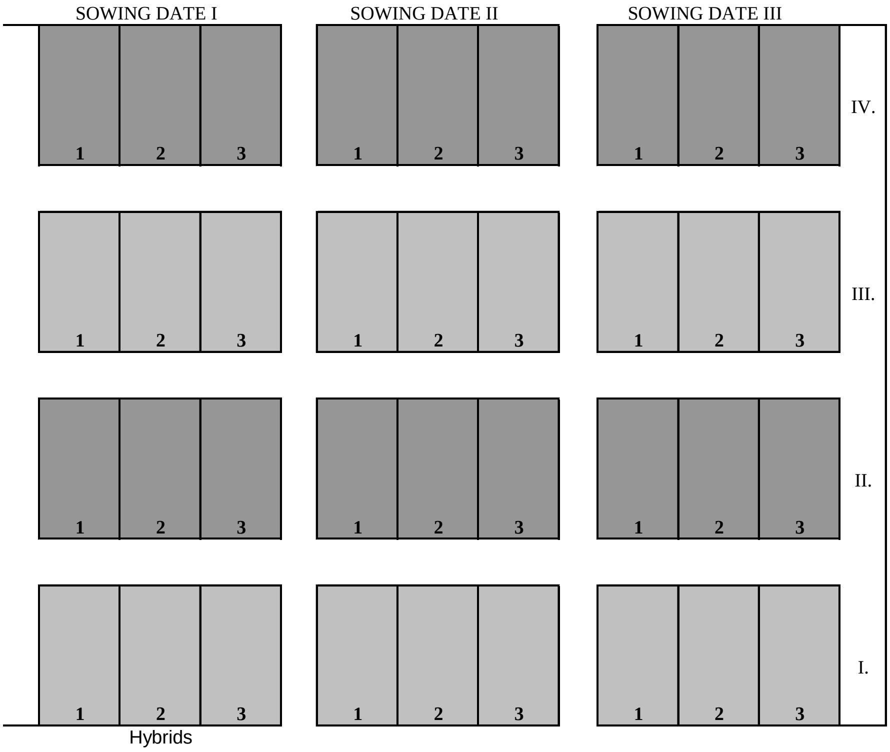
Weather: Weather was evaluated based on the data measured by the automated weather station located in the area of the experiment.

3.2. The sowing date experiment in Nagykereki

The tests were carried out in the flood meadow soil formed on the alluvial cone of Sebes-Körös in Nagykereki belonging to the Bihari plane small region between 2007 and 2012. The position of the area is illustrated in *Figure 2* and the experiment arrangement is shown in *Figure 3*.

Figure 2 The position of the experiment area

Figure 3 The arrangement of the sowing date experiment in Nagykereki



In the farming area the plots of a size of 45 m^2 were formed in a randomized block arrangement, in 4 repetitions. Practically we followed the growing technology applied in the region. The green crop was maize in each year. After stalk crushing 150 kg N ha^{-1}, 65 kg P_2O_4 ha^{-1} and 130 kg K_2O ha^{-1} fertilizer active substance were supplied to the area, and it was worked into by IH6.2 disc. 50% of the 34% ammonium-nitrate quantity was introduced into the soil in autumn, 50% of it was introduced before the seed bed preparation in spring, whereas phosphorus and potassium were introduced in 100% during the autumn basic cultivation. Autumn ploughing was done with Vogel Noot machine in a depth of 30 cm. Seed bed preparation happened immediately before sowing with the use of Omikron 3m combinator. Sowing was done with our own cup feed type drill, and it happened at the early (10 April), optimal (24 April) and late (10 May) dates in a unified manner, each time with a stem number of 70 thousand stems/ha. After sowing Güttler ringed cylinder was used. In the subsequent years different genotypes belonging to three maturity groups (FAO 200, FAO 300 and FAO 400) were involved. In all 6 years of the experiment the same genotypes were involved. Postemergent weed control (Ordax Super) and single spacing cultivation were applied. Harvest happened in the second week of October in each year, with Class Tucano combine harvester then the quantity was weighed. The harvested grain crop was given with a humidity content of 14%.

Soil: It has the mechanical composition of adobe clay, it is flood meadow soil. The average pHKCl value of the cultivated layer is 6.1 (weakly acidic chemical effect), Arany-type compactness value is 40, hygroscopicity is 2.8%. Organic material quantity is between 2–3%, AL-soluble P_2O_5 is 150 mg kg^{-1}, AL-soluble K_2O is 195 mg kg^{-1}. Ground water varies between 3 and 4 m. Its fertility class is 45–60 (int) ground quality category.

Weather: Weather was evaluated based on the data measured by the simple instruments (vapour content measuring device, precipitation measuring device, max-min temperature thermometer) placed in the area of the experiment.

The change in soil temperature was monitored with the help of bimetal soil thermometer, in the upper 10 cm layer of the soil.

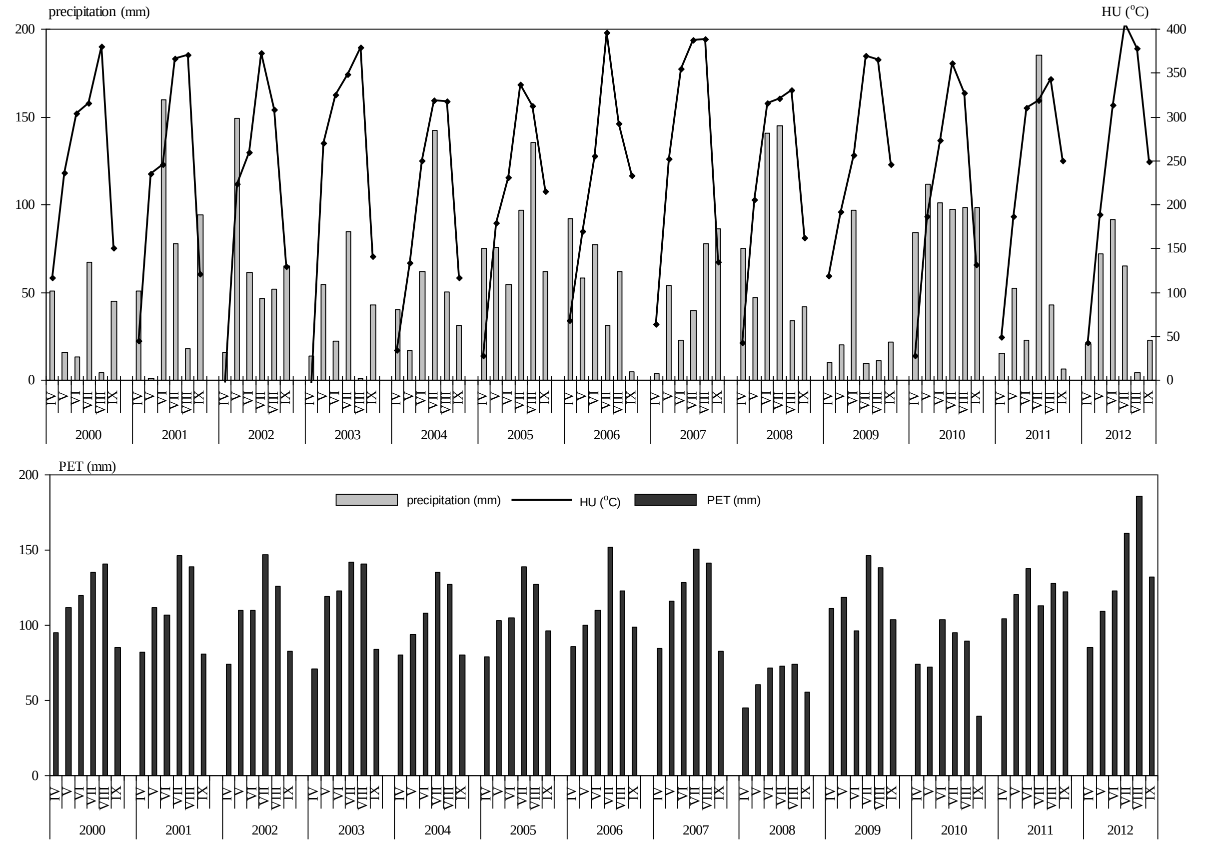
Starch content was assessed by means of close spectroscopy technique, with the Foss Infratec™ 1241 instrument based on transmission measurement principle. This instrument performs the high precision analysis of grain maize within one minute. In the close infrared range of 800–1050 nm the sample is scanned by means of a high resolution monochromator (*Net1*). The instrument was provided by the Institute for Land Utilisation, Technology and Regional Development of the Faculty of Agricultural and Food Sciences of the University of Debrecen.

Statistical evaluation: For the assessment of the effects exercised on the moisture content of the soil, on the moisture content of the grain, on the yield, and on the starch content by the treatments, a general linear model (GLM) was used. For the comparison of treatment mean values, 5% significant difference (SD5%) was determined, as well as homogeneous groups were formed by means of multiple mean values comparison test, with the Duncan method. The yields within the homogeneous group do not differ from one another in the case of a significance level of 5%. For the assessment of the correlation between the independent and dependent variables linear and quadratic regression analysis was made. The evaluation was prepared with the use of the SPSS for Windows 13.0 statistical programme package.

3.3. The evaluation of weather

In the growing season of the year *2002* it was by 0.5°C cooler than in the past 50 years. The effective heat sum (HU) of the vegetation period was 1288°C. Only the precipitation of September (64.9 mm) exceeded the average over many years, in the other months less precipitation fell, by a total of 84 mm. In summary: the growing season was much drier (with 256 mm precipitation), and the potential evapotranspiration (PET) value of this period also exceeded the quantity of precipitation by 394 mm (*Figure 4*).

Figure 4 Trend in precipitation falling in the growing season, effective temperature and potential evapotranspiration
(Debrecen–Nagykereki, 2000–2012)



The growing season of *2003* started with a significant lack of precipitation (–56 mm). The HU-value used by the plant in the growing season was 1439°C, and the yearly PET value was 846 mm. The difference between the precipitation quantity and potential evapotranspiration was –410 mm. The quantity of precipitation falling in the growing season (219 mm) was less than the PET-value of the same period (460 mm).

Year 2004: it was rainier than the average and distribution was favourable as well. The maize used 1181°C in the growing season for the formation of the yield. Yearly potential evapotranspiration was 814 mm, which is by 210 mm more than the quantity of precipitation falling in the concerned year (604 mm). The quantity of precipitation falling in the growing season (343 mm) was exceeded by the PET-value (624 mm).

Year 2005: water supply was optimal in the growing season of the year, 499 mm precipitation fell, which exceeded the 50-year average by 159 mm. Temperature conditions were also around the average, except for the cooler days in the beginning of May and June.

The HU-value used by the plant was 1302^{o}C. The PET-value (649 mm) exceeded by 150 mm the precipitation that fell.

Spring of *2006* was much rainier than the average, especially April (92 mm). The effective heat sum was 1414°C in the growing season. The yearly quantity of precipitation was 522 mm, whereas the PET-value was 866 mm, which meant a difference of –344 mm. The PET-value of the growing season was 670 mm, which is higher than the quantity of precipitation that fell from April to October (326 mm).

The year 2007 had an extreme weather. The effective heat sum of the growing season (1573°C) exceeded tha maximum value needed for the growing of maize. Yearly potential evapotranspiration was 899 mm, out of which 651 mm would have been needed in the growing season for evaporation. The quantity of precipitation value in the vegetation period was by 425 mm exceeded by the PET-value.

The year 2008 was rainier (657 mm) than the average (583 mm). Maize used 1475°C for the formation of the yield. The yearly potential evapotranspiration was 565 mm, which was by 92 mm less than the quantity of precipitation falling in the concerned year. The precipitation of the growing season (488 mm) exceeded the PET-value (380 mm).

In the growing season of the year *2009* there was not sufficient precipitation for maize (161 mm). Also the distribution of precipitation was unfavourable. There was sufficient precipitation in June (92 mm), however, in July and August a total precipitation of 17 mm fell. In this year precipitation was by 171 mm less than the 50-year average. Regarding temperature, the situation was also unfavourable as in July – in the period of the blooming of the maize – it was by 2.6^{o}C warmer than the 50-year average. The temperature measured in August was also above average (by 2.8^{o}C). The HU-value of the growing season was 1547°C, and its PET-value exceeded the quantity of precipitation in this period by 554 mm.

In *2010* the quantity of precipitation in May was nearly twice as much as that of the average over many years (114 mm), June was similarly rainy (103 mm), and the precipitation that fell was by 34 mm more than the 50-year average. The quantity of precipitation was considerable in July, August and September as well. The 595 mm precipitation of the growing season considerably exceeded (+255 mm) the average over many years. Temperature was higher than the 50-year average except for August and September. The plant used 1304^{o}C for its growth. The quantity of precipitation exceeded the PET-value (474 mm) by 121 mm.

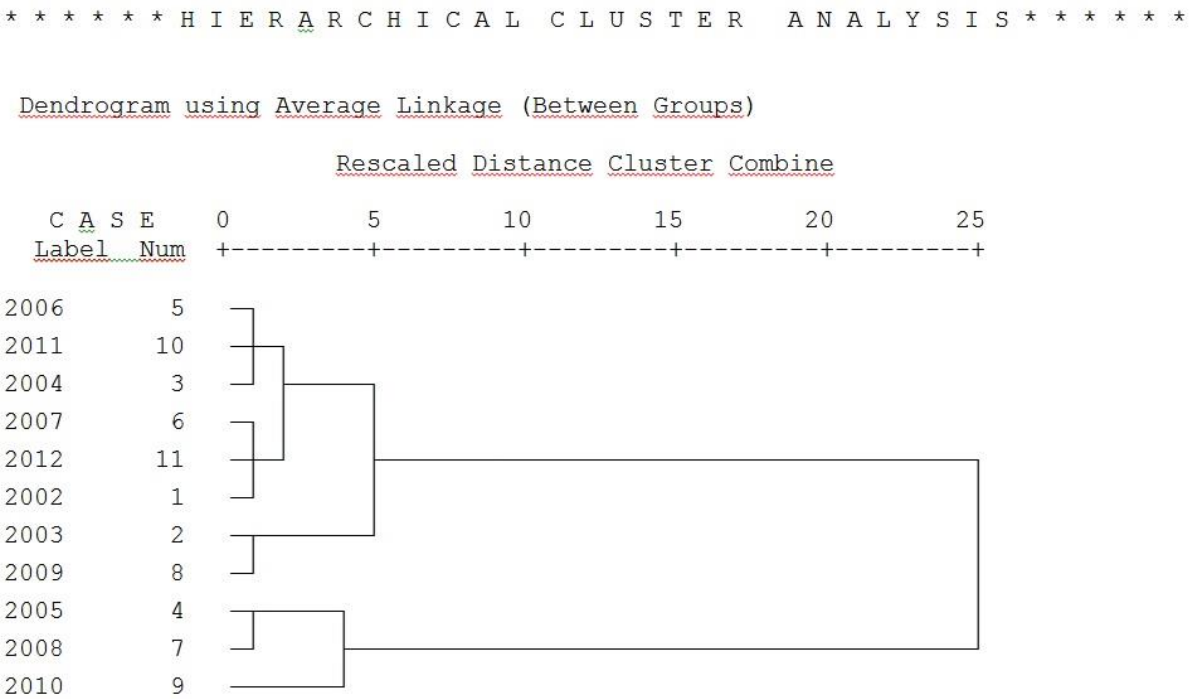
In *2011* 78% of the yearly quantity of precipitation (413 mm) fell in the growing season. In each month of the vegetation period, less precipitation fell, except for July when the precipitation that fell was by 122 mm more than the average over many years. The temperature value was only lower than the 50-year average in the rainy month of July. The HU-value was 1457°C. The PET-value exceeded the quantity of precipitation by 403 mm.

In *2012* the quantity of precipitation that fell in the growing season of the maize was by 23% less than that of the average over many years. It is a positive weather factor that there was precipitation in the period of blooming, however, only 4 mm precipitation fell in the period of grain filling. The temperature of the vegetation period – except for May – was higher than the average over many years. The HU-value was 1576°C. The PET-value was nearly three times as many as the quantity of precipitation (796 mm).

In summary in the growing period 78% of the average evapotranspiration of 11 years (827 mm) was typical, the average quantity of precipitation was 342 mm, and the average potential evapotranspiration was 642 mm.

Homogeneous groups were formed by means of hierarchical cluster analysis based on the precipitation falling in the growing season, and the EH and PET values. Dry, droughty years were 2002, 2007 and 2012, dry years were 2003 and 2009, rainy years were 2005, 2008 and 2010, and the favourable, average years were 2004, 2006 and 2011 (*Figure 5*).

Figure 5 The result of hierarchical cluster analysis
(Debrecen-Nagykereki, 2000–2012)



4. RESULTS

4.1. The evaluation of the effects of plant cultivation factors on the maize yield in the long-term experiment in Debrecen

4.1.1. The evaluation of the effect of soil cultivation by years

The effect of the plant cultivation factor was studied for 5 years (2002–2006). It can be concluded from the assessment of the two-sample T-test of the soil cultivation variation that in the droughty year of 2002 spring ploughing – in the average of the treatments – proved to be more successful by 1490 kg ha^{-1} ($P<0.001$) than spring shallow cultivation. In the also dry year of 2003 it was not possible to harvest a greater crop from the area cultivated by spring shallow cultivation, but this difference of 706 kg ha^{-1} is significant. The crop was the greatest in a favourable crop year (2004), the difference between the two soil cultivation variations was 606 kg ha^{-1} ($P<0.05$). In the extremely rainy year of 2005 and in the average crop year of 2006 the grain crops of the two soil cultivation variations were almost identical (the deviations are 0.272; 0.044 t ha^{-1}), which difference is not significant (*Table 1*).

Table 1 The effects of crop year and soil cultivation variations on the maize yield (Debrecen, 2002–2006)

Soil cultivation	Yield average (t ha^{-1})				
	2002	2003	2004	2005	2006
spring ploughing	5.376***	6.963^{ns}	11.073*	9.553^{ns}	8.057^{ns}
spring shallow cultivation	3.886	7.669	10.467	9.281	8.013

Explanation to symbols: ***P=0.001%, *P=0.05, ns= not significant

The application of spring shallow cultivation was more favourable in FAO 400 hybrids in only two years, in 2002 by 856 kg ha^{-1} ($P<0.05$) and in 2004 by 1051 kg ha^{-1} ($P<0.05$). In the other studied crop years there were no deviations that could be statistically evidenced between the hybrids. In the spring ploughing treatment it was only the year of 2002 when the production of maize hybrids did not show a significant difference. In dry years it was the FAO 300 hybrid yield that was considerably increased by the spring ploughing, in 2003 by 1091 kg ha^{-1} ($P<0.05$) and in 2006 by 1155 kg ha^{-1} ($P<0.001$), however, the greatest yield increase of 1870 kg ha^{-1} ($P<0.001$) occurred in the rainy year of 2005. In a favourable crop year (2004) the application of spring ploughing increased the yield result of FAO 400 hybrid by ($P<0.05$) 997 kg ha^{-1} (*Table 2*).

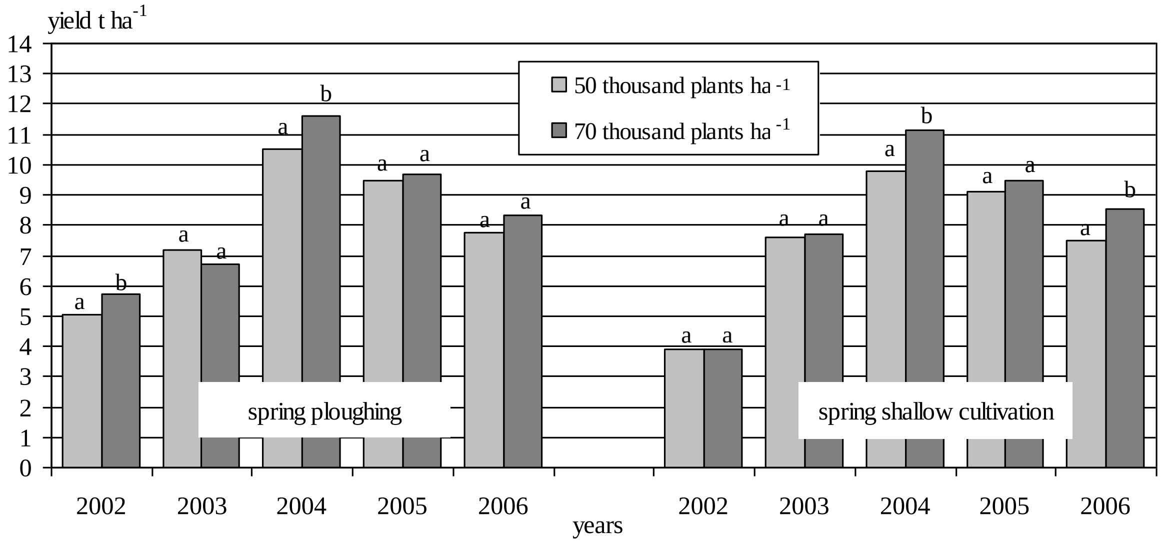
Spring shallow cultivation, in the stock of 70 thousand stems/ha resulted in a greater yield in each studied year, however, it only had a statistically reliable yield increasing effect in 2004 (1336 kg ha^{-1}, P<0.01) and in 2006 (1034 kg ha^{-1}, P<0.01). In the case of spring ploughing as well – except for the year 2003 – the greater yield occurred with the plant stock of 70 thousand, and significant yield increase occurred in 2002 (668 kg ha^{-1}, P<0.05) and in 2004 (1082 kg ha^{-1} P<0.05) (*Figure 6*).

Table 2 The effects of crop year and soil cultivation variations on the yields of maize hybrids with different FAO numbers
(Debrecen, 2002–2006)

Soil cultivation	Hybrid	Yield, t ha^{-1} years 2002	2003	2004	2005	2006	Average
spring shallow cultivation	FAO 300	3.458**	8.032^{ns}	9.942*	9.187^{ns}	8.224^{ns}	7,769
	FAO 400	4.314	7.306	10.993	9.375	7.801	7,958
	average	*3,886*	*7.669*	*10.467*	*9.281*	*8.013*	7.863
spring ploughing	FAO 300	5.485^{ns}	7.508*	10.574*	10.488***	8.635***	8,538
	FAO 400	5.267	6.417	11.571	8.618	7.480	7,871
	average	*5,376*	*6.963*	*11.073*	*9.553*	*8.057*	8.204

Explanation to symbols: ***P=0.001%, **P=0.01%, *P=0.05%, ns= not significant

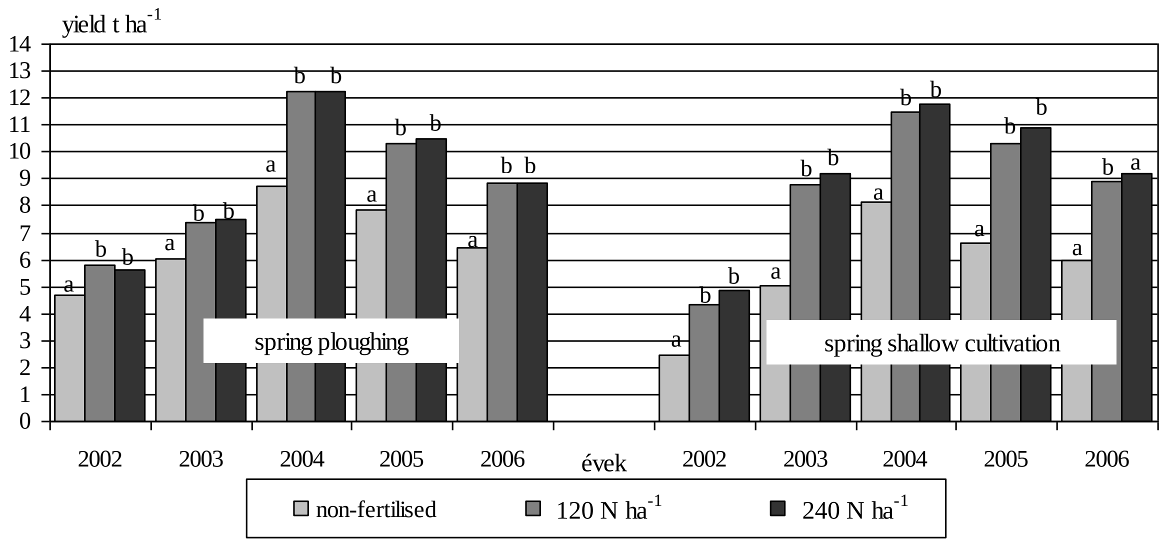
Figure 6 The effects of crop year and soil cultivation variations on the yield in different plant numbers
(Debrecen, 2002–2006)



Explanation to symbols: The data marked by the same letters do not significantly differ from one another based on the Duncan-test

When studying the effect of fertilization it can be assessed that in both soil cultivation variations and in all the 5 studied years there was statistically evidenced difference between the yields of the non-fertilized and fertilized plots. In spring shallow cultivation the average extra yield from fertilization was the highest in the rainy year of 2005 (3.979 t ha^{-1}), whereas it was the lowest in the droughty year of 2002 (2.154 t ha^{-1}). The fertilization treatment with 120 kg N ha^{-1} and at a 0.1% significance level resulted in an extra yield over 3 t ha^{-1} even in three years (2003, 2004 and 2005). The extra yield from fertilization was greater in spring ploughing in a favourable crop year (3.516 t ha^{-1}), and this effect was only 998 kg ha^{-1} in the droughty year of 2002. The fertilizer treatment with 120 kg N ha^{-1} brought a greater extra yield of 3.520 t ha^{-1} (P<0.001) in a favourable crop year (*Figure 7*).

Figure 7 The effects of crop year and soil cultivation variations on the yield in different fertilizer treatments
(Debrecen, 2002–2006)



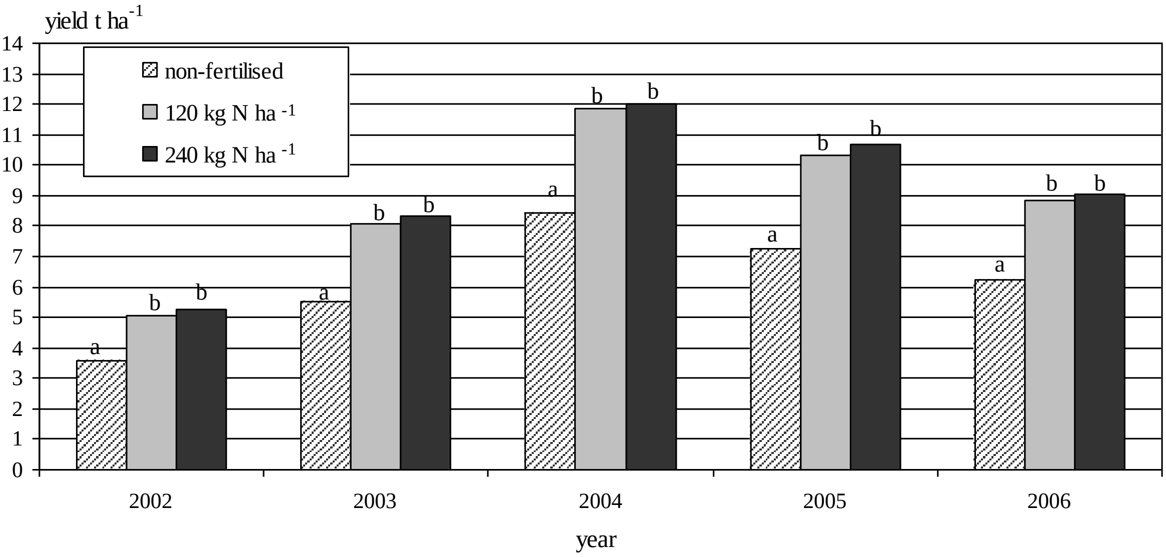
Explanation to symbols: The data marked by the same letters do not significantly differ from one another based on the Duncan-test

4.1.2. The evaluation of the effect of fertilization by years

The greatest yield – in the average of fertilizer treatments – was in a favourable crop year, in 2004 (10.770 t ha^{-1}). The difference between the yields of the non-fertilized and fertilized plots was reliable in each of the studied 5 years (*Figure 8*). The extra yield from fertilization – with a significance of 0.1% – was the greatest in 2004 (3431 kg ha^{-1}) and 2005 (3093 kg ha^{-1}).

Compared to FAO 300 hybrid, the FAO 400 hybrid – except for the favourable crop year – reacted with a yield drop to the non-fertilized treatment, which caused a yield loss of 1803 kg ha^{-1} (P<0.001) in a rainy year (2005). The nutrient demand of hybrids with longer growing season is higher than that of hybrids with shorter growing season. The nutrient mobilization ability of the soil was decreased by the unfavourable weather. The lot of precipitation and the temperature below average made the physiological processes of the maize plant slower. Stress effects increased, quick and intensive development was missing. A two-week phonological delay occurred, which was further increased by the longer growing season. This was accompanied by the fact that the FAO 400 hybrid could be harvested with high grain moisture content. It is highly probable that this significant yield drop may be due to this. A considerable yield drop ($P<0.001$) could be assessed in 2003 as well, when it was 1336 kg ha^{-1}. The treatment with 120 kg N ha^{-1} – in the comparison of hybrids – showed an identical tendency with the results of the non-fertilized plots. Compared to FAO 300 hybrid, the yield of FAO 400 hybrid in a favourable crop year (2004) was significantly ($P<0.001$) higher with 1240 kg ha^{-1}, whereas in an average crop year (2006) it decreased by 768 kg ha^{-1} ($P<0.001$). When using more fertilizer doses (240 kg N ha^{-1}), in a favourable crop year, a crop increase of 10.8% ($P<0.001$) could be reached with FAO 400 hybrid, whereas in the average year of 2006 a yield drop of 13.7% occurred. The difference between non-fertilized and 120 kg N ha^{-1} treatments was significant in the case of FAO 300 hybrid in a favourable crop year (2004) (3.114 t ha^{-1}, $P<0.001$), whereas in the case of FAO 400 hybrid it was significantly steady in two years, in 2004 it was 3.748 t ha^{-1} and in 2005 it was 3.811 t ha^{-1} (*Table 3*).

Figure 8 The effects of crop year and fertilization variations on the maize yield (Debrecen, 2002–2006)



Explanation to symbols: The data marked by the same letters do not significantly differ from one another based on the Duncan-test.

Table 3 The effects of crop year and fertilization treatments on the yields of maize hybrids with different FAO numbers
(Debrecen, 2002–2006)

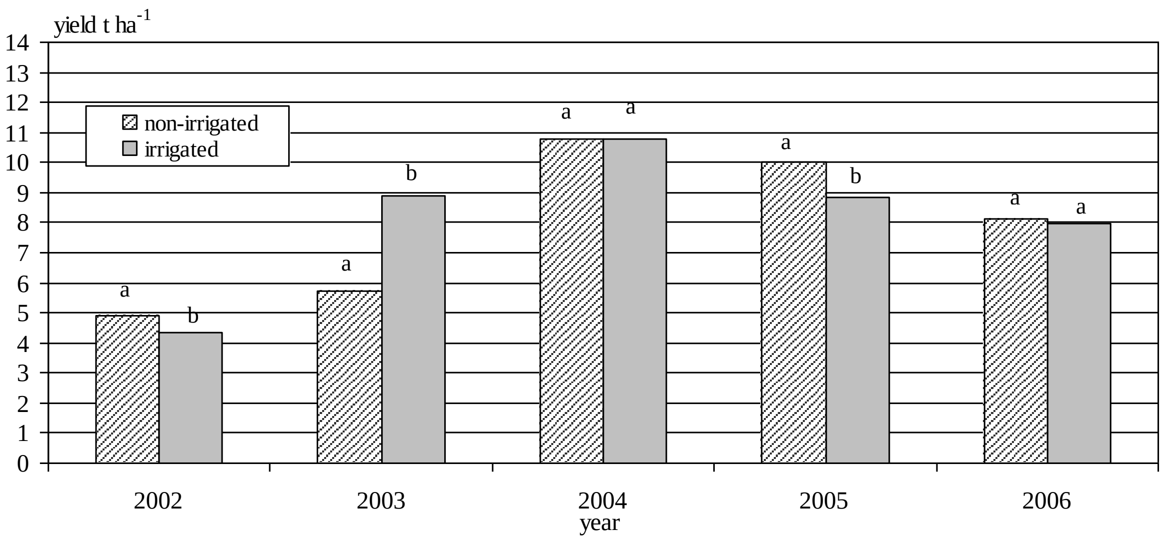
Fertilizer treatment	Hybrid	Yield, t ha^{-1} years 2002	2003	2004	2005	2006	Average
Non-fertilized	FAO 300	3.580^{ns}	6.201***	8.140*	8.136***	6.439^{ns}	6.499
	FAO 400	3.581	4.865	8.746	6.333	5.997	5.904
	average	*3.580*	*5.533*	*8.443*	*7.235*	*6.218*	*6.202*
120 kg N ha^{-1}	FAO 300	4.756^{ns}	8.386^{ns}	11.254***	10.512^{ns}	9.244*	8.83
	FAO 400	5.380	7.768	12.494	10.144	8.476	8.853
	average	*5.068*	*8.077*	*11.874*	*10.328*	*8.860*	*8.841*
240 kg N ha^{-1}	FAO 300	5.079^{ns}	8.724^{ns}	11.380***	10.865^{ns}	9.606***	9.131
	FAO 400	5.410	7.951	12.606	10.513	8.448	8.986

Explanation to symbols: ***P=0.001%, *P=0.05%, ns= not significant

4.1.3. The evaluation of the effect of irrigation by years

In 2002 – in the average of treatments – irrigation did not have a yield increasing effect ($P<0.05$), however, in 2003 it increased the quantity of yield by 3170 kg ha^{-1}. In a favourable crop year (2004) there was no significant difference between the yields of non-irrigated and irrigated treatments, whereas in an extremely rainy year the yield decreasing effect of irrigation was 1148 t ha^{-1}. In 2006 the difference between the two variations is not statistically evidenced (*Figure 9*).

Figure 9 The effects of crop year and irrigation variations on the maize yield
(Debrecen, 2002–2006)



Explanation to symbols: The data marked by the same letters do not significantly differ from one another based on the Duncan-test.

By analysing the two soil cultivation variations implemented in the non-irrigated plots, it may be stated that spring ploughing had a positive effect (1812 kg ha^{-1}, P<0.001) in the droughty year 2002, and it had a negative effect in 2003, when it decreased the yield by 1367 kg ha^{-1} (P<0.001). In the other studied years spring ploughing had a yield increasing effect. Under irrigated conditions spring ploughing significantly increased the yield compared to that of the spring shallow cultivation in 2002 (1169 kg ha^{-1}, P<0.001) and in 2004 (911 kg ha^{-1} P<0.05). In the other four years the difference between the two applied soil cultivation variations showed no reliable deviation.

The application of spring shallow cultivation significantly improved the effect of irrigation in 2003 (2508 kg ha^{-1}, P<0.001). In the rainy year of 2005 it caused a considerable yield drop of 1027 kg ha^{-1} (P<0.05). Spring ploughing did not affect the efficiency of irrigation in the favourable (2004) and average (2006) years. Irrigation had a significant yield increasing effect (3.830 kg ha^{-1} P<0.001) in 2003, whereas in 2002 (876 kg ha^{-1}, P<0.05) and 2005 (1269 kg ha^{-1}, P<0.001) it decreased the yield (*Table 4*).

Table 4 The effects of crop year and irrigation on the yield in the different soil cultivation variations
(Debrecen, 2002–2006)

Irrigation	Soil cultivation	Yield, t ha^{-1} years 2002	2003	2004	2005	2006	Average
non-irrigated	spring shallow cultivation	4.002***	6.415***	10.626^{ns}	9.795^{ns}	7.966^{ns}	7.761
	spring ploughing	5.814	5.048	10.927	10.188	8.264	8.048
	average	*4.908*	*5.731*	*10.777*	*9.991*	*8.115*	*7.904*
irrigated	spring shallow cultivation	3.769***	8.923^{ns}	10.308*	8.768^{ns}	8.059^{ns}	7.965
	spring ploughing	4.938	8.878	11.219	8.919	7.851	8.361
	average	*4.354*	*8.901*	*10.764*	*8.843*	*7.955*	*8.163*

Explanation to symbols: ***P=0.001%, *P=0.05%, ns= not significant

In the non-irrigated variation, the difference between the non-fertilized and fertilized (120 kg N ha^{-1}, 240 kg N ha^{-1}) treatments can be evidenced with a significance of 0.1%. The fertilizer quantity of 120 kg N ha^{-1} increased the yield to the greatest extent (2729 kg ha^{-1}) in a favourable crop year (2004). Its yield increasing effect was above 2 t ha^{-1} in 2005 and 2006. The average extra yield from fertilization proved to be significant (2804 kg ha^{-1}) in 2004. In the irrigated variation the yield increasing effect of the fertilizer treatments with 120 kg N ha^{-1} varied between 1131 and 4135 kg ha^{-1}.

Irrigation exercised its positive effect on the non-fertilized plots in 2003 (1331 kg ha^{-1}, P<0.001), and it decreased the yield (P<0.001) in the favourable, rainy and average years. When using the treatment with 120 kg N ha^{-1}, irrigation exceeded the value measured in the non-irrigated treatment by 3416 kg ha^{-1}. Irrigation did not have a reliable effect in the favourable and average crop years, whereas in the rainy year it decreased the yield by 586 kg ha^{-1} (P<0.05). When using the treatment with 240 kg N ha^{-1}, irrigation exercised its positive effect in 2003 with 4761 kg ha^{-1} (P<0.001), however, in a rainy year (2005) a yield decrease of 678 kg ha^{-1} occurred. In the other studied years, although the yield was greater in the irrigated treatment, but the yield differences measured here did not prove to be significant (*Table 5*).

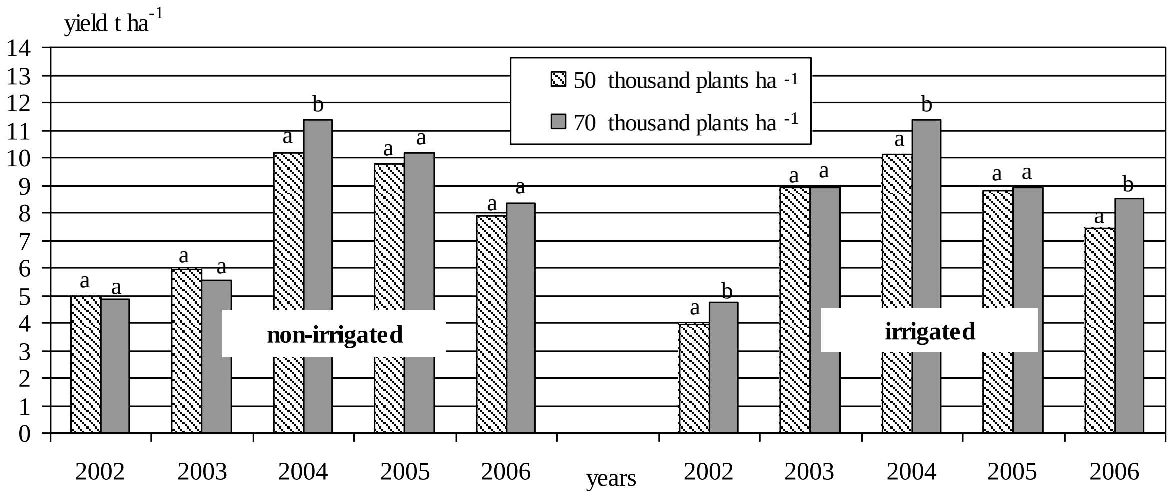
Table 5 The effects of crop year and irrigation on the yield in different fertilizer treatments (Debrecen, 2002–2006)

Irrigations	Fertilizer treatment	Yield, t ha^{-1} years 2002	2003	2004	2005	2006	Average
non-irrigated	non-fertilized	3.920	4.868	8.907	8.325	6.702	6.545
	120 kg N ha^{-1}	5.764	6.369	11.636	10.621	8.756	8.629
	240 kg N ha^{-1}	5.040	5.957	11.786	11.028	8.887	8.540
	average	*4.908*	*5.731*	*10.777*	*9.991*	*8.115*	*7.904*
irrigated	non-fertilized	3.240	6.199	7.978	6.144	5.734	5.859
	120 kg N ha^{-1}	4.372	9.785	12.113	10.035	8.964	9.054
	240 kg N ha^{-1}	5.449	10.718	12.201	10.350	9.166	9.577
	average	*4.354*	*8.901*	*10.764*	*8.843*	*7.955*	*8.163*

The plant number per hectare under the different crop year conditions considerably determined the success and safety of maize growing. In the non-irrigated variation, in two years, in the droughty and dry 2002 and 2003 the stock of 70 thousand stems/ha had lower yield than the stock of 50 thousand stems/ha did. In the other studied years (2004, 2005 and 2006) the use of 70 thousand stems/ha resulted in a decrease of yield, significant effect (1163 kg ha^{-1}, P<0.01) could only be detected in the favourable year of 2004. In the irrigated variation the greater stock of 70 thousand stems/ha gave a greater yield in each studied year. In two years, in the dry 2003 and in the rainy 2005, the increase in the plant number did not result in a significant change in the volume of yield. In the favourable year of 2004 with sufficient rainfall the stock of 70 thousand stems/ha proved to be more favourable by 1255 kg ha^{-1}, which could be also evidenced statistically (P<0.01). The increase in stem number resulted in a considerably greater yield in 2006 (1106 kg ha^{-1}, P<0.01) and in 2002 (801 kg ha^{-1}, P<0.05) too.

Irrigation – excluding 2004 and 2006 – significantly modified the yield result of the stock of 50 thousand stems/ha. Yield increase occurred in 2003 (2965 kg ha^{-1}, $P<0.001$), yield decrease occurred in 2002 (1021 kg ha^{-1}, $P<0.01$) and 2005 (1012 kg ha^{-1}, $P<0.05$). The irrigation exercised its effect with a stock density of 70 thousand stems/ha, and yield results significantly increased in each year, excluding 2002 (*Figure 10*).

Figure 10 The effects of crop year and irrigation on the yield in the variations with different plant numbers
(Debrecen, 2002–2006)

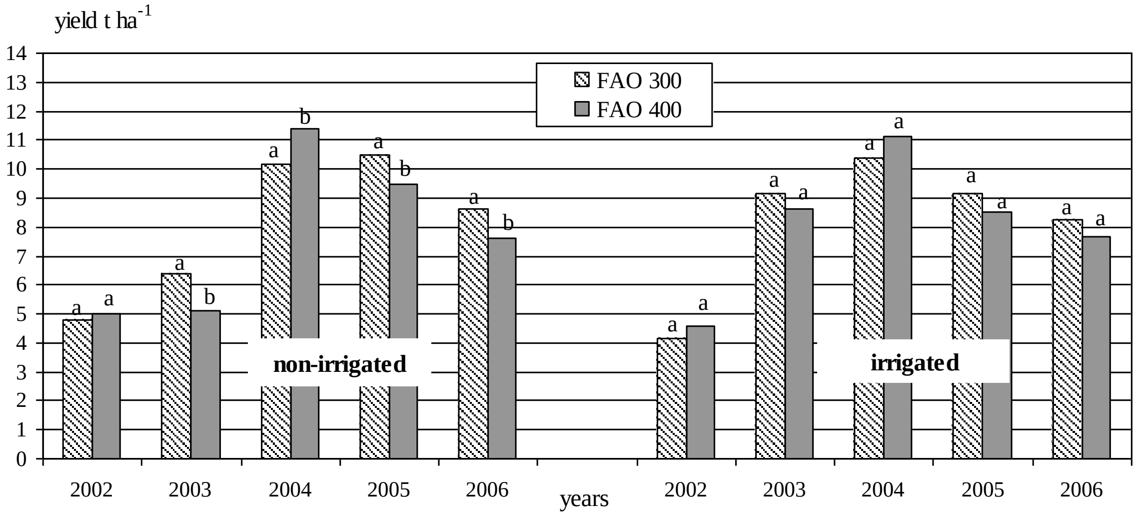


Explanation to symbols: The data marked by the same letters do not significantly differ from one another based on the Duncan-test.

In the non-irrigated variation, compared to the FAO 300, the yield of FAO 400 hybrid was higher in 2 years and lower in 3 years. In the studied years – excluding 2002 – the difference was reliable. In 2003 the yield of FAO 400 hybrid was by 1262 kg ha^{-1} ($P<0.001$), whereas in 2005 by 1032 kg ha^{-1} ($P<0.01$), and in 2006 by 970 kg ha^{-1} ($P<0.001$) lower than the yield of FAO 300 hybrid. In a year with sufficient rainfall (2004) the use of FAO 400 hybrid was more favourable (1271 kg ha^{-1}, $P<0.001$). Under irrigated conditions there was no statistically evidenced difference in the yield volumes of the two hybrids in any of the studied years.

In FAO 300 hybrid of short growing season, irrigation caused an extra yield of 2816 kg ha^{-1} ($P<0.001$) in 2003, whereas in 2005 it resulted in a yield drop of 1032 kg ha^{-1} ($P<0.001$). In FAO 400 hybrid – similarly to FAO 300 hybrid – irrigation had a yield increasing effect in 2003 (3523 kg ha^{-1}, $P<0.001$) and a yield decreasing effect in 2005 (957 kg ha^{-1}, $P<0.05$) (*Figure 11*).

Figure 11 The effects of crop year and irrigation on the yields of maize hybrids with different FAO numbers
(Debrecen, 2002–2006)

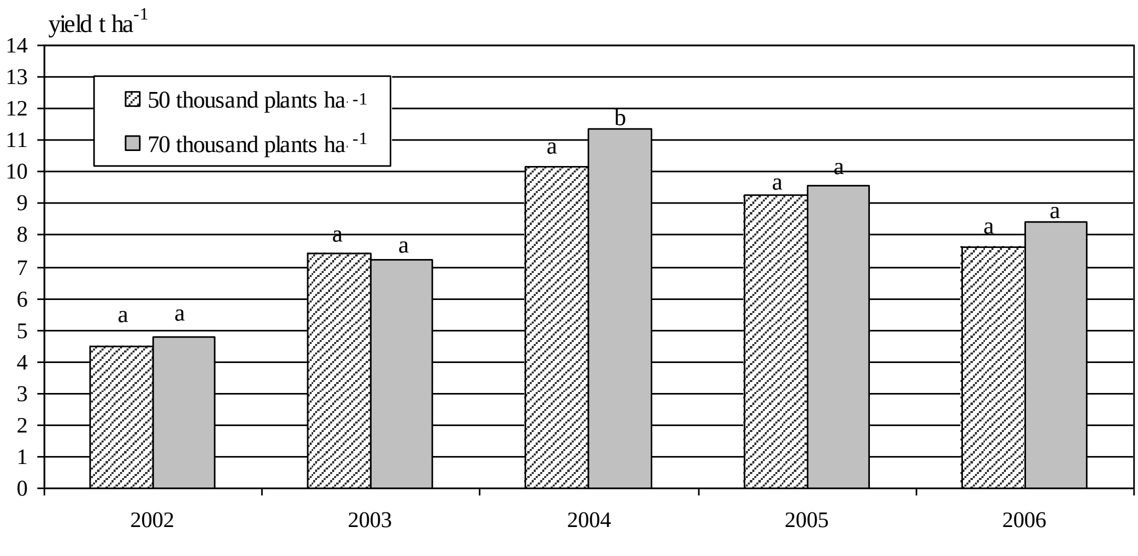


Explanation to symbols: The data marked by the same letters do not significantly differ from one another based on the Duncan-test.

4.1.4. The evaluation of the effect of plant number by years

The plant number of 70 thousand stems/ha – in the average of the other treatments – resulted in a yield increase of 11.9% in the favourable crop year of 2004, and 10.5% in 2006. Yield difference is evidenced in both years with a level of 0.1%. In dry years the deviations between plant numbers were not reliable (*Figure 12*).

Figure 12 The effects of crop year and stem number variations on the maize yield
(Debrecen, 2002–2006)



Explanation to symbols: The data marked by the same letters do not significantly differ from one another based on the Duncan-test.

In the stock of 50 thousand stems/ha, fertilization consistently increased the yield volume in each year. There was no significant difference detected between the two fertilizer treatments (120 and 240 kg ha^{-1}). The deviation between the non-fertilized and 120 kg N ha^{-1} treatments is evidenced at a level of 0.1% – excluding the year 2002 where it is 5% – and it had the greatest yield increasing effect in 2004 (2587 kg ha^{-1}). The average extra yield from fertilization varied between 1285 and 2795 kg ha^{-1}. It can be stated for the use of the 70 thousand stems/ha as well that a significant difference only occurred between the non-fertilized and fertilized treatments. The 120 kg N ha^{-1} treatment proved to be more successful in each year at the level of 0.1% compared to the non-fertilized treatment, and it had the greatest yield increasing effect in 2004 (4277 kg ha^{-1}). Fertilization also had a considerable average yield increasing effect (1868–4404 kg ha^{-1}) as well.

The increase in the plant number resulted in a slight yield decrease in every case in the non-fertilized treatments. In the treatment with 120 kg N ha^{-1}, out of the 5 years, the use of the 70 thousand stems/ha did not bring reliably high yield level in 2 years (2002 and 2003), whereas in 3 years (2004, 2005, and 2006) it did so ($P<0.001$), and it gave the highest extra yield (1683 kg ha^{-1}) with favourable water supply (2004). The treatment with 240 kg N ha^{-1} resulted in a similar maize yield tendency to that of the treatment with 120 kg N ha^{-1}, except for the rainy year of 2005, when growth was not significant. The use of 240 kg N ha^{-1} proved to be the more efficient in 2004, when it resulted in an extra yield of 1951 kg ha^{-1} ($P<0.001$) (*Table 6*).

Table 6 The effects of crop year and plant number on the yield in different fertilizer treatments
(Debrecen, 2002–2006)

Plant number	Fertilizer treatment	Yield, t ha^{-1} years 2002	2003	2004	2005	2006	Average
50 thousand stems ha^{-1}	non-fertilized	3.607	5.885	8.446	7.416	6.235	6.318
	120 kg N ha^{-1}	4.736	8.073	11.033	9.948	8.276	8.413
	240 kg N ha^{-1}	5.047	8.256	11.018	10.475	8.391	8.638
	average	4.463	7.405	10.166	9.280	7.634	7.789
70 thousand stems ha^{-1}	non-fertilized	3.553	5.182	8.439	7.053	6.201	6.086
	120 kg N ha^{-1}	5.400	8.081	12.716	10.708	9.445	9.270
	240 kg N ha^{-1}	5.442	8.419	12.969	10.902	9.663	9.479
	average	4.799	7.227	11.374	9.555	8.436	8.278

4.1.5. The evaluation of the yield results of maize hybrids with different FAO numbers

As a result of the effect of the applied treatments, the yields of the hybrids with different FAO numbers were considerably different from one another except for the year 2002. In a dry year (2003) the FAO 400 hybrid brought by 908 kg ha^{-1} less yield ($P<0.05$) than FAO 300 hybrid. In a favourable year (2004) the opposite of this, 1024 kg ha^{-1} significant ($P<0.001$) yield increase could be observed. In the extremely rainy year 2005, ploughing of the FAO 400 hybrid caused a yield loss of 841 kg ha^{-1} ($P<0.01$), whereas in the average year of 2006 this was 790 kg ha^{-1} ($P<0.001$) (*Table 7*).

Table 7 The effects of crop year and different FAO number on the maize yield (Debrecen, 2002–2006)

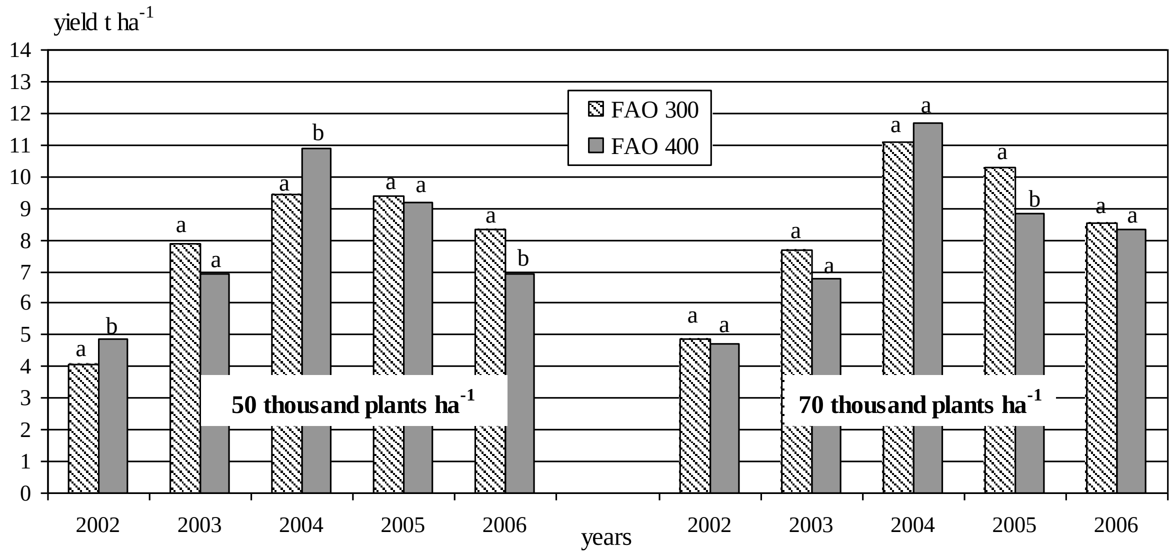
FAO number	Yield average (t ha^{-1})				
	2002	2003	2004	2005	2006
FAO 300	4.471^{ns}	7.770^{*}	10.258^{***}	9.838^{**}	8.430^{***}
FAO 400	4.790	6.862	11.282	8.997	7.640

Explanation to symbols: ***P=0.001%, **P=0.01%, *P=0.05%, ns= not significant

In the stock of 50 thousand stems/ha – in two years, in 2003 and 2005 – the yield result difference of the hybrid with higher FAO number did not prove to be evidenced compared to the FAO 300 hybrid, however, in 2006 (1374 kg ha^{-1}, $P<0.001$) the decrease was obvious. In the plant stock of 70 thousand stems/ha the results of the hybrids with both FAO numbers were similar, except for the extremely rainy year (2005), when the treatment of the 70 thousand stems/ha decreased the yield by 1486 kg ha^{-1} ($P<0.05$).

Based on the evaluation of the research results, the FAO 300 hybrid allowed the increase of stem number in two years, in 2004 (1644 kg ha^{-1}, $P<0.001$) and in 2005 (921 kg ha^{-1}, $P<0.05$). In FAO 400 hybrid, the use of higher stem number was only favourable in one year, in 2006 (1387 kg ha^{-1}, $P<0.001$) (*Figure 13*).

Figure 13 The effects of crop year and stem number variations on the yield of the maize with different FAO numbers
(Debrecen, 2002–2006)



Explanation to symbols: The data marked by the same letters do not significantly differ from one another based on the Duncan-test.

4.1.6. The summarized evaluation of plant cultivation factors

Based on the MQ value of the multifactorial variance analysis, fertilization had a relatively considerable yield modifying effect in three years out of the studied ones (2004, 2005 and 2006), whereas soil cultivation had such an effect in 2002, and irrigation had it in 2003. Each effect is evidenced at a level of 0.1%. Out of the main factors, the plant number in 2002 and 2003, the hybrid in 2002, and irrigation and soil cultivation in 2006 did not show significant difference.

Out of the significant interactions, soil cultivation × hybrid in two years in 2002 ($P<0.01$) and in 2005 ($P<0.001$), fertilization × irrigation in 2003 ($P<0.001$), fertilization × plant number in 2004 ($P<0.001$), and in 2006 plant number × hybrid ($P<0.001$) interaction proved to be stronger (*Table 8*).

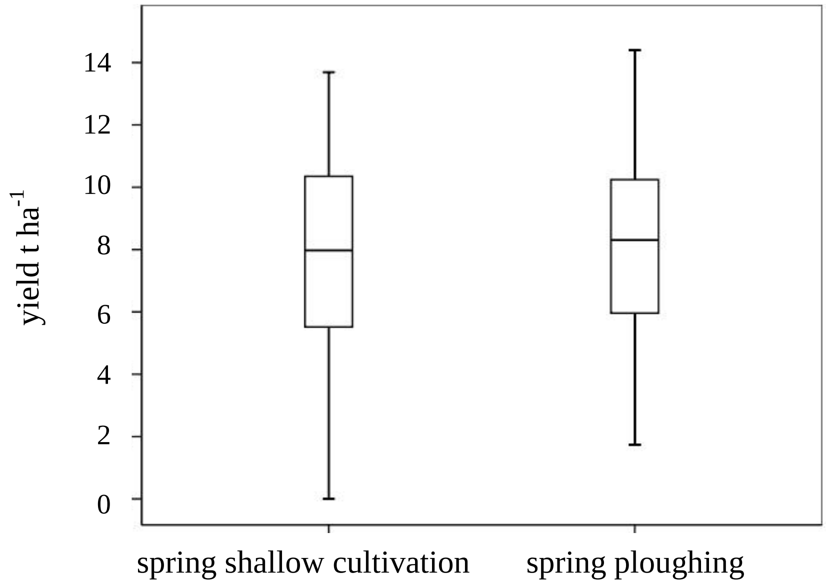
In summary it can be assessed based on the T-test – in the average of treatments – that spring ploughing (8.204 t ha^{-1}) provided the better conditions to the maize, however, the extra yield of 341 kg ha^{-1} did not prove to be a significant difference compared to spring shallow cultivation (7.863 t ha^{-1}) (*Figure 14*). There was also no statistically evidenced difference between the non-irrigated (7.904 t ha^{-1}) and irrigated (8.163 t ha^{-1}) treatments, and between the FAO 300 (8.153 t ha^{-1}) and FAO 400 (7.914 t ha^{-1}) hybrids.

Table 8 Consolidated variance analysis result of maize yield
(Debrecen, 2002–2006)

Factors	2002	2003	2004	2005	2006
	Significance level				
Irrigation (A)	**	***	ns	***	ns
Soil cultivation(B)	***	***	***	*	ns
Plant number (C)	ns	ns	***	*	***
Hybrid (D)	ns	***	***	***	***
Fertilizer (E)	***	***	***	***	***
A × B	ns	***	*	ns	*
A × C	*	ns	ns	ns	**
A × D	ns	ns	*	ns	ns
A × E	***	***	***	***	***
B × C	ns	ns	ns	ns	*
B × D	**	ns	ns	***	***
B × E	**	***	ns	***	*
C × D	*	ns	***	***	***
C × E	ns	ns	***	**	***
D × E	ns	ns	ns	***	*

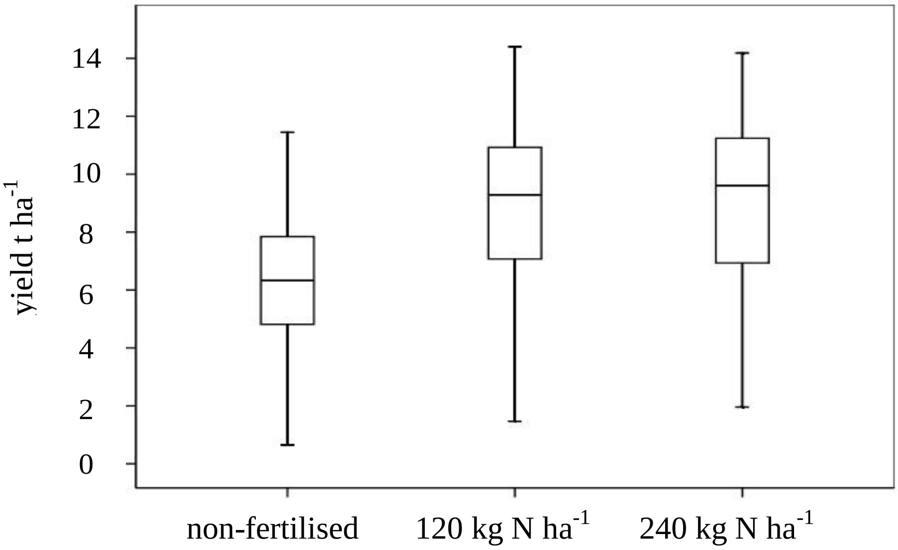
Explanation to symbols: ***P=0.001%, **P=0.01%, *P=0.05%, ns= not significant

Figure 14 The effect of soil cultivation on the maize yield
(Debrecen, 2002–2006)



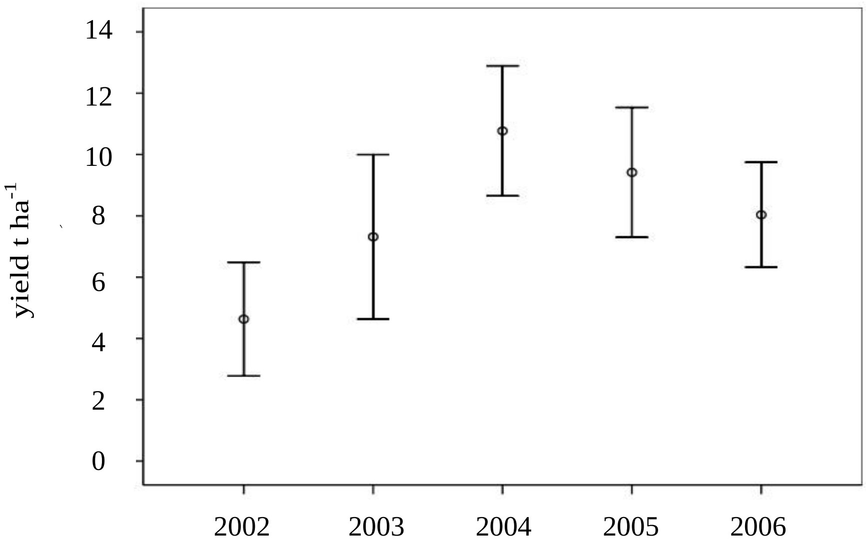
The yield of the stock of 70 thousand stems/ha – at a level of significance of 5% – was by 489 kg ha^{-1} reliably higher than the yield of the 50 thousand stems/ha. Among the fertilization treatments, there was a significant difference between the non-fertilized (6.202 t ha^{-1}) and fertilized treatments. The yield result of the treatment with 240 kg ha^{-1} did not significantly differ from that of the treatment with 120 kg N ha^{-1} (*Figure 15*).

Figure 15 The effect of fertilization on the maize yield (Debrecen, 2002–2006)



When evaluating the yield results of the five years it can be assessed that environment factors exercise a considerable effect ($P<0.05$) on the yield (*Figure 16*). In a favourable crop year (2004) the yield quantity of 10.770 t ha^{-1} exceeded the yield of the dry crop year (2002) by 6139 kg ha^{-1}. A difference of 2685 kg ha^{-1} between yields occurred in even two dry years (e.g. 2002 and 2003). Compared to the favourable crop year (2004), the yield was lower in 2005 by 1354 kg ha^{-1}, and in 2006 by 2735 kg ha^{-1}.

Figure 16 The effect of crop year on the maize yield (Debrecen, 2002–2006)



4.1.7. The evaluation of the correlation analysis of plant cultivation factors

The correlations between the agrotechnical factors (soil cultivation, fertilization, plant number and genotype) and the yield were studied in a non-irrigated and irrigated variation (*Table 9*).

Table 9 Correlation analysis between the agrotechnical factors (soil cultivation, fertilization, plant number and genotype) and the yield quantity by means of regression analysis in a non-irrigated and irrigated variation
(Debrecen, 2002–2006)

Correlation	Non-irrigated					Irrigated				
	2002	2003	2004	2005	2006	2002	2003	2004	2005	2006
Soil cultivation-Yield	0.490^{***}	0.358^{***}	0.077^{ns}	0.111^{ns}	0.103^{ns}	0.322^{***}	0.009^{ns}	0.200^{*}	0.034^{ns}	0.054^{ns}
Fertilization-Yield	0.410^{***}	0.331^{**}	0.680^{***}	0.669^{***}	0.694^{***}	0.496^{***}	0.822^{***}	0.867^{***}	0.845^{***}	0.814^{***}
Plant number-Yield	0.031^{ns}	0.100^{ns}	0.299^{**}	0.115^{ns}	0.173^{ns}	0.221^{*}	0.006^{ns}	0.276^{**}	0.031^{ns}	0.272^{**}
Hybrid-Yield	0.057^{ns}	0.330^{***}	0.327^{***}	0.290^{**}	0.336^{***}	0.117^{ns}	0.117^{ns}	0.171^{ns}	0.143^{ns}	0.157^{ns}

Explanation to symbols: ***P=0.001%, **P=0.01%, *P=0.05%, ns= not significant

In the non-irrigated variation, by studying each year separately, the different methods how each agrotechnical element contributed to the formation of the yield can be quantified. Soil cultivation showed a weak positive correlation in the two dry years (r=0.490***, r=0.358***), whereas in the more favourable years the closeness of the correlation between the two soil cultivation variations and the yield is weaker. This correlation did not change to the effect of irrigation either. Soil cultivation exercised the strongest effect (with 24%), based on the determination coefficient, in the droughty year 2002 in the non-irrigated variation.

Fertilization showed weak correlation in the dry years (r=0.410***, r=0.331**), whereas in the favourable years 2004 and 2006, based on the determination coefficient, it influenced the trend of yield in 46 and 48%, and in the extremely rainy year (2005) it influenced the yield trend in 45%. To the effect of irrigation, the direction of correlation was similar, and its closeness became stronger and stronger every year. The greatest effect of fertilization occurred in 2004 in the irrigated variation (r=0.867***).

The applied plant numbers showed a very weak correlation with the yield in both the non-irrigated and irrigated variation. Out of the years 2004 proved to be relatively favourable, and based on the determination coefficient, it had a yield influencing effect of 8.9% (non-irrigated) and 7.6% (irrigated).

Regarding the FAO number, the weakest correlation occurred in the non-irrigated variation in the droughty 2002 then in the more favourable crop years this correlation became closer. To the effect of irrigation, the genotypes played a less important role.

In summary it can be stated that among the agrotechnical factors, regarding the effect exercised on yield, fertilization showed the closest correlation, which was further increased by irrigation.

4.2. The evaluation of the effect of sowing date in the experiment of Nagykereki

4.2.1. The evaluation of the change in soil temperature

In 2007 at the time of early sowing soil temperature exceeded (15.7°C) the recommended value of 12°C, however, the average temperature of the 12 days preceding sowing (12.7°C) was also higher. High temperatures (16.5, and 14.9°C) were measured on the two further sowing dates as well.

In the year 2008, at the time of sowing and on the days preceding sowing a significantly lower temperature was measured compared to the previous year. The soil temperature measured at the time of early sowing (11.2°C) and the average of the days before sowing (10.6°C) did not reach the minimum temperature of 12.0°C needed for sowing. Soil started to warm up starting from 21 April, and it permanently exceeded the threshold value.

In April 2009 it was by over 4.0°C warmer, consequently the soil became warmed up more quickly. Soil temperature was already optimal at the early sowing date as soil temperature permanently exceeded 12.0°C from 8 April.

In spring 2010 it was rainier than the average, and temperature was also cooler, as a result of this the average of the days before the early sowing (10.0°C) did not reach the temperature of 12.0°C needed for sowing. Soil only became permanently warm above 12.0°C starting from 24 April.

In 2011 soil temperature was 5.6°C at the time of the first sowing, and it did not reach the threshold value of 12.0°C during the next 10 days either. On the sowing date considered optimal, it was 14.5°C, and at the late sowing it was 20.6°C, which contributed to steady shooting.

In 2012 soil temperature did not reach a permanent 12.0°C at the time of either early or optimal sowing. By the time of late sowing soil became properly warm (16.8°C).

When evaluating the variance analysis of the test results, it is obvious that – in the average of the 6 years – the soil temperature at the time of sowing did not have an effect on the yield, however, the soil temperature of the period from sowing to shooting did have a significant effect ($P<0.001$) on the yield.

The regression correlation analysis carried out yearly only showed a close correlation ($r=0.806$) between soil temperature at the time of sowing and yield in 2011, in the other studied years this correlation proved to be weak (*Table 10*). The stress factors that influence the seeds in the period from sowing to shooting (temperature, precipitation, pests in the ground, etc.) are shown in the yield results as well therefore quick and steady shooting is important. Soil temperature showed a direct effect in 2012 ($r=0.638^{***}$) and 2011 ($r=0.787^{***}$) in the studied crop years, in the other cases other factors (e.g. moisture content of the upper layer of the soil, quality of seed bed, depth of sowing etc.) proved to be decisive.

In the early sowing – in the average of the 6 years – soil temperature was 11.7 ^{o}C; in the optimal and late sowing the number of shooting days will decrease as soil temperature increases. In late sowing there was a medium correlation (r=0.503***) between the soil temperature of the period from sowing to shooting and yield, i.e. yield was influenced by soil temperature – based on the determination coefficient – in 25.3%.

Table 10 The regression analysis result of the examination of the correlation between soil temperature (at the time of sowing, during the period from sowing to shooting) and quantity of yield (Nagykereki, 2007–2012)

Correlation	Years					
	2007	2008	2009	2010	2011	2012
Soil temperature at the time of sowing –yield	0.366^{*}	0.022^{ns}	0.290^{ns}	0.272^{ns}	0.806^{***}	0.273^{ns}
Soil temperature during the period from sowing to shooting – yield	0.133^{ns}	0.020^{ns}	0.176^{ns}	0.452^{ns}	0.787^{***}	0.638^{***}

Explanation to symbols: ***P=0.001%, *P=0.05%, ns= not significant

In the hybrids with all the three FAO numbers – in the average of sowing dates – in 2011 there was a close positive, whereas in 2012 in the FAO 200 (r=0.814***), FAO 300 (r=0.821***) hybrids there was a close negative, and in the FAO 400 hybrid there was medium negative (r=0.583*) correlation between the yield and the soil temperature of germination period. In the extremely rainy year (2010) in the FAO 200 (r=0.693*) and FAO 400 (r=0.535*) hybrids there was a medium positive, whereas in the FAO 300 hybrid there was a weak positive correlation. In the other years of the study the ambient soil temperature affecting the seeds had a weak positive effect on the germinating power, except for the results in the years 2007, 2008 and 2009 of the FAO 400 hybrid, where correlation was also weak, however, with a negative sign (*Table 11*).

Table 11 The effect of crop year on the correlation between soil temperature in the period from sowing to shooting and yield quantities of hybrids with different FAO numbers, regression analysis result
(Nagykereki, 2007–2012)

Hybrids	Correlation between the period from sowing to shooting and yield					
	2007	2008	2009	2010	2011	2012
FAO 200	0.174^{ns}	0.135^{ns}	0.258^{ns}	0.693^{*}	0.807^{**}	-0.814^{***}
FAO 300	0.218^{ns}	0.255^{ns}	0.495^{*}	0.111^{ns}	0.893^{***}	-0.821^{***}
FAO 400	-0.465^{ns}	-0.349^{ns}	-0.128^{ns}	0.535^{*}	0.831^{**}	-0.583^{*}

Explanation to symbols: ***P=0.001%, **P=0.01%, *P=0.05%, ns= not significant

The regression analysis prepared in the average of the years showed that a weak positive correlation occurred between the soil temperature in the period from sowing to shooting and the yield of hybrids with relatively short growing season when early sowing is applied, however, its influencing effect in FAO 400 hybrid, based on the determination coefficient, was 46.5%. On the optimal sowing date, the yield average of FAO 300 and FAO 400 hybrids showed a weak correlation with the soil temperature of the period from sowing to shooting, whereas in FAO 200 hybrid it showed a medium close correlation (r=0.520*). In the late sowing – similarly to early sowing – the soil temperature of the period from sowing to shooting had a more decisive effect in the trend of the yield of FAO 400 hybrid (r=0.531**) (*Table 12*).

Table 12 The effect of the different FAO number on the correlation between the soil temperature in the period from sowing to shooting and the yield quantities of different sowing dates, regression analysis result
(Nagykereki, 2007–2012)

Sowing date	Correlation between the period from sowing to shooting and the yield		
	FAO 200	FAO 300	FAO 400
Early	0.129^{ns}	0.153^{ns}	0.682^{***}
Optimal	0.520^{*}	0.147^{ns}	0.430^{*}
Late	0.121^{ns}	0.142^{ns}	0.531^{**}

Explanation to symbols: ***P=0.001%, **P=0.01%, *P=0.05%, ns= not significant

4.2.2. The effect of sowing date on the yield

The two-way variance analysis for the grain crop of the randomized block experiment design was prepared yearly *(Table 13)*. Based on the mean square deviation (MQ) values, out of the factors the sowing date had the most important effect in the years 2010, 2011 and 2012, whereas in the years 2008 and 2009 the effect of sowing date was not statistically evidenced. The difference between the hybrids of 0.1% (2007, 2008, 2012), 1% (2009) and 5% (2010, 2011) proved to be statistically reliable in each year. The hybrid × sowing date correlation could be significantly evidenced in 2007.

In the year 2007 the average yield of the hybrids – with the Duncan-test and a significance level of 5% – was the greatest at the optimal sowing date (6.521 t ha^{-1}). Its grain crop was by 1087 kg ha^{-1} greater than that of the late sowing, and by 840 kg ha^{-1} greater than that of the early sowing. The yield of early sowing was not significantly greater (5.681 t ha^{-1}) than that experienced at late sowing

(5.434 t ha^{-1}). In the years 2008 and 2009 sowing dates did not influence the trend in yield. In 2010 the optimal sowing date proved to be productive (9.251 t ha^{-1}), its extra yield was 1223 kg ha^{-1} compared to the early sowing. There was no significant deviation detected between the optimal and late sowing. In the 2011 crop year the yield result of early sowing was considerably (by 1883 kg ha^{-1}) lower than that of optimal sowing. The yield of optimal sowing was not significantly greater (11.083 t ha^{-1}) than that of late sowing (11.678 t ha^{-1}). In 2012 the hybrids reached their greatest average yield (12.533 t ha^{-1}) with the early sowing date, this resulted in a 17.7% increase in the yield compared to optimal sowing (10,650 t ha^{-1}). The late sowing (10.283 t ha^{-1}) decreased their yields, compared to early sowing yield loss was 21.9%. The decrease between the yields of optimal and late sowing was 3.6%, which is statistically not reliable (*Table 14*).

Table 13 The variance analysis result of the effects of sowing date and hybrid yield, t ha^{-1} (Nagykereki, 2007–2012)

Factors	MQ	DF	F-value
2007			
Sowing date [A]	3.893	2	11.863***
Hybrid [B]	7.957	2	24.245***
A x B	0.969	4	2.953*
2008			
Sowing date [A]	0.015	2	0.041ns
Hybrid [B]	8.271	2	22.411***
A x B	0.357	4	0.967ns
2009			
Sowing date [A]	2.649	2	3.254ns
Hybrid [B]	5.166	2	6.347**
A x B	1.530	4	1.880ns
2010			
Sowing date [A]	6.028	2	5.711**
Hybrid [B]	3.680	2	3.487*
A x B	1.599	4	1.514ns
2011			
Sowing date [A]	60.452	2	40.330***
Hybrid [B]	7.205	2	4.807*
A x B	3,321	4	2,216ns
2012			
Sowing date [A]	17,488	2	23,045***
Hybrid [B]	10,339	2	13,624***
A x B	1,642	4	2,163ns

Explanation to symbols: ***P=0.001%, **P=0.01%, *P=0.05%, ns= not significant

Table 14 The effect of sowing date on the yield, t ha^{-1} (Nagykereki, 2007–2012)

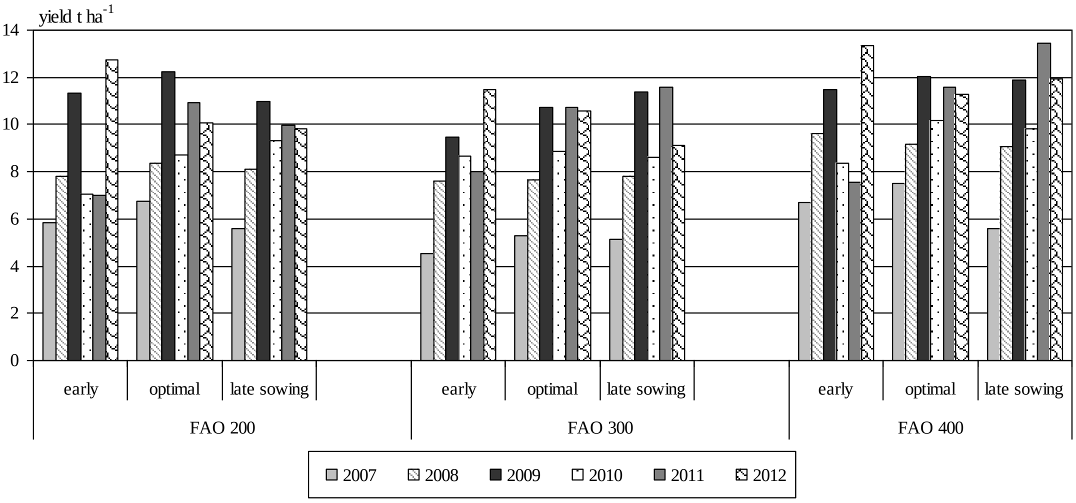
Years	Sowing date		
	early	optimal	late
2007	5.681a	6.521b	5.434a
2008	8.409a	8.392a	8.285a
2009	10.758a	11.667a	11.421a
2010	8.028a	9.251b	9.262b
2011	7.526a	11.083b	11.678b
2012	12.533a	10.650b	10.283b

The data marked by the same letters do not significantly differ from one another based on the Duncan-test

In FAO 200 maize hybrid no statistically quantifiable difference could be detected in three years (2007, 2008, 2009). In 2010 the yield was the lowest in the early sowing (7.075 t ha^{-1}), compared to this in the optimal (8.705 t ha^{-1}), and late (9.318) sowing the yields were greater. With the use of the Duncan test, at a level of significance of 5%, a yield difference of 1630 kg ha^{-1} between the optimal and early sowing, and a difference of 2243 kg ha^{-1} between the early and late sowing could be evidenced. In 2011, compared to the early sowing (7.015 t ha^{-1}), the optimal sowing resulted in an extra yield of 3913 kg ha^{-1}. The yield drop (943 kg ha^{-1}) between the optimal and late (9.985 t ha^{-1}) sowing is a difference that cannot be mathematically evidenced. The most productive yield of the year 2012 can be associated with the early sowing (12.750 t ha^{-1}). In later sowing a decreasing trend occurred, although the extent of decrease between the yields of the optimal (10.075 t ha^{-1}) and late (9.800 t ha^{-1}) sowing is not significant (*Figure 17*).

In FAO 300 hybrid, among the yield results of the three sowing dates there was no detectable difference in the years 2007, 2008 and 2010. In 2009 the highest yield level occurred in the late sowing date with an average yield of 11.400 t ha^{-1}, and at a significance level of 5%, this did not differ from the quantity reached in the optimal (10.738 t ha^{-1}) sowing. The difference between the yields of the early (9.488 t ha^{-1}) and optimal sowing dates was significant. In 2011, compared to the early (8.025 t ha^{-1}) sowing an increasing trend can be observed in the yield results of both sowing dates, however, there was no statistically evidenced increase between the optimal (10.723 t ha^{-1}) and late (11.600 t ha^{-1}) sowing. In 2012, similarly to the FAO 200 hybrid, early (11.500 t ha^{-1}) sowing had the greatest yield, by 925 kg ha^{-1} more than that of optimal sowing, however, this difference cannot be statistically quantified. Late (9.125 t ha^{-1}) sowing involved a definite yield drop compared to the optimal sowing. The FAO 400 hybrid had its greatest yield in 2007 on the optimal (7.498 t ha^{-1}) sowing date, which is significantly higher than the yield of the late (5.583 t ha^{-1}) sowing, however, no difference was evidenced compared to the early (6.675 t ha^{-1}) sowing. No mathematically evidenced difference was detected by the statistical analysis among the yield results of the sowing dates in 2008, 2009 and 2010. In 2011, with the advancement of sowing dates, with an early sowing of 7.538 t ha^{-1}, the yields showed an increasing tendency. The optimal sowing date resulted in a significant yield increase of 4063 kg ha^{-1}, whereas the late sowing resulted in an additional yield increase of 1848 kg ha^{-1}. The difference between the optimal and late sowing is not statistically evidenced. In 2012 the yields had an opposite trend compared to 2011. In this year the yields decreased due to the postponement of sowing. Early sowing resulted in the greatest yield (13.350 t ha^{-1}), the yield of the optimal sowing date was by 2050 kg ha^{-1} lower, and late sowing resulted in further decrease (625 kg ha^{-1}). However, the difference between the yield volumes of the optimal and late sowing is mathematically not evidenced.

Figure 17 The effects of crop year and sowing date on the yields of maize hybrids with different FAO numbers
(Nagykereki, 2007–2012)



The results evidence that sowing date does not significantly modify the yields of maize hybrids in every crop year. In the years when sowing date had a modifying effect, the reliable yield level could be reached on the optimal (24 April) sowing date, except for 2012 when it could be reached in the early sowing.

When studying FAO 200 hybrid, it can be observed that the lower value of yield level is 6.063 t ha^{-1}, and its upper value is 11.513 t ha^{-1}. Yield fluctuation is 5450 kg ha^{-1}. The yield difference is of similar grade in the FAO 300 hybrid as well (lower value: 4.988 t ha^{-1}, upper value: 10.542 t ha^{-1}). The greatest difference between the least and most yields (5607 kg ha^{-1}) occurred in FAO 400 hybrid (*Figure 18*). The result of variance analysis showed that crop year influenced the yield of FAO 300 hybrid to the greatest extent (*Table 15*). Based on the three-way variance analysis it can be stated that in the average of the six years all the three factors (sowing date, hybrid, crop year) reliably ($P<0.001$) influenced the maize yield.

Figure 18 The effect of crop year on the yields of maize hybrids with different FAO numbers (Nagykereki, 2007–2012)

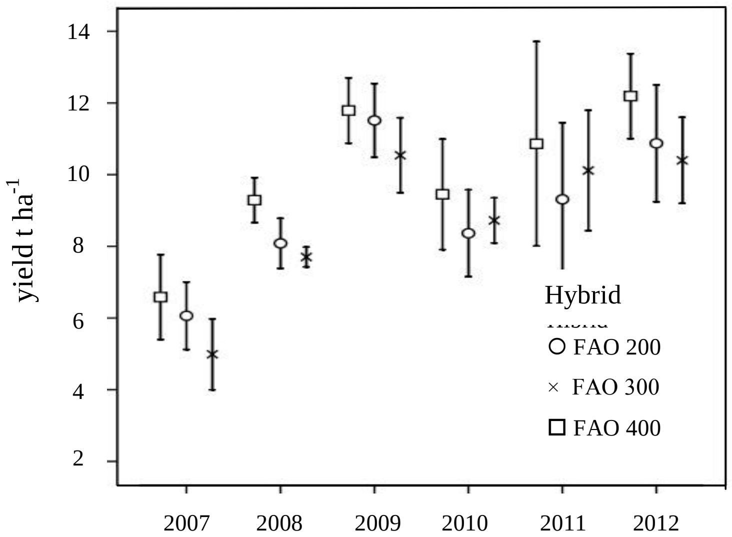


Table 15 The variance analysis result of the effect of crop year and sowing date yield, t ha^{-1} (Nagykereki, 2007–2012)

Factors	MQ	DF	F-value
FAO 200			
Sowing date[A]	4.615	2	4.734*
Year [B]	47.507	5	48.732***
A x B	6.280	10	6.442***
FAO 300			
Sowing date[A]	3.261	2	6.737**
Year [B]	55.270	5	114.176***
A x B	4.129	10	8.529***
FAO 400			
Sowing date[A]	5.032	2	4.914*
Year [B]	50.940	5	49.738***
A x B	8.832	10	8.623***

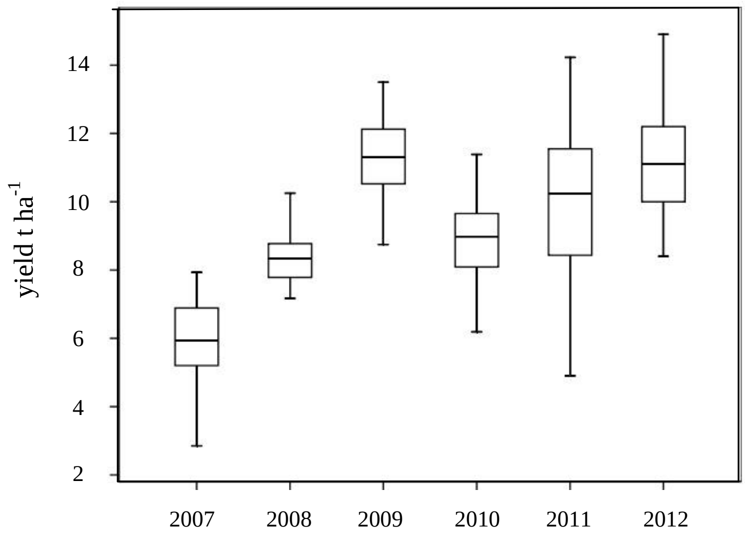
Explanation to symbols: ***P=0.001%, **P=0.01%, *P=0.05%, ns= not significant

Based on the MQ values the effect of the year was the more considerable, which shows that from the aspect of the yield the crop years meant a greater environmental variance than the different sowing dates within the years. The sowing date x year ($P<0.001$) and year ×

hybrid (P<0.05) interactions were significant, whereas the sowing date × hybrid interaction did not influence the studied parameter.

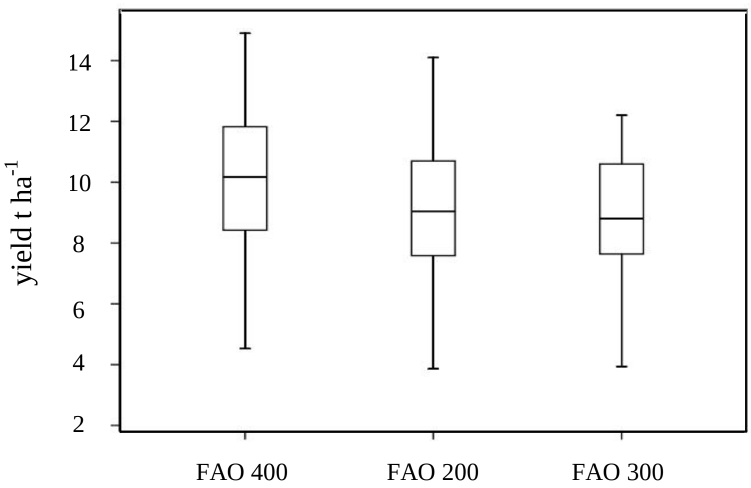
Based on the LSD test, no detectable difference could be evidenced among the yields quantified by crop years in the average of the hybrids and sowing dates between the yields of the years 2008 and 2010, and 2009 and 2012 (*Figure 19*).

Figure 19 The effect of crop year on the maize yield (Nagykereki, 2007–2012)



Based on the results obtained in the six years it can be stated that FAO 400 hybrid provided the reliable yield result (10.028 t ha^{-1}). The only 290 kg ha^{-1} yield difference between the FAO 200 and FAO 300 hybrids is statistically not evidenced (*Figure 20*).

Figure 20 The effect of crop year on the maize yield (Nagykereki, 2007–2012)

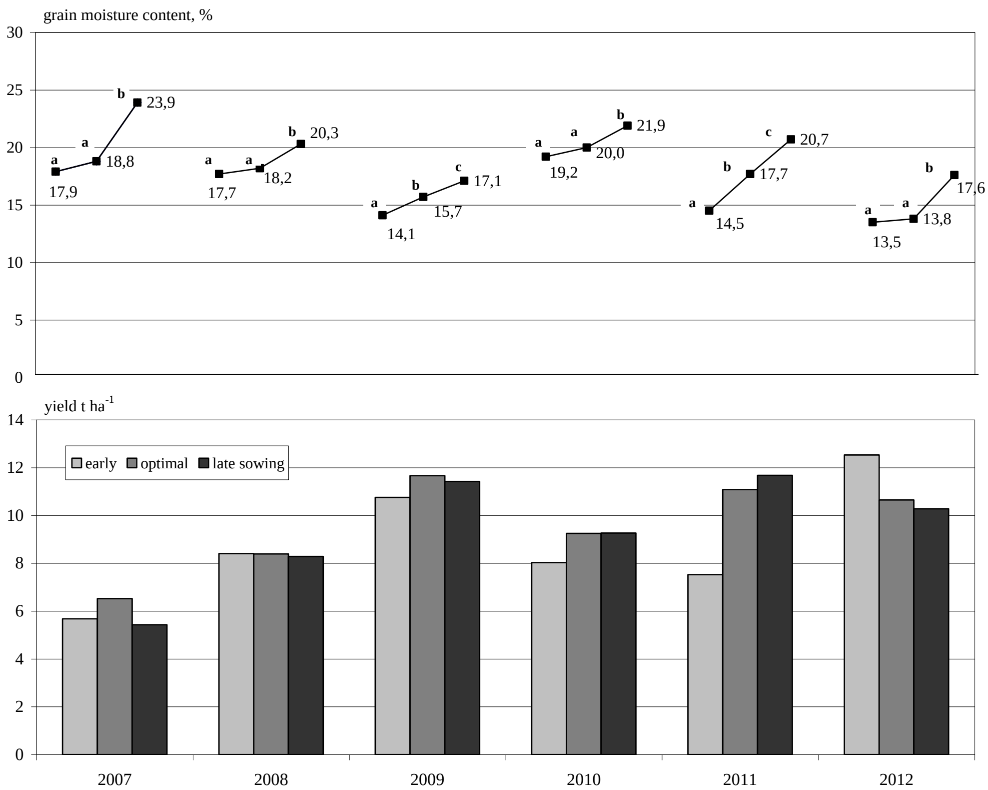


4.2.3. The effect of sowing date on the grain moisture content at the time of harvest

Grain moisture content at the time of harvest was influenced by sowing date in every year, which was statistically evidenced ($P<0.001$). There was no significant difference between the early and optimal sowing dates except for the years 2009 and 2011, where there was an evidenced difference among the grain moisture contents of all the three sowing dates, without a significant difference. Compared to optimal sowing, late sowing caused an increase in the grain moisture content ($P<0.05$). The lower value of grain moisture increase caused by late sowing was 8.7% (2009), its upper value was 27.5% (2012) (*Figure 21*).

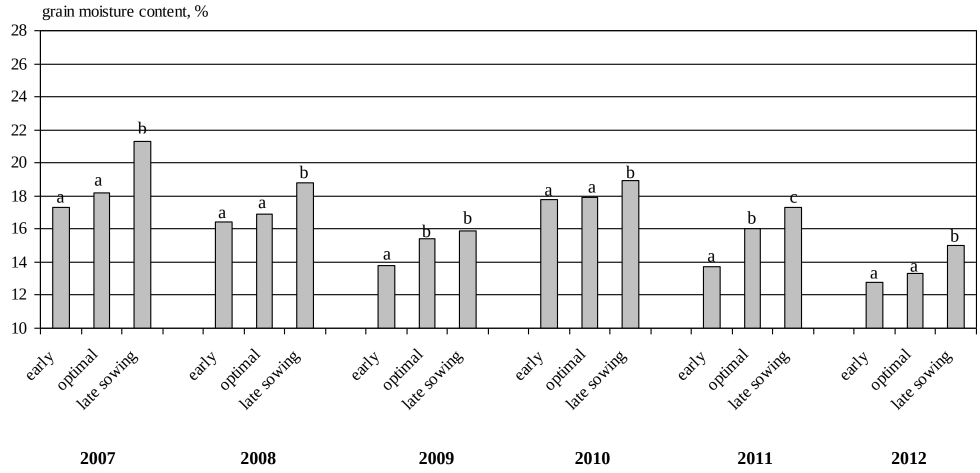
In FAO 200 maize hybrid, statistical tests showed differences that can be evidenced mathematically ($P<0.05$) between the grain moisture contents of the optimal and late sowing in each studied year except for 2009. The most significant increase, i.e. 17.5% occurred in 2007, whereas the least increase, i.e. 2.9% occurred in 2009. The difference between the grain moisture contents of the early and late sowing cannot be significantly evidenced in the years 2007, 2008, 2010 and 2012. It was in 2011 that the grain moisture contents of all the three sowing dates gave a reliable ($P<0.05$) difference (*Figure 22*).

Figure 21 The grain moisture content and yield of maize
(Nagykereki, 2007–2012)



Explanation to symbols: The data marked by the same letters do not significantly differ from one another based on the Duncan-test

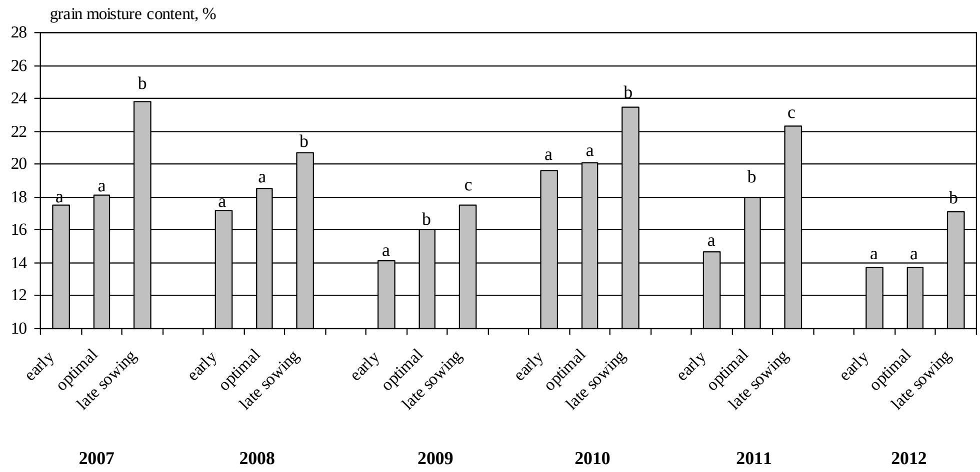
Figure 22 The trend in grain moisture content of FAO 200 hybrid
(Nagykereki, 2007–20012)



Explanation to symbols: The data marked by the same letters do not significantly differ from one another based on the Duncan-test

In FAO 300 hybrid, out of the studied years grain moisture content increase ($P<0.05$) occurred in 2009 and 2010 among all the three sowing dates, whereas in the other years among the optimal and late sowing dates. Similarly to FAO 200 hybrid, grain moisture content increase was the greatest in 2007 (31.4%), whereas it was the lowest in 2009 (9.2%) (*Figure 23*).

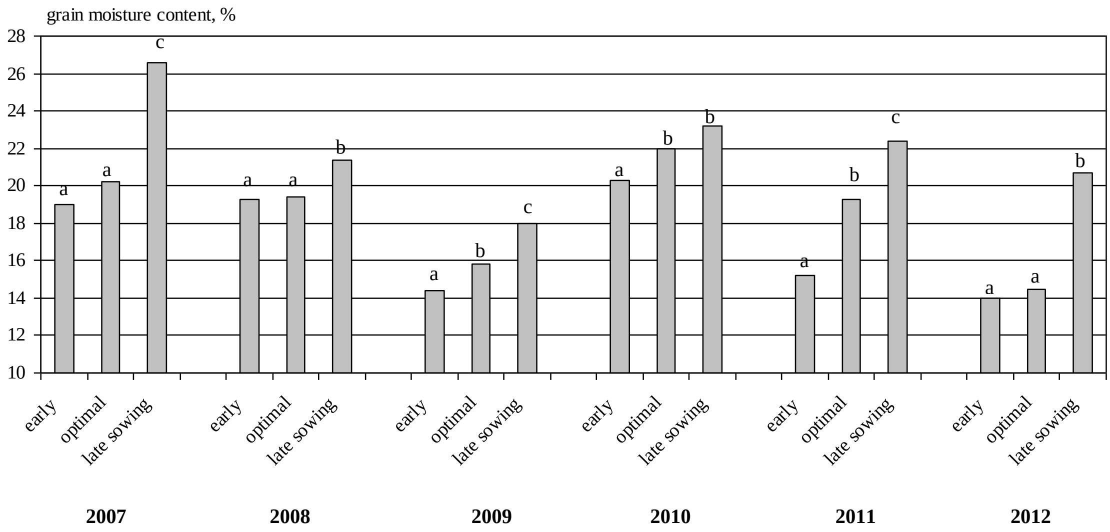
Figure 23 The trend in grain moisture of FAO 300 hybrid
(Nagykereki, 2007–20012)



Explanation to symbols: The data marked by the same letters do not significantly differ from one another based on the Duncan-test

In FAO 400 hybrid, by means of the postponement of sowing date a significant ($P<0.05$) grain moisture content increase could be measured in three years (2007, 2009 and 2011). The difference between the optimal and early (2008, 2012), as well as optimal and late (2010) sowing is not evidenced mathematically. Compared to the optimal sowing, the grain moisture content increase of late sowing was the greatest in 2012 (42.9%) and the least in 2010 (5.7%) (*Figure 24*).

Figure 24 The trend in grain moisture of FAO 400 hybrid
(Nagykereki, 2007–20012)



Explanation to symbols: The data marked by the same letters do not significantly differ from one another based on the Duncan-test

The variance analysis result showed that in FAO 200 hybrid it was the crop year, whereas in FAO 300 and FAO 400 hybrid it was the sowing date that influenced grain moisture content to the greatest extent (*Table 16*).

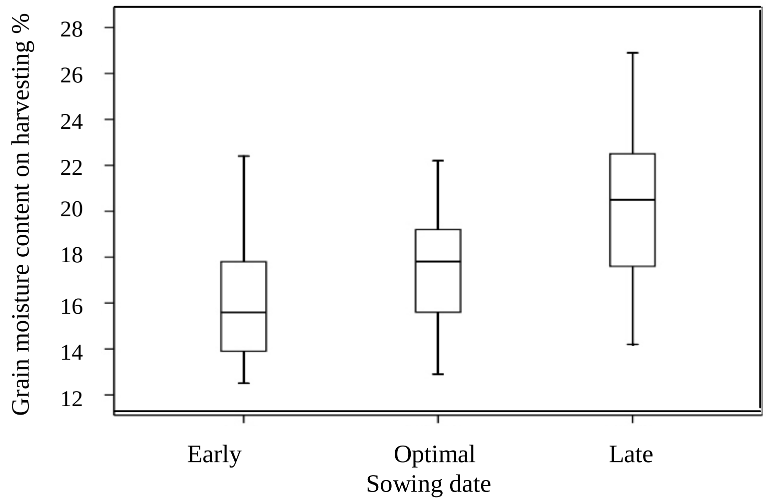
Table 16 The variance analysis results of the effects of crop year and sowing date in hybrids with different FAO numbers, grain moisture content, %
(Nagykereki, 2007–2012)

Factors	MQ	DF	F-value
FAO 200			
Sowing date [A]	40.115	2	148.619***
Hybrid [B]	48.858	5	181.007***
A x B	1.837	10	6.807***
FAO 300			
Sowing date [A]	141.030	2	229.573***
Hybrid [B]	67.171	5	109.342***
A x B	4.736	10	7.710***
FAO 400			
Sowing date [A]	157.613	2	316.379***
Hybrid [B]	78.978	5	158.533***
A x B	8.519	10	17.100***

Explanation to symbols: ***P=0.001%,

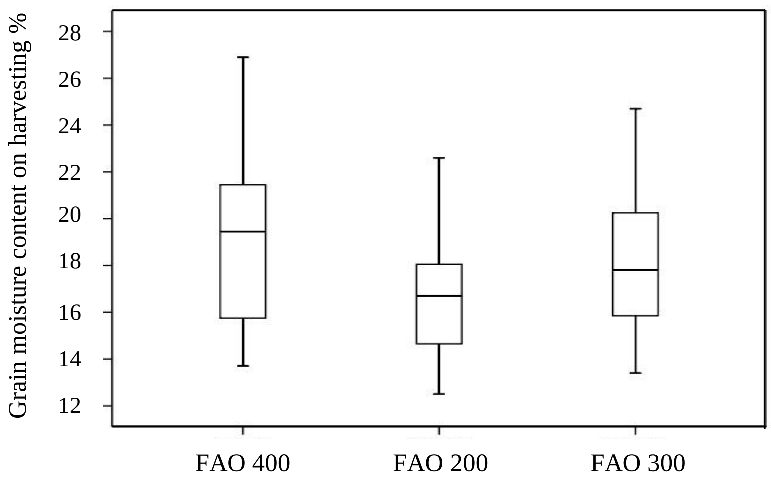
The comparison of the studied years shows that the grain moisture content of the maize hybrids is greatly determined by the sowing date, hybrid and crop year (P<0.001). Out of the factors, based on the MQ value, the sowing date modifying effect was the most considerable. The greatest grain moisture contents occurred in 2010 in the early and optimal sowing dates, as well as in 2007 in the late sowing date. In early sowing the average grain moisture content was 16.1%, in the optimal sowing date this value increased to 17.4%, and in the late sowing date it reached even 20.2%. Differences were significant in all the three cases (P<0.05) (*Figure 25*).

Figure 25 The effect of sowing date on the grain moisture content of maize (Nagykereki, 2007–2012)



Regarding grain moisture content, in the average of the years and sowing dates, definite differences (P<0.05) occurred among the hybrids. Grain moisture content definitely increased with the increase of the FAO number (*Figure 26*).

Figure 26 The grain moisture contents of the hybrids with different FAO numbers (Nagykereki, 2007–2012)



4.2.4. The analysis of the correlation between grain moisture content and yield quantity

The grade and direction of the interaction between the grain moisture content and yield of maize was studied by means of linear regression. In the analysis, the correlation between the dependent and independent variables can be considered weak below 0.5, medium between 0.5 and 0.7, and close above 0.7. In the early sowing a medium positive (0.641*) correlation occurred between the grain moisture content and yield in 2008, in the other studied years the correlation was weak and non-significant. In the optimal sowing date the interaction of the two variables showed a medium, positive (0.630*) correlation in the extremely rainy year (2010), and a close (0.705*) correlation in the droughty year (2007). In the late sowing a close correlation could be assessed even in two years (2011 and 2012) (*Table 17*).

In summary it can be stated that in the dry years except for the extremely droughty year 2007 the grain moisture content had a greater and greater effect on the yield with the sowing date postponed. In a favourable crop year (2008) this correlation had an opposite trend as the closest (0.641*) correlation was in the early sowing, and this became weaker and weaker in the later sowing.

Table 17 The linear regression results between the grain moisture content of the maize hybrids and the yield in different sowing dates (Nagykereki, 2007–2012)

Years	Sowing date		
	early	optimal	late
	r values		
2007	0.493^{ns}	0.705^{*}	0.205^{ns}
2008	0.641^{*}	0.346^{*}	0.291^{ns}
2009	0.424^{ns}	0.525^{*}	0.584^{*}
2010	0.233^{ns}	0.630^{*}	0.070^{ns}
2011	0.260^{ns}	0.293^{ns}	0.701^{*}
2012	0.181^{ns}	0.564^{*}	0.759^{**}

Explanation to symbols: **P=0.01%, *P=0.05%, ns= not significant

4.2.5. The effect of sowing date on the starch content of maize kernel

The control of the reliability of starch content by means of variance analysis showed that sowing date had the greatest effect on starch content in every year except for the year 2012 with 5%, reliability was 0.1%. Hybrids exercised a weaker effect, and in the extremely rainy year no significant effect could be detected. Sowing date × hybrid interaction did not show a statistically detectable effect in any years (*Table 18*).

The starch content of the maize kernel was of identical value in 2007 in early and optimal sowing date, with a level of significance of 5% by Duncan-test, and late sowing date showed deviation (66.3 g/100g dry substance). In the favourable year 2008 the starch content decreased by the postponement of sowing date, however, in this case the difference between the early and optimal sowing dates was not mathematically evidenced either, whereas the deviation between early and late sowing (3.0%), as well as optimal and late sowing (2.3%) was. Regarding the trend in the starch content of the kernels in 2009 no definite effect of the sowing date between the optimal and late sowing can be observed. The same can be experienced in the extremely rainy year 2010. In 2011 the change in the sowing date had a considerable effect on the starch content. In the dry year 2012 the deviation between the early and optimal sowing dates did not result in a significant difference (*Table 19*).

Table 18 The variance analysis result of the effect of sowing date and hybrid, starch g/100g dry substance (Nagykereki, 2007–2012)

Factors	MQ	DF	F-value
2007			
Sowing date [A]	42.095	2	35.106^{***}
Hybrid [B]	5.584	2	4.657^{*}
A x B	0.665	4	0.554^{nsz}
2008			
Sowing date [A]	12.223	2	24.137^{***}
Hybrid [B]	13.203	2	26.074^{***}
A x B	1.195	4	2.360^{nsz}
2009			
Sowing date [A]	3.933	2	25.510^{***}
Hybrid [B]	0.877	2	5.691^{**}
A x B	0.922	4	5.980^{**}
2010			
Sowing date [A]	8.936	2	26.604^{***}
Hybrid [B]	0.999	2	2.974^{nsz}
A x B	0.284	4	0.847^{nsz}
2011			
Sowing date [A]	13.241	2	45.961^{***}
Hybrid [B]	2.441	2	8.473^{**}
A x B	0.595	4	2.067^{nsz}
2012			
Sowing date [A]	2.581	2	3.891^{*}
Hybrid [B]	3.161	2	4.766^{*}
A x B	0.514	4	0.775^{nsz}

Explanation to symbols: **P=0.01%, **P=0.01%, *P=0.05%, ns= not significant

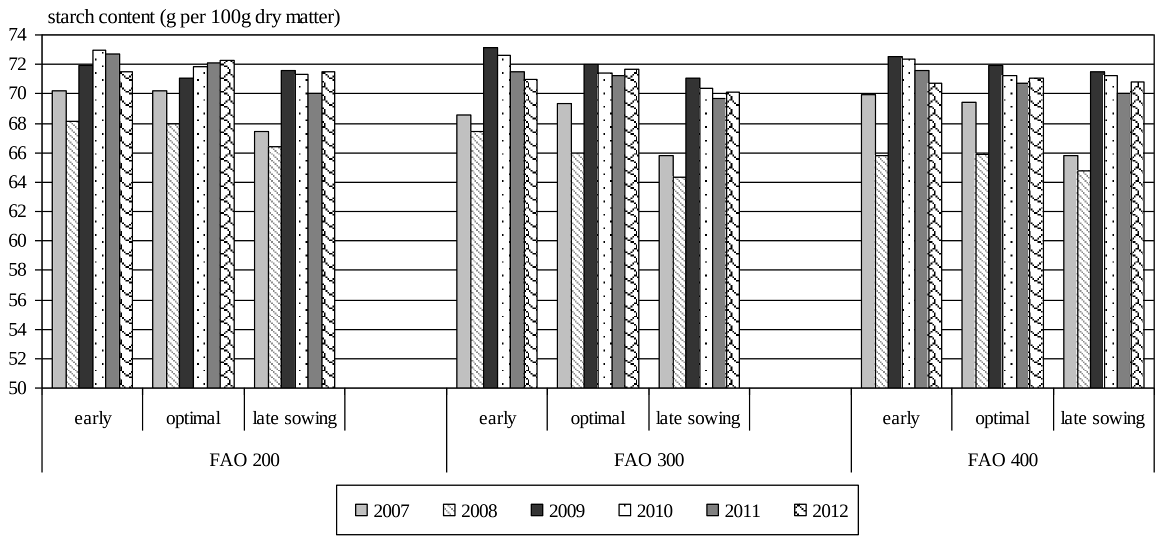
Table 19 the effect of sowing date on the starch content, g/100g dry substance (Nagykereki, 2007–2012)

Years	Sowing date		
	early	optimal	late
2007	69.6a	69.6a	66.3b
2008	67.0a	66.6a	65.1b
2009	72.5a	71.7b	71.4b
2010	72.6a	71.5b	70.9b
2011	71.9a	71.3b	69.9c
2012	71.1a	71.7a	70.8b

The data marked by the same letters do not significantly differ from one another based on the Duncan-test

In FAO 200 hybrid, with a significance level of 5% by Duncan-test, the starch content decrease in three years (2007, 2008 and 2011) is not reliable only in optimal sowing date compared to early sowing. In the extremely rainy year (2010) the application of early sowing resulted in the greatest starch content (73 g/100g dry substance), subsequent sowing showed a decreasing trend, however, the decrease of 1.7 g/100g dry substance was only significant between the early and late sowing. In two years (2009, 2012) no statistically quantifiable deviation could be detected between the sowing dates (*Figure 27*).

Figure 27 The effect of sowing date on the starch contents of maize hybrids with different FAO numbers, (Nagykereki, 2007–2012)



The FAO 300 hybrid in the optimal date, differently from what previously happened, had higher starch content in two years (2007 and 2012) than early sowing, however, the deviation did not show a difference that can be evidenced. There was no significant difference between the two sowing dates in another two years (2008, 2011) either. In 2010 the starch content of early sowing (72.6 g/100 g dry substance) decreased with the advancement of the sowing dates, a statistically evidenced difference resulted in a reliable deviation between the early and optimal (1.2 g/100 g dry substance), as well as early and late (2.2 g/100 g dry substance) sowing. The starch contents of all the three sowing dates were only fully different in 2009.

In FAO 400 hybrid, similarly to FAO 200 and FAO 300 hybrids, in 2007 and 2008 there was no detectable difference between the starch contents of the early and optimal sowing, which can be also assessed for this hybrid for the year 2010. There was a quantifiable difference between the optimal and late sowing in 2009 (1.0 g/100g dry substance) and in 2011 (1.6 g/100g dry substance). In 2012 the starch content of optimal sowing was the greatest (71.1 g/100g dry substance), however, the sowing of different dates did not cause a significant difference.

The modifying effect of the crop year is also very significant regarding each sowing date, the quantified effect was checked by means of variance analysis. In the early sowing date the lowest starch content (67.0 g/100g dry substance) occurred in a favourable crop year (2008), whereas the highest starch content (72.6 g/100g dry substance) occurred in the rainiest year (2010). The difference between the results of the two years considered extreme (2007 and 2010) is also very significant (3.0 g/100g dry substance). Also in optimal sowing, starch content was the lowest (66.6 g/100g dry substance) in the favourable crop year of 2008 as well. Compared to this year, starch content increase was 4.5% in the droughty year 2007, and 7.1% on average in the other dry years. In the case of late sowing as well, starch content was also the lowest (65.1 g/100g dry substance) in 2008, and the greatest deviation between the years was in this sowing date, which is also indicated by the grade of the MQ value (87.007) of the variance analysis (*Table 20*).

Table 20 The variance analysis result of the effect of crop year and sowing date starch content, g/100g dry substance, (Nagykereki, 2007–2012)

Factors	MQ	DF	F-value
early sowing			
Year [A]	51.413	5	125.245***
Hybrid [B]	3.492	2	8.506***
A x B	1.787	10	4.353**
optimal sowing			
Year [A]	47.901	5	238.726***
Hybrid [B]	5.048	2	25.159***
A x B	1.260	10	6.277***
late sowing			
Year [A]	87.007	2	84.372***
Hybrid [B]	7.598	2	7.368**
A x B	.696	4	.675ns

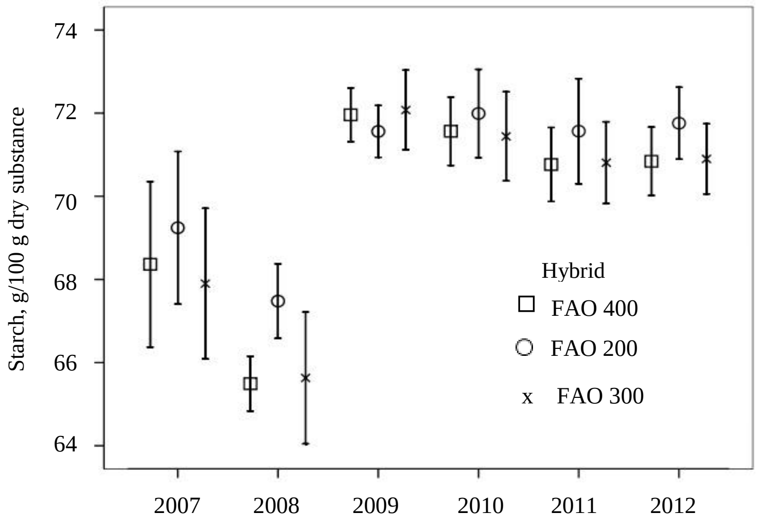
Explanation to symbols: **P=0.01%, **P=0.01%, *P=0.05%, ns= not significant

For the hybrids with all the three FAO numbers it can be stated that the lowest starch content was in the year 2008, which is considered a favourable crop year, and in the dry years this value increased. Among the hybrids, in the average of sowing dates, there was a quantifiable difference in the starch content only in two years, i.e. in 2008 and 2012, between FAO 200 and FAO 300 hybrids (2008, 1.9 g/100g dry substance; 2012, 0.9 g/100g dry substance), as well as between FAO 200 and FAO 400 hybrids (2008, 2.0 g/100g dry substance; 2012, 1.0 g/100g dry substance) (*Figure 28*).

In the hybrids with all the three FAO numbers, in the average of sowing dates, it can be assessed that compared to the most favourable crop year (2008), the starch content of each year showed a significant ($P<0.001$) increase, and the same can be stated for the droughty year (2007) as well.

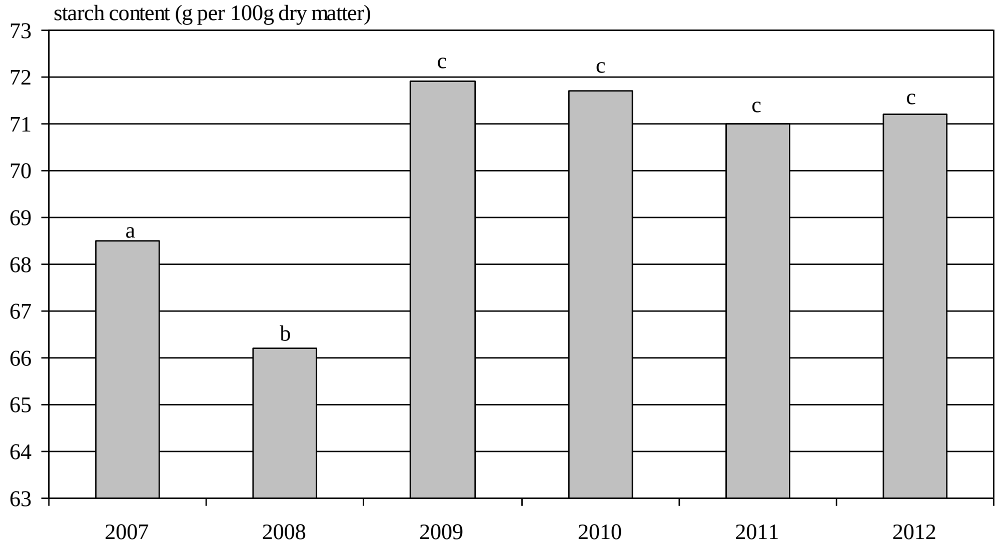
The three-way variance analysis showed that in the average of six years all the three factors (sowing date, hybrid, crop year) reliably ($P<0.001$) influenced the starch content of the maize kernel. Based on the MQ values the effect of the crop year (178.391) was the most significant, this was followed by the sowing date (57.547), the lowest values were represented by the hybrids (14.294). Out of the interactions, sowing date x year ($P<0.001$) and year × hybrid ($P<0.001$) are significant, whereas sowing date × hybrid did not prove to be a significant interaction.

Figure 28 The effect of crop year on the starch content of maize hybrids with different FAO numbers, (Nagykereki, 2007–2012)



The starch content quantified by crop years, in the average of treatments, was the highest in 2009 (71.9 g/100g dry substance) and the lowest in 2008 (66.2 g/100g dry substance). The droughty year 2007 and the favourable year 2008, with a significance level of 0.1%, differ from the starch content of each year. No significant difference among the other years occurred (*Figure 29*).

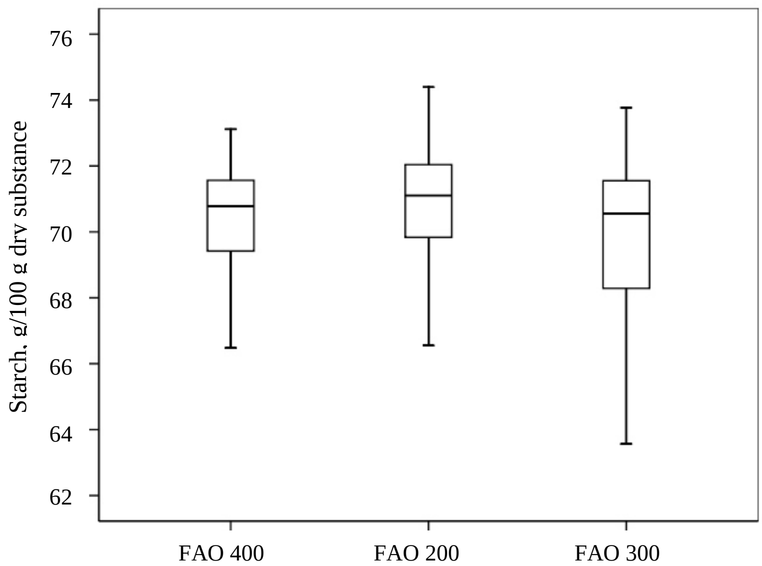
Figure 29 The effect of crop year on the trend in starch content (Nagykereki, 2007–2012)



Explanation to symbols: The data marked by the same letters do not significantly differ from one another based on the Duncan-test

According to the evaluation of the results of the six years the highest (70.8 g/100g dry substance) starch content can be reached by the early sowing, and the lowest (69.0 g/100g dry substance) starch content can be reached by the late sowing. The FAO 200 hybrid had the highest 70.6 g/100g starch content, however, the difference between the hybrids is minimal (*Figure 30*).

Figure 30 The effect of crop year on the starch contents of the hybrids with different FAO numbers, (Nagykereki, 2007–2010)



4.2.6. The correlation analysis between the starch content of maize kernel and yield quantity

The correlations between the starch content and yield were greatly influenced by the crop year and sowing date. There was a correlation of medium strength in the droughty 2007 in the early sowing date (r=0.654*) and in the favourable (2008) crop year (r=0.663*) in the optimal sowing date. In the extremely droughty year (2010) a close positive (r=0.726**) correlation occurred in the late sowing date between the yield and starch content. In the other studied years the correlation was weak in all the three sowing dates (*Table 21*).

The most important correlation between the starch content and the yield quantity in the average of the years occurred in the late sowing of FAO 300 hybrid (r=0.679***). In FAO 200 hybrid, in the early (r=0.326*) and optimal (0.461*) sowing there was a weak correlation, whereas in the late sowing there was a medium (r=0.593**) correlation. The hybrid of the longest growing season (FAO 400) showed a non-significant correlation in the sowing dates. In summary the FAO 300 hybrid showed the closest correlation between the starch content and yield in all the three sowing dates (*Table 22*).

Table 21 The linear regression results between the starch contents of maize kernels and the yield in different crop years
(Nagykereki, 2007–2012)

Sowing date	2007	2008	2009	2010	2011	2012
Early	0.654*	0.547*	0.315*	0.217 ^{ns}	0.135 ns	0.209 ^{ns}
Optimal	0.287*	0.663*	0.372*	0.196 ^{ns}	0.494*	0.508*
Late	0.133^{ns}	0.060^{ns}	0.117^{ns}	0.726**	0.065 ^{ns}	0.180 ^{ns}

Explanation to symbols: **P=0.01%, **P=0.01%, *P=0.05%, ns= not significant

Table 22 The linear regression results between the starch contents of maize kernels and the yield in different sowing dates
(Nagykereki, 2007–2012)

FAO number	Sowing date		
	early	optimal	late
FAO 200	0.326*	0.461*	0.593**
FAO 300	0.526*	0.615***	0.679***
FAO 400	0.046^{ns}	0.393^{ns}	0.219^{ns}

5. CONCLUSIONS, RECOMMENDATIONS

The quantity and quality of the maize yield greatly depends on the genetic, agrotechnical and ecophysiological changes, which are further modified by the change of the climate. The knowledge and evaluation of the effects and interactions of plant cultivation factors, in connection with the given ecological factors, provide the most important thing to the producer, the safety of yield.

The aim of the research is to analyse how the most important plant cultivation factors (soil cultivation, fertilization, irrigation, plant number and genotype, FAO number) affect the yield of maize under the different environmental conditions.

The maize evaporates 300 litre of water in order to produce 1 kg of dry substance, if you calculate with a yield average of 8 t ha^{-1}, this means a water demand of 480 mm. Out of the studied years, the quantity of fallen precipitation only reached this value in 3 years (2005, 2008 and 2010). The evaluation of climatic factors shows that drought occurs more and more frequently, the drought index and the number of heat day increase. You cannot influence the weather trend, but the damages caused by it can be mitigated by the correct agrotechnical procedures.

Depending on the method of soil cultivation and the quantity of the applied fertilizer, there was a significant yield difference among the treatments. The yield results measured in the non-fertilized plots, in the spring ploughing treatment significantly exceeded those measured in spring shallow cultivation. The yield increasing effect of the application of the treatment with 120 kg N could be detected in one year, i.e. in the droughty year (2002) in the spring ploughing treatment, whereas in 4 years there was no significant difference in the yields between the spring ploughing and spring shallow cultivation. When evaluating the joint effect of soil cultivation and fertilization, it can be assessed that the joint yield increasing effect of the two factors was significant except for the year 2004.

The effect of irrigation was very different in each year. In the dry year (2003) the irrigation water supplied at the proper time and in the proper quantity caused an extra yield of 3170 kg ha^{-1}. The quantity of precipitation fallen in the extremely dry, droughty year 2002 and the 100 mm irrigation water did not cover the water demand of the plant, so the yield increasing effect of irrigation did not occur. In the extremely rainy year (2005), to the effect of the too much water the soil solution became diluted, there were fewer nutrients in one volume unit, the operation of microorganisms became moderated, and the quantity of easy-to-absorb forms of nitrogen also decreased, which led to the decrease of the yield. The results evidence that reasons of water shortage and harmful water abundance, and their elimination are highly important from the aspect of successful growing.

According to the yearly evaluation of the effect of plant number, in the dry years the smaller stock of 50 thousand stems/ha is sufficient in order to reach a proper yield, however, in the rainy and favourable years the greater stock of 70 thousand stems/ha plant density will result in the maximum yield. The greatest yield can be reached in a favourable crop year (2004) and with appropriate nutrient supply (120 kg N ha^{-1}).

The two maize hybrids of different growing seasons reacted in a different way to the effects of the agrotechnical factors, except for the year 2002. The correlation between the genotype and yield was weak with natural precipitation supply, but to the effect of irrigation this correlation became closer.

Sowing date did not show a significant effect on the yield in every year. Crop year, mainly the quantity and distribution of precipitation in the growing season was an important influencing factor. In the years when the effect of sowing date was significant, optimal sowing date (the second half of April) resulted in the greatest yield. Soil temperature is an important factor when selecting the sowing date. Soil temperature of the period from sowing to shooting has a strongly significant effect on the yield. The greatest soil temperature fluctuation occurs in the early sowing period so shooting can be postponed and it will be unsteady, which may cause yield loss. In early sowing harvest may happen earlier and the grain moisture content is lower as well than in late sowing.

In the average of six years, the highest (70.8 g/100g dry substance) starch content was in the early sowing, whereas the lowest (69.0 g/100g dry substance) was in the late sowing.

6. NEW AND NOVEL SCIENTIFIC RESULTS

1. In the spring ploughing treatment the yield results (6.758 t ha^{-1}) measured in the non-fertilized plots significantly exceeded the yield results (5.646 t ha^{-1}) of spring shallow cultivation. In both soil cultivation variations 120 kg N ha^{-1} resulted in the greatest statistically evidenced yield.
2. Out of the agrotechnical factors, fertilization had the greatest effect on the yield. Irrigation had a yield increasing effect in the dry crop year in all the three fertilizer treatments.
3. In the rainy years and under irrigated conditions a plant number of 70 thousand per hectare ($P<0.05$) is needed. In droughty years the lower 50 thousand stems/ha is more efficient. In the non-fertilized treatments the increase in the plant number caused a yield drop in every year.
4. The hybrid of longer growing season (FAO 400) brought good yield in the favourable crop year (2004), its extra yield was 1024 kg ha^{-1} ($P<0.001$), in the other studied years the FAO 300 hybrid brought more yield.
5. The correlation between the soil temperature of the period from sowing to shooting and the yield influenced the result of the FAO 400 hybrid of longer growing season to the greatest extent in all the three sowing dates. The correlation was the closest in the early sowing.
6. From the aspect of the yield trend, crop years mean a greater effect than the different sowing dates within the years. The sowing dates of the maize hybrids are important yield influencing factors. Reliable yield results were in 2009, 2011 and 2012 in the optimal (24 April) sowing date treatment. The crop year influenced the yield of the FAO 300 hybrid to the greatest extent.
7. The highest starch content can be reached by means of the early sowing, whereas the lowest starch content can be reached by means of the late sowing.

7. THE PRACTICAL APPLICABILITY OF THE RESULTS

1. The comparison of the different agrotechnical factors and the result of the efficiency test for their effects exercised on the yield allow such growing technological solutions in the fields of soil cultivation, nutrient supply, irrigation and plant number that increase yield safety and the income achievable in a unit area, while reducing environmental loading.
2. For the protection against the weather extremities, the risk of growth may be decreased by extending the blooming period, which can be implemented with different sowing dates and with the use of hybrids with different FAO numbers.
3. Research results contribute to the selection of the hybrids that have the best parameters with the appropriate internal contents for the aim of the growth and the use of the end product.

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