

Theses of doctoral (PhD) dissertation

**THE IMPACT OF AGROTECHNICAL FACTORS ON THE YIELD AND
STARCH YIELD OF MAIZE HYBRIDS**

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INTRODUCTION

Today, major industrial difficulties are faced by modern, developed countries in their production due to the presence of unstable buying-in prices, volatility in production (overproduction), extreme climatic conditions, and major deterioration in farmland conditions, mostly due to unilateral land use. In general, it is true that problems are caused by cultivation factors (agrotechnical, biological and ecological), the development of weather extremes caused by climate change, the deterioration of soil conditions, the increasing use of organic fertilisation, which results in a decrease in soil activity, soil fertility, heat-water-air management.

According to 2014 data, the world's total corn yielded 939 million tonnes, produced on approximately 178 million hectares, with a yield of 5.27 t/ha. According to the five-year forecast, this figure will increase by an additional 63 million tonnes, which may have a significant impact on prices as well. This means that practically 12.6 million extra tons has to be produced in the world each year (*Szanyi, 2016*).

In addition to grain cereals, maize is the most important arable plant in Hungary. Its cropping area reaches 1 million hectares each year. Nevertheless, the cornfield area decreased significantly due to lower demand for the plant. As a result of the 135,000 hectare change, the sown area in 2016 (1.03 million hectares) reaches only 88% of the previous year (*Statisztikai Tükör, 2016*).

The most important objective of today is compliance with the requirements of sustainable farming.

Sustainable development also requires the adaptation of ecological and economical conditions to agriculture, that is, the practical application of an approach that realizes the alignment of production needs and environmental objectives and takes into account the site conditions and minimizes the environmental burden, while achieving economical production.

Significance of maize

Maize production is a top priority in the world's agriculture. Maize is one of the most important crop in addition to rice and wheat (*Nagy and Sárvári, 2005*).

Maize is mostly used for animal nutrition purposes in Hungary. In industrial use, maize is utilised as a starch, a basic ingredient in the production of distillate. Its byproduct is not negligible either as it can be used for nutrition, energy purposes and nutrient replenishment in soil (*Hidvégi, 2007*).

The biggest problem of domestic crop production is climate change, the decrease in precipitation and its extremely unfavorable distribution, as well as a rise in temperature which increases groundwater evaporation - evaporation - which further increases water scarcity (*Sárvári and Kovács, 2016*).

The role of cultivation technology elements in crop production

One of the important issues of maize cultivation agronomy is the use of water conservation soil cultivation (*Antal, 1987*).

Fertilisation is the most important agrotechnical method of nutrient supply. According to Loch and *Jászberényi (1987)*, *Sarkadi (1991)*, *Csathó et al., (2000)*, the dosage used in fertilisation above a given quantity does not serve the plant's needs but serves to saturate the soil. According to *Ványiné (2008)*, determining the optimal plant density for maize production has a decade-long history. The methodology of the beginning of the 20th century showed that it is necessary to apply a smaller plant density on good nutrient and water management areas, as these results in a large amount of plant vegetation.

The correlation according to which plant density greatly influences the amount of yield was also documented by *Sárvári et al., in 1994 (1994)*.

The quality properties of the crop yields are determined primarily by genetic background which can be modified by the cultivation technology and the site conditions, according to *Jellium-Marion (1966)*, *Debreczeni (1979)*, *Aildson et al. (2005)* and *Izsáki (1999, 2006)*.

According to *Sárvári and Győri (1982)*, variety characteristics, production site, fertilisation, irrigation and plant protection are important and determinant in relation to the development of quality parameters.

Objectives

In relation to maize production, the basis for ongoing and emerging research is that it is also a plant widely cultivated, which has a high yield potential. In addition, its use is very diverse - food, feed, industrial raw material and energy (*Mengel, 1993*).

An essential element of safe crop production is the development of agrotechnical proposals and solutions that promote the sustainability of the sector, its economy and its efficiency.

In the PhD thesis, my purpose was to examine the cultivation of maize hybrids that could serve as raw material for bioethanol production. I wanted to compare the nutritional values of the selected hybrids, with a focus on starch content that was important for ethanol production, using near infrared spectroscopy. The further aims of my research is to examine the effect of soil cultivation, fertilisation and different plant densities on the development of starch, oil and protein components of the maize hybrids involved in the experiment in 2012, 2013 and 2014.

The main objectives of the performed examinations:

- analysis of the effects of the examined years, the effect of crop year on yields;
- analysis of the effects of the examined years, the effect of crop year on starch yield;
- analysis of the effects of tillage methods on yield during the examined years;
- analysis of the effects of tillage methods on starch yield during the examined years;
- analysis of the effects of fertiliser doses on yield during the examined years;

- analysis of the effects of fertiliser doses on starch yield during the examined years;
- analysis of the effects of plant density on yield during the examined years;
- analysis of the effects of plant density on starch yield during the examined years;
- complex analysis of factors and the quantification of their interactions.

MATERIAL AND METHODS

Production site characteristics, Debrecen - Characterisation of the small plot experiment of the Látókép Experiment Site

Examinations were performed on mid-heavy, calcareous chernozem soil on the Látókép Experiment Site (N 47°33' E 21°27') of the Debrecen Study Farm and Land Research Institute of the Agricultural Research Institutes and Study Farm (AKIT) of the University of Debrecen in 2012 2013 and 2014.

The long-term field experiment has a split-strip-plot design with the main plots representing tillage and irrigation treatments without replication. In the primary subplot, the maize hybrids have 70,000 and 50,000 plant density values, while fertiliser treatment in the secondary subplots is randomized in four replications. One soil cultivation block has an area of 8064 m² divided into an irrigated and a non-irrigated block. In our experiments, we only analyzed the data of the non-irrigated experiment.

In each of the three examined years, the same maize hybrids are present in the experiment, with different ripening time (*Table 1*). The size of a main plot adjusted with a certain hybrid: 2688 m², size of fertiliser treatment plots: 336 m². Net size of a plot: 30 m². The experimental area used in the dissertation is shown in *Figure 1* in red.

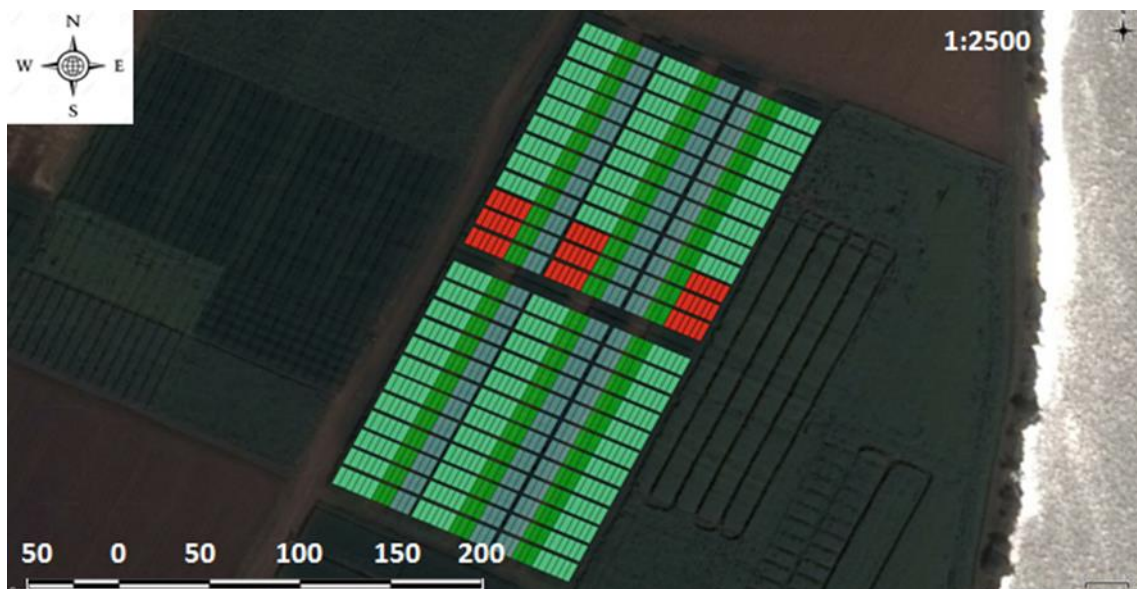


Figure 1: Geographical location of the experiment

Source: Google Earth, own construction based on KML layer

1. Table: Hybrids in the experiment 2012-2014

	2012		2013		2014	
	Hybrid	FAO	Hybrid	FAO	Hybrid	FAO
1	<i>RENFOR</i>	300	<i>RENFOR</i>	300	<i>RENFOR</i>	300
2	<i>NEFFEL</i>	350	<i>NEFFEL</i>	350	<i>NEFFEL</i>	350
3	<i>ARMAGNAC</i>	490	<i>ARMAGNAC</i>	490	<i>ARMAGNAC</i>	490

Treatments of the polyfactoral long-term experiment:

Tillage treatment: T₁= autumn ploughing (30 cm)
T₂= spring ploughing (25 cm)
T₃= spring shallow tillage (12-15 cm)

Irrigation treatment: non-irrigated

Fertiliser treatment: 1. N 0 kg/ha P₂O₅ 0 kg/ha K₂O 0 kg/ha
2. N 120 kg/ha P₂O₅ 90 kg/ha K₂O 106 kg/ha
3. N 240 kg/ha P₂O₅ 180 kg/ha K₂O 212 kg/ha

The aim of developing the tillage treatments was to differ not only in the cultivation depth but also in the quality of soil preparation.

In each crop year, the applied fertiliser was 27% MAS (Genezis Pétisó), i.e. NH₄NO₃ + CaMg (CO₃)₂. Exact composition: 27% nitrogen (N) in the form of urea (NH₄) and nitrate (NO₃), 1:1 ratio 5% calcium (Ca), which, expressed in calcium oxide is 7% CaO, 3% magnesium (Mg), which, expressed in magnesium oxide is 5% MgO.

The agrotechnical data of the complex long-term experiment is shown in **Table 2**.

Table 2: Agrotechnical data of the experiem

Autumn ploughing	Spring ploughing	Spring shallow tillage
Stem crushing	Stem crushing	Stem crushing
Fertilisation	Fertilisation	Fertilisation
Disking	Disking	Disking
Finishing autumn ploughing		
Weed control	Spring ploughing	Weed control
Seedbed preparation	Finishing ploughing, seedbed preparation	Disking
Sowing	Sowing	Sowing
	Rolling	
Weed control	Weed control	Weed control
Interrow cultivator	Interrow cultivator	Interrow cultivator
Harvesting	Harvesting	Harvesting

Evaluation of the nutritional values of the samples

Due to the comparability of the maize hybrids with different moisture content collected during the three years of the study, the starch content of the different samples on the dry substance had to be determined. This data is also called relative starch content. This value makes it possible to compare the sample of hybrids of different moisture content.

The relative starch content can be calculated using the following equation:

$$\text{Relative starch content} = [(100/(100-A) \times B)],$$

where

A= actual moisture content measured

B= starch content of the sample of the given moisture content as measured by spectroscopy

Description of the applied statistical methods

The statistical analysis was performed using R 3.4.1.RStudio (RStudio Team, 2016) with a graphic interface, using the packages "car" (Fox and Weisberg, 2011) and "agricolae" (de Mendiburu, 2016) Graphs were prepared using Ms Excel 2013 Alpha error was 5% (alpha = 0.05) Example of ANOVAs in R:

```
model<- aov(vizsgált_változó ~ (főparcella*osztó_parcella*osztó-osztó_parcella)+  
Error(ismétlés/főparcella/(osztó_parcella*osztó-osztó_parcella), data=forrás_adatbázis))  
summary(modell)
```

where the examined variables are the measured yields, the ~ sign represents the main plot as tillage, split plot represents fertilisation, and split-split plot represents the hybrid which is used to provide a better estimation of the effect of fertilisation. +Error defines the error of the model in which the main plot follows the experimental replication, as well as the main, split and split-split plot in accordance with the design.

A repeated measurement model was used to analyse the effect of crop year on yield, where the time factor represented each examined year:

```
modell<-  
aov(ismételt_mérési_változó~kezelés*év+Error(egyedi_azonosító/mérési_időpontok),data=forrás_adatbázis))  
summary(modell)
```

Duncan's test was used to perform a mean value comparison of yield and starch yields (Huzsvai and Balogh, 2015).

Degrees of freedom (df) and mean square errors (MSE) can be individually defined for each post hoc test of the repeated measurement model and the split-strip ANOVA. These were performed for each model individually by using the following code (Huzsvai and Balogh, 2015):

```
df=df.residual(modell$"hiba:hiba") mse=deviance(modell$"hiba:hiba")/df DUNCAN<- with(adatbázis,  
duncan.test(függő_változó,modellből_a_szignifikáns_hatás, df, mse, console = T).
```

RESULTS

Based on the results of small plot long-term field experiments, we have been looking for the effect of the three corn hybrids we have chosen per hectare and the change in soil cultivation, fertilisation and plant density per hectare starch yield. The reliable evaluation of the results of fertiliser treatments increases the fact that the duration of the treatments in the long-term field experiment of Látókép exceeds 25 years.

The experimental results refer to 2012-2014. As regards the three-year period of examination, it can be stated that there are extremes for both rainfall and temperature, based on data from the past 100 years.

Based on the evaluation of results, it was found that during 2012 and 2013 there was no statistically significant effect on any of the cultivation technological factors, yield and starch yield based on the post hoc test.

Thus, it was found that the effect of the weather on yields and on starch yields in drought years in non-irrigated conditions exceeds the effect of all other agrotechnical factors. Duncan's test was performed to carry out a more accurate analysis of the results.

During 2014, the following findings were verified using statistical measurements:

In the case of 50 thousand plants per hectare, the yield is significantly different from the crop yield achieved by different cultivation methods, hybrids, the effect of fertilisation was not statistically verifiable. The yield reached by spring shallow tillage (11.61 t/ha) was significantly higher than that of autumn ploughing (9.17 t/ha) and spring ploughing (8.42 t/ha) (**Figure 2**).

The average yields of hybrids ARMAGNAC, RENFOR and NEFFEL significantly differ from each other. The main average yield of the group was 9.73 t/ha.

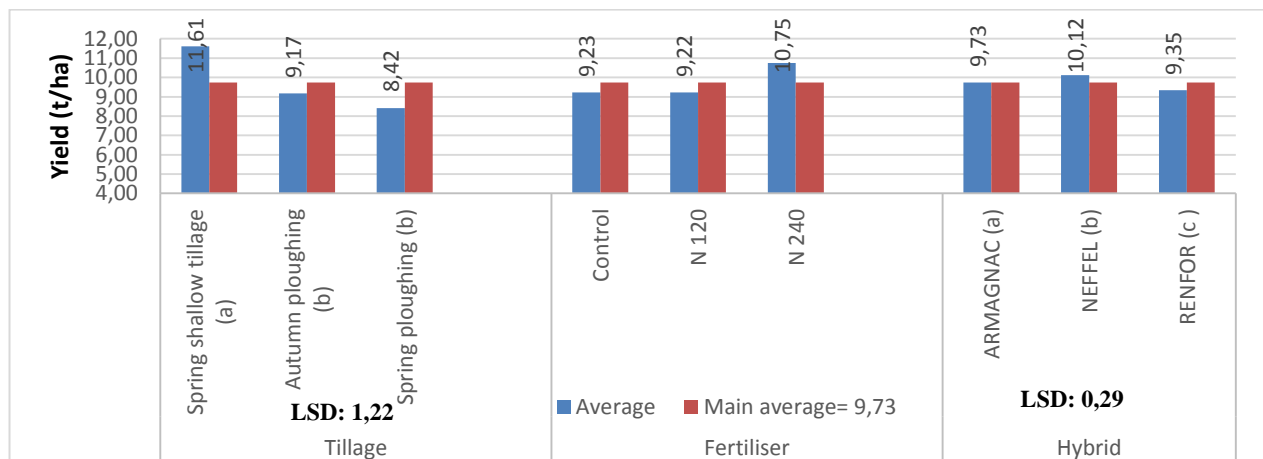


Figure 2.: The yields achieved in the case of the applied tillage, fertilisation and hybrid selection, compared with the main average, plant density: 50 thousand t/ha (Debrecen, 2014)

In the case of 50 thousand plants per hectare, the starch yield is significantly different from the crop yield achieved by different cultivation methods, hybrids, the effect of fertilisation was not statistically verifiable.

The main average starch yield of the group was 6.13 t/ha in 2014. Examining tillage, there is a difference of +1,16 t/ha between the main average yield and spring shallow tillage a significantly lower yield than the main average in the case of RENFOR (5.87 t/ha), ARMAGNAC (+0.34 t/ha) and NEFFEL (0.44 t/ha). The starch content of A RENFOR (5.87 t/ha) is 0.26 t lower than that of the main average of the starch yield in 2014. Following the analysis of hybrid selection, it was concluded that of all hybrids, the average starch content of RENFOR (5.87 t/ha) is significantly lower than that of ARMAGNAC (6.21 t/ha) and NEFFEL (6.31 t/ha) (**Figure 3**).

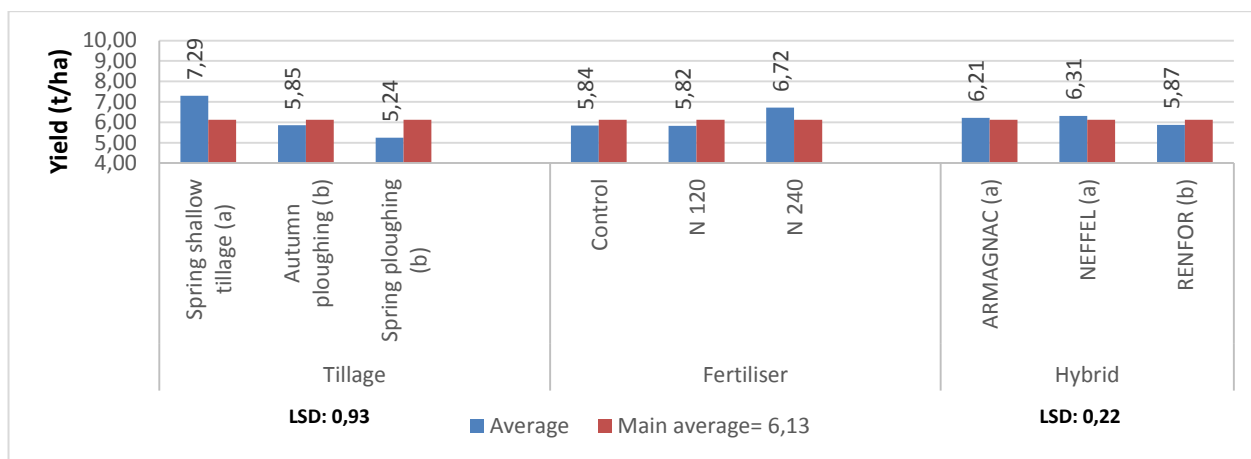


Figure 3.:The yields achieved in the case of the applied tillage, fertilisation and hybrid selection, compared with the main average, plant density: 50 thousand t/ha (Debrecen, 2014)

In the case of 70 thousand plants per hectare, the yield is significantly different from the crop yield achieved by different cultivation methods, hybrids, the effect of fertilisation was not statistically verifiable. According to the Duncan's test's results, the yield of winter ploughing tillage (10.21 t/ha) was significantly higher than the average of spring tillage (9.58 t/ha), which is significantly higher than the yield of spring ploughing (8.91 t/ha). Based on the analysis of the results reached in relation to the hybrid selection, it can be stated that the yield of RENFOR (9.46 t/ha) is significantly higher than that of ARMAGNAC (9.13 t/ha) and significantly lower than that of NEFFEL (10.12 t/ha) (**Figure 4**). The main average yield of the group was 7.67 t/ha.

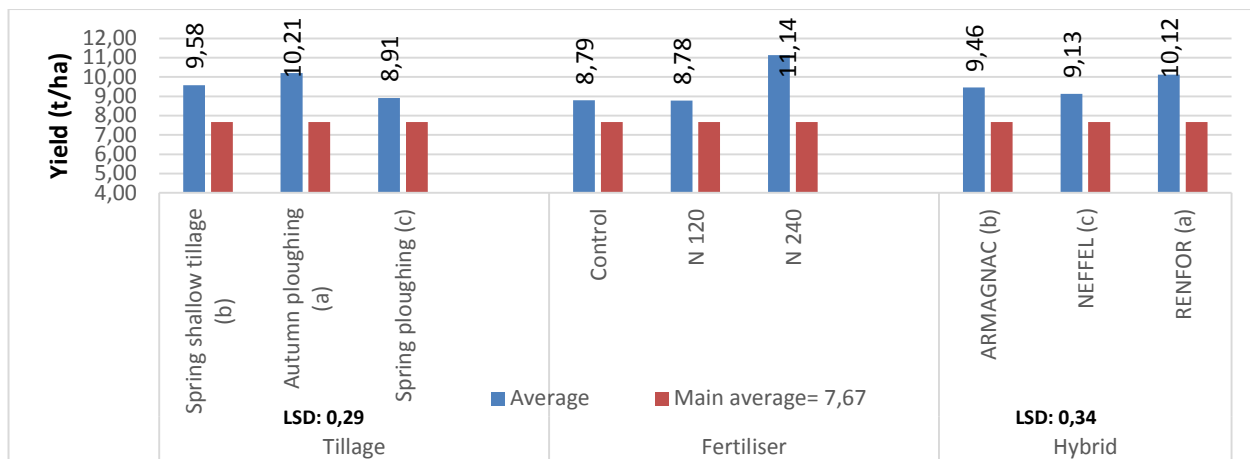


Figure 4.: The yields achieved in the case of the applied tillage, fertilisation and hybrid selection, compared with the main average, plant density: 70 thousand t/ha (Debrecen, 2014)

In the case of 70 thousand plants per hectare, the starch yield is significantly different from the crop yield achieved by different cultivation methods per hybrid

The starch yield of maize with a plant density of 70 thousand tonnes per hectare in 2014 was significantly affected by tillage as an agrotechnical factor. In this experimental year, the highest starch yield was achieved by the autumn ploughing primary tillage. The maximum starch yield achieved with the use of autumn ploughing and the finding in the literature that most starch yields can be reached at the highest yield level is in accordance with *Makra* (2012). In the case of autumn ploughing, the obtained yield was 10,21 t/ha in the case of 70 thousand plants per ha in 2014 and the starch yield was 6,53 t/ha. The starch yield of RENFOR per hectare was 6.57 t/ha, which is 0.67 tonnes per hectare higher than the starch yield of ARMAGNAC (5.90 t/ha). NEFFEL (5.77 t/ha) achieved 0.8 t/ha smaller yields on the same area unit. The main average yield of the group was 6.08 t/ha (*Figure 5*).

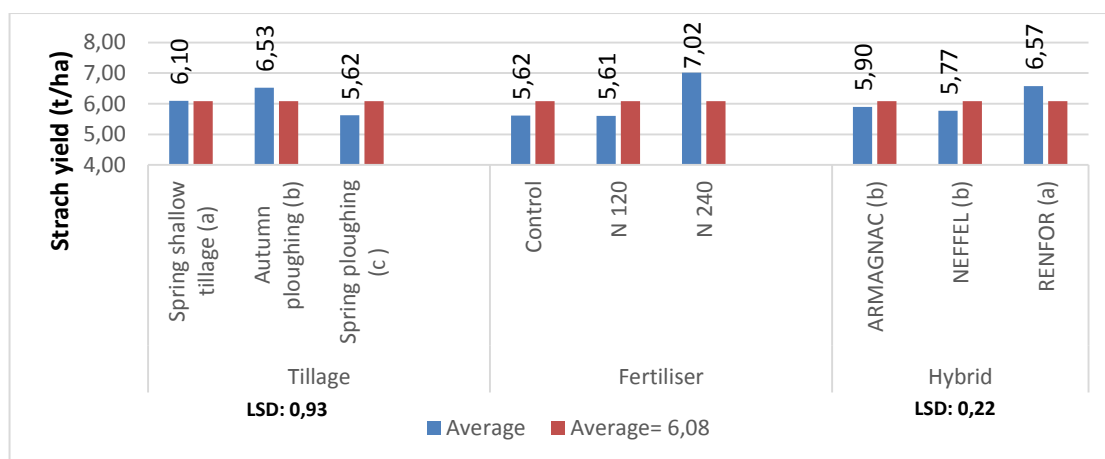


Figure 5. : The strachyields achieved in the case of the applied tillage, fertilisation and hybrid selection, compared with the main average, plant density: 70 thousand t/ha (Debrecen, 2014)

Repeated measurements of ANOVA for 50 and 70 thousand plants per hectare on the yield of corn and starch yield (2012-2014)

Compared to the previous study of the examined factors, the experimental results of the three years were subjected to further testing. Our aim was to carry out a statistical test in addition to the above method, where crop year, as an effect, as an independent factor, is involved in the method of analysis. For this reason, repeated measurements of ANOVA were performed for 50 and 70 thousand plants per hectare in relation to maize and starch yield.

The effect of tillage and crop year on maize yield (50 thousand plants per hectare)

The effect of tillage on the average yield of maize was examined averaged over three years (*Figure 6*).

On the basis of the obtained research results, it was found that the average crop yield was the highest (9,49 t/ha) in the case of a plant density of 50 thousand plants per hectare and spring shallow tillage in the average of three years. Autumn ploughing (8,43 t/ha) resulted in a yield decrease of 1.06 t, while spring ploughing (8,30 t/ha) led to a yield decrease of 1.19 t. The surplus yield achieved through the use of spring shallow tillage was achieved in the average of the three years in the case of unfavorable rainfall distribution, in addition to a soil cultivation process which has a favorable effect on water-preserving, soil water balance, and minimizes the evaporation of ground water. In the case of dry crop year, it is recommended that spring shallow cultivation be used to maximize crop yield under non-irrigated conditions.

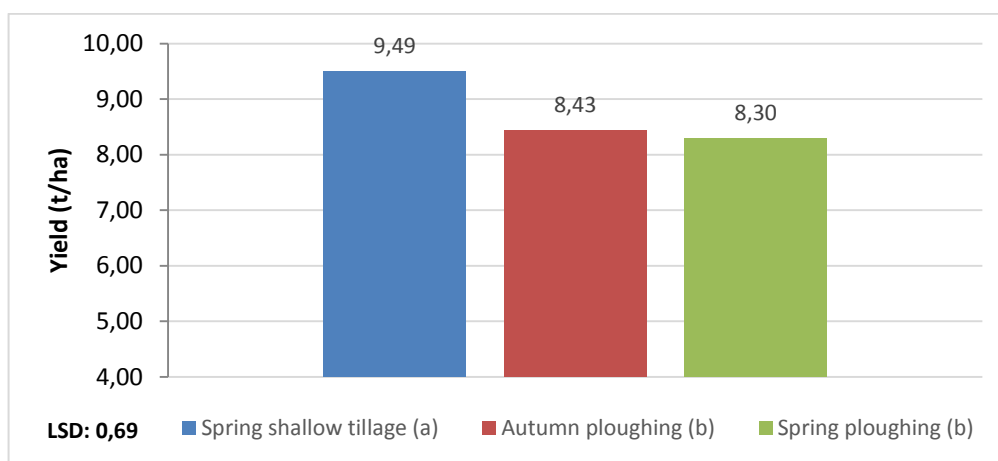


Figure 6.: The effect of tillage on yield (plant density: 50 thousand plants per hectare) (Debrecen, 2012-2014)

In non-irrigated cultivation technologies, the crop year effect is the most significant in determining yields. This is proved by the studies in which crop year was not a factor in the study but as factor 0. The weather was able to suppress fertilisation, tillage and hybrid selection in dry years. Thus, it had the most influential effect on crop yields.

Based on the results of the repeated measurement of variance analysis, after examining the effect of crop year, it was concluded that the yields achieved in 2012 (9,33 t/ha) and 2014 (9,73 t/ha) were significantly higher than the yield obtained in 2013 (7,16 t/ha) (*Figure 7*).

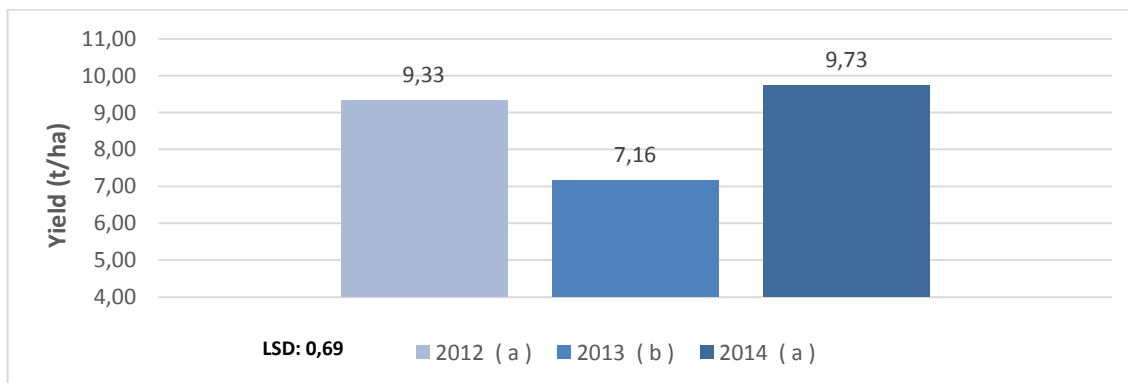


Figure 7. Yields in each examined year (plant density: 50 thousand plants per hectare) (Debrecen, 2012-2014)

With regard to the effect of crop year and tillage (50 thousand plants per hectare) it can be concluded that in spring 2014, which was the most favorable year of all three years in terms of weather - spring shallow tillage resulted in the highest yield (11.61 t/ha). The significant correlation between 2012 and 2014 in *Figure 7* is shown in *Figure 8*, i.e., the tendency of these two years is identical, that is, different tillage treatments follow each other subsequently in affecting yields. In the case of both crop yields, the highest yield was obtained in the case of spring shallow tillage, followed by autumn ploughing primary tillage and spring ploughing.

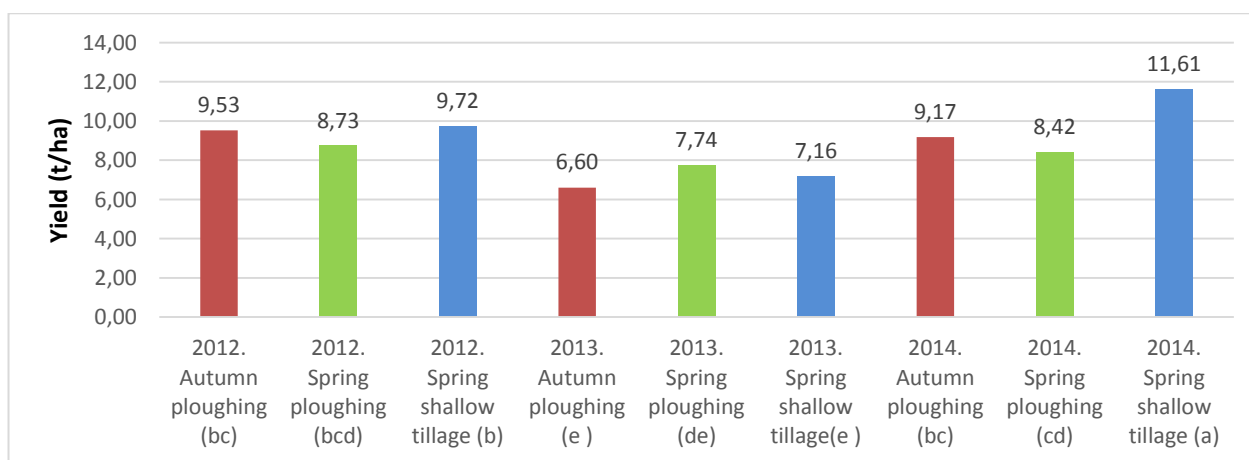


Figure 8. Maize yield per year, broken down to tillage methods, plant density: 50 thousand plants per ha (Debrecen, 2012-2014)

Fertiliser, as an agrotechnical factor, also shows a significant effect (Sig. = 0.000* <0.05), averaged over 2012-2014 in relation to yield, plant density: 50 thousand plants per ha.

Following the analysis of the fertiliser effect, it was found that control (b) and 120 kg / ha nitrogen [N120 (b)] were significantly lower than the yields obtained by the fertiliser 240 kg / ha nitrogen (N 240 (a)) (**Figure 9**).

In the case of 3 fertiliser treatments, the highest yield was obtained by applying the highest amount of nitrogen, which is consistent with the finding that the amount of nitrogen applied has the highest role in achieving maize yield surplus (*Győrffy and I'só, 1966; Balláné, 1968; Latkovicsné and Krámer, 1968; Bocz, 1974; Bocz, 1976; Anda, 1987; Nagy, 1986; Ahmad, 2000; Berzsenyi, 2009b*), especially in the case of monoculture (*Dóka and Pepó, 2007*).

Considering the findings of several researchers, we found no correlation with the results obtained by the fact that in the case of the reduced plant density, in non-irrigated culture, the highest yield was obtained by applying 240 kg / ha of nitrogen. According to *Nagy (2007b)*, in dry years, it is justified to apply nitrogen at a maximum of 60 kg / ha as the production risk is higher.

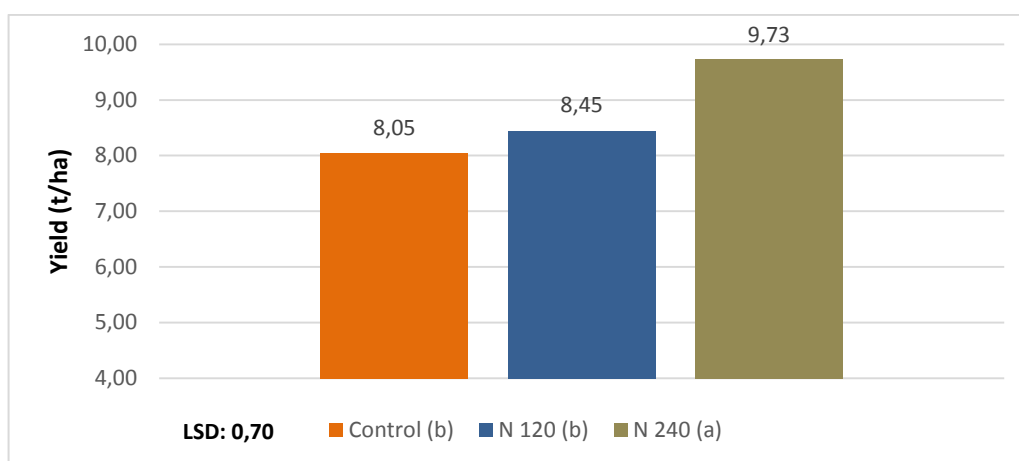


Figure 9.: The effect of fertilisation on maize yield (50 thousand plants per hectare) (Debrecen, 2012-2014)

The effect of tillage and crop year on maize yield (70 thousand plants per hectare)

The following results were obtained in the case of 70 thousand plants per hectare, the plant density value most often used in maize production.

Soil cultivation as an agrotechnical factor has a significant effect on maize yield in the case of 70 thousand plants per hectare, averaged over the years between 2012-2014. **Figure 10** shows that, in the average of 3 years, the highest yield, which is significantly higher than the results of the other primary tillage methods, was achieved in the case of spring shallow tillage (9.56 t/ha). Yields achieved by autumn ploughing (8,49 t/ha) and spring ploughing (8,37 t/ha) were significantly lower.

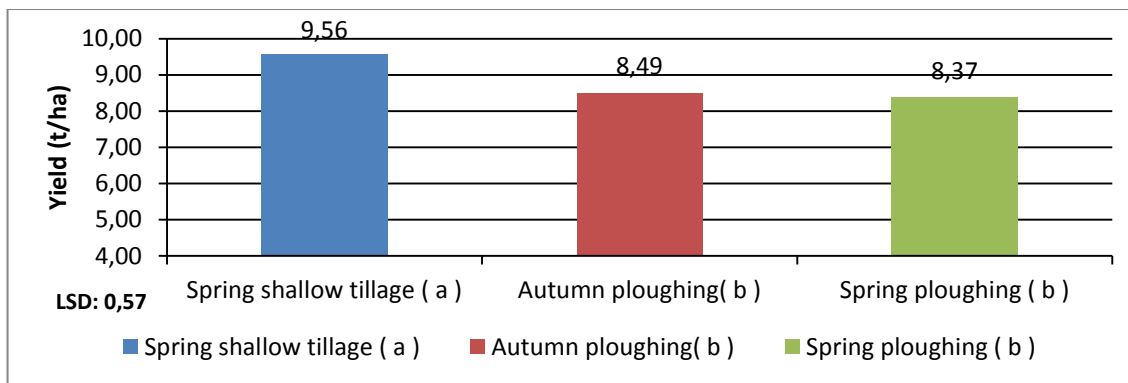


Figure 10.: The effect of tillage on yield (plant density: 70 thousand plants per hectare) (Debrecen, 2012-2014)

Figure 11 shows the effect of crop year on yield in the case of 70 thousand plants per hectare, averaged over 2012-2014.

Based on the results we found that the yield of the year 2013 (b) was significantly lower than the average yield in 2012 (a) and 2014 (a). In the average of three years, the average yield in the year 2014 is 9.57 t/ha, which is significantly higher than the yield of 7.68 t/ha in 2013.

Overall, we concluded that the crop year effect has a major influence on crop yield.

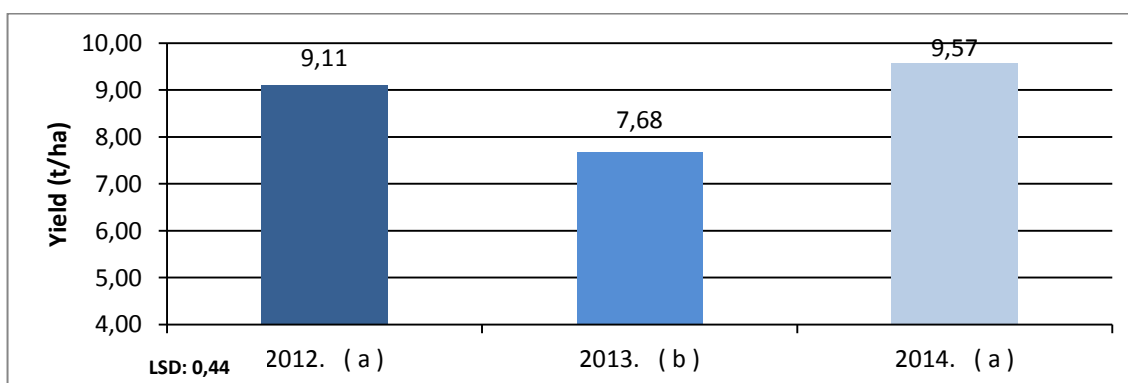


Figure 11.: The effect of crop year on maize yield (70 thousand plants per hectare) (Debrecen, 2012-2014)

In addition to tillage, fertilisation is an important agrotechnical factor, which can affect yield under irrigated conditions, with 70 thousand plants per hectare. Averaged over 2012-2014, fertilisation had a significant effect on the yield of maize.

After analyzing the effect of fertilisation, it was found that the amount of yield achieved at 240 kg/ha nitrogen (N 240 (a)) was significantly higher averaged over the three examined years compared to other fertiliser doses (N 120 (b) and control (b) (**Figure 12**)). The yield of 10 t/ha achieved by applying 240 kg/ha nitrogen is higher than the yield average of 1.59 t/ha by applying a nitrogen fertiliser dose of 120 kg/ha. In the case of control treatment, the yield of 7,97 t/ha is 2.03 t/ha lower than most obtained yields (10 t/ha).

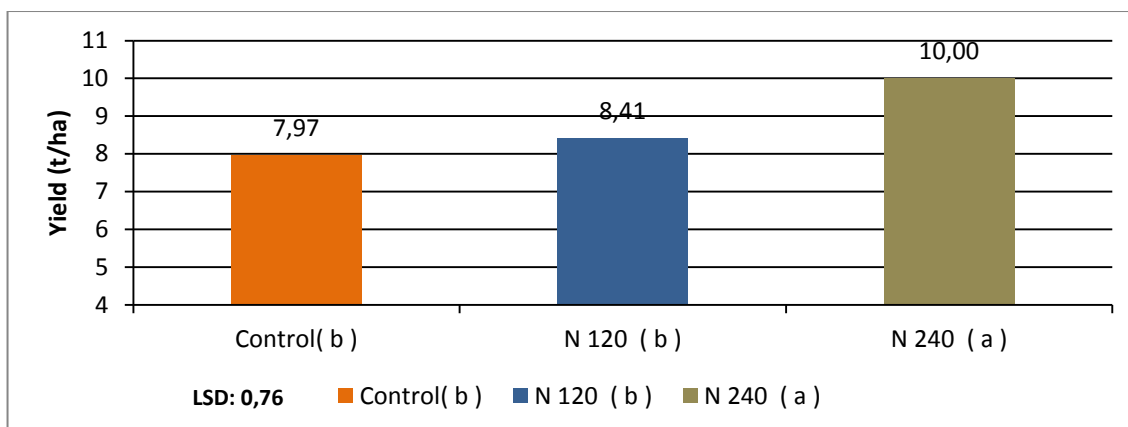


Figure 12.: The effect of fertilisation on yield (plant density: 70 thousand plants per hectare) (Debrecen, 2012-2014)

The most approximate value for the plant density used in practice is 70 thousand / ha value used in the research. The resulting fertiliser effect suggests that the highest amount of yield is determined by the amount of the largest amount of nitrogen in non-irrigated conditions.

The effect of tillage and crop year on starch yield (50 thousand plants per hectare)

The yield results and the effects of the starch yield per hectare in terms of soil cultivation, fertilisation, hybrid, plant density and weather (crop year) constituted another part of the experiment.

As it can be seen in **Figure 13**, averaged over 2012-2014, the maximum starch yield was achieved in the case of the spring tillage (a) method (5.94 t/ha). This yield is significantly higher than that of autumn ploughing (b) (5.33 t/ha) and spring ploughing (b) (5.19 t/ha).

In the case of non-irrigated conditions, in dry years, spring shallow tillage as a water-saving tillage process resulted in the highest yield (9.49 t/ha) using the same agrotechnical factors. (**Figure 6**) The highest starch yield is achieved in the case of the highest yield, as confirmed again, reported by *Makra* (2012).

As discussed above, the tillage methods of spring cultivation have resulted in the highest starch yield and yield. In the case of extreme crop years, it is important to preserve the water resources of our soils because, under non-irrigated conditions, the population can only use natural precipitation. For this purpose, the maximum yield and starch yields can be realized with the tillage method which best preserves the water base of the soils, with a reduced plant density (50 thousand plants/ha).

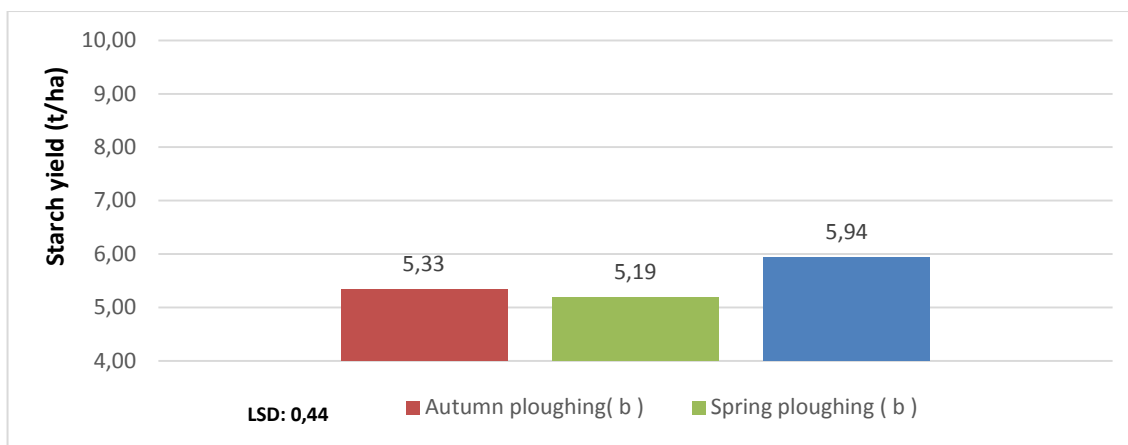


Figure 13. The effect of tillage on starch yield (plant density: 50 thousand plants per hectare) (Debrecen, 2012-2014)

In addition to tillage, the effect of fertilisation in the production technology was also studied in terms of starch yield.

Based on the Duncan's test results, it was found that the starch yield of 6.08 t / ha at 240 kg / ha nitrogen fertiliser dose (N 240 (a)) was significantly higher than the control (b) 5.06 t / ha and the starch yield obtained by applying 120 kg / ha nitrogen (5.33 t/ha) (N 120 (b)) (**Figure 14**).

It was found that when the reduced plant density (50 thousand plants/ha) was applied, the maximum crop yield was reached at a nitrogen dose of 240 kg/ha (9.73 t/ha). Starch yield was also shown to be the highest at the same dose.

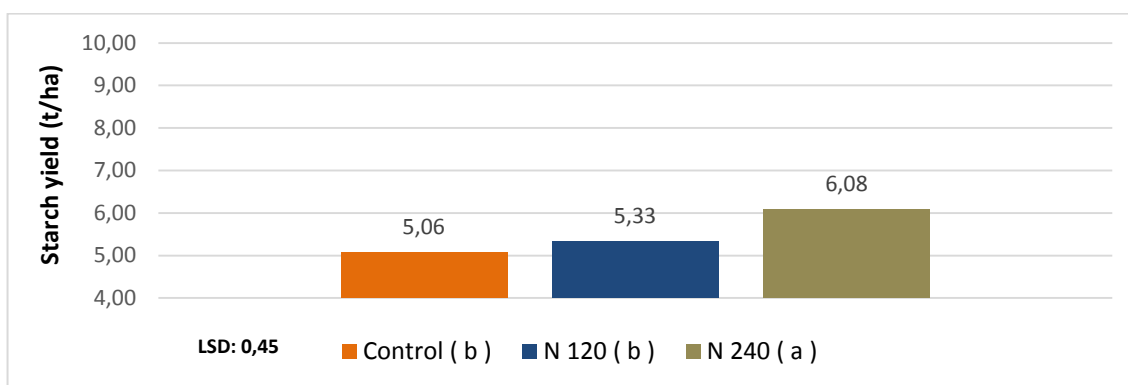


Figure 14. The effect of fertilisation on starch yield (plant density: 50 thousand plants per hectare) (Debrecen, 2012-2014)

The effect of tillage and crop year on starch yield (70 thousand plants per hectare)

The plant density of 70 thousand plants per ha is the most approximative value in relation to values used in practice. For this reason, the analysis of yield per hectare was to be performed with all the agronomic factors applied by us.

Based on the obtained results, it was concluded that, averaged over 2012-2014, in the case of 70 thousand plants / ha, tillage and crop year had a significant effect on starch yield.

Again, Duncan's test was used to perform a closer examination of the effect of tillage. The averages of the letters marked with different letters differ significantly (Sig. <0.05).

Of the three tillage methods in the experiment spring shallow tillage resulted in significantly higher starch yield (6.03 t/ha) than that of autumn ploughing (5.34 t/ha) and spring ploughing (5.28 t/ha) in the case of 70 thousand plants per ha (*Figure 15*).

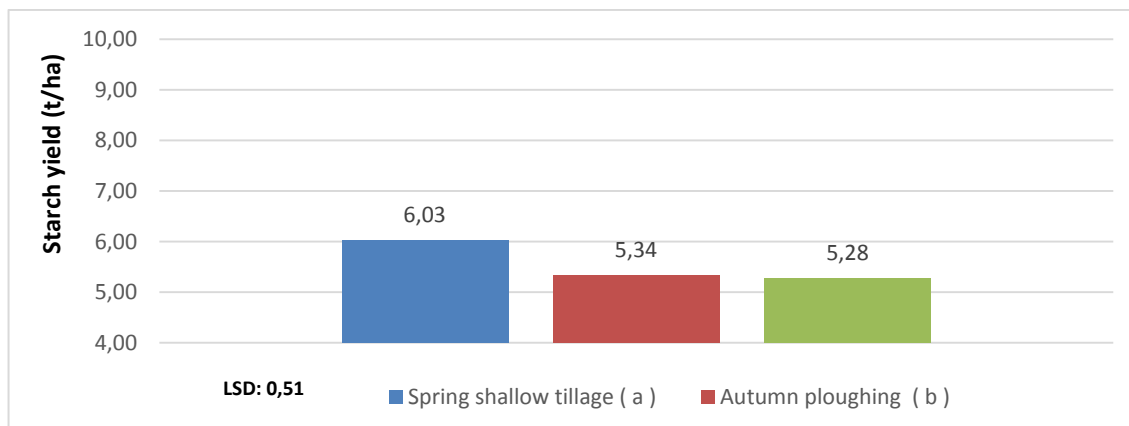


Figure 15. The effect of tillage on starch yield (plant density: 70 thousand plants per hectare) (Debrecen, 2012-2014)

Examining the crop year effect, it can be concluded that, as with previous experiences and statistical results, the crop year as a factor influences both maize yield and starch yield.

Averaged over 2012-2014, in the case of 70 thousand plants per ha, the starch yield of 2013 (b) (4,83 t/ha) was significantly lower than that of 2012 (5,69 t/ha) and 2014 (6,08 t/ha). Therefore, the average for extreme dry years (2012, 2013) remained below the average of the favorable year (2014) (*Figure 16*).

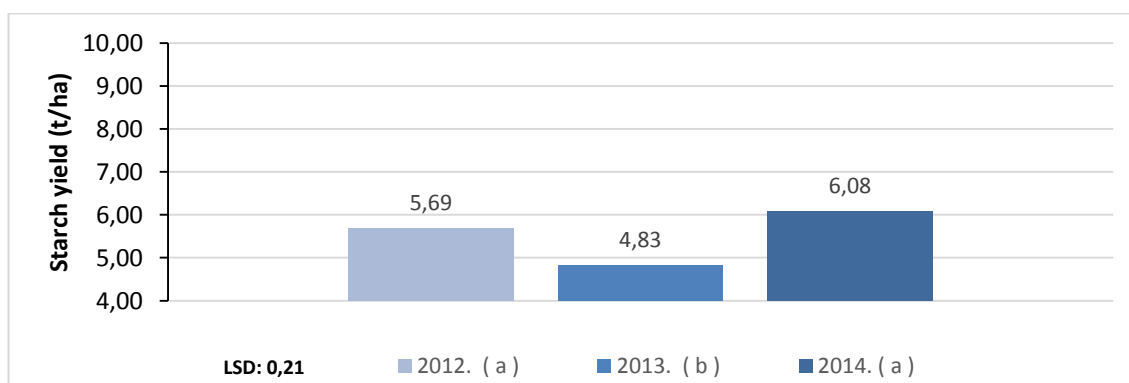


Figure 16. Starch yield of maize, averaged over the experimental years, plant density: 70 thousand plants per hectare (Debrecen, 2012-2014)

As regards the development of starch yield, we also wanted to find out about the effect of fertilisation on starch yield, in the case of a 70 thousand plants per ha.

Based on the obtained results, it was concluded that fertilisation and crop year had a significant effect on starch yield.

Based on data from **Figure 17**, it was found that the highest starch yield in the crop stand of a plant density value of 70 thousand plants per ha was obtained at 240 kg / ha fertiliser dose (6,26 t / ha). This value is significantly higher than the starch yield obtained in the control (b) (5.03 t/ha) and the 120 kg/ha nitrogen (N 120 (b)) treatment (5.33 t/ha).

The highest yield in the average of these years was also obtained at the 240 kg / ha nitrogen level. (**Figure 12**) As a result, it can be concluded that the highest starch yield was obtained in the case of the highest fertiliser dose applied.

In the case of drought years and 70 thousand plants per hectare, the highest starch yields was attainable at the highest fertiliser dose in non-irrigated treatment.

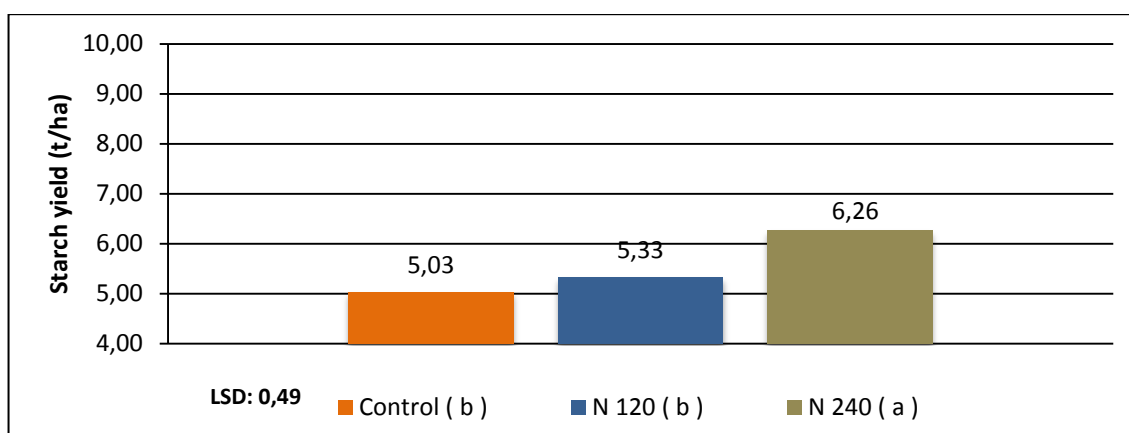


Figure 17. The effect of fertilisation on starch yield (plant density: 70 thousand plants per hectare) (Debrecen, 2012-2014)

CONCLUSIONS

Folloughing the examination and evaluation of the data, the folloughing conclusions can be drawn from the objectives:

(1) *Analysis of the effects of the examined years, the effect of crop year on yields;*

We quantified the effect of crop year on yield, using repeated measurement variance analysis. Based on the results of the repeated measurement of variance analysis, after examining the effect of crop year, it was concluded that the yields achieved in 2012 (9,33 t/ha) and 2014 (9,73 t/ha) were significantly higher than the yield obtained in 2013 (7,16 t/ha). This result confirmed the conclusions of several Hungarian researchers (*Csathó et al.*, 1991; *Kádár*, 1992; *Nagy and Huzsvai* 1995; *Nagy*, 2007b). In non-irrigated cultivation technologies, the crop year effect is the most significant in determining yields. Crop year was able to suppress fertilisation, tillage and hybrid selection in dry years. Thus, it had the most influential effect on crop yields.

(2) *Analysis of the effects of the examined years, the effect of crop year on starch yield;*

Among the nutritional properties, the starch content of maize is an important factor in the production of industrial ethanol, from which we can determine the yield per hectare in terms of crop yields. Based on the results obtained during the three examined years, it was concluded that, averaged over 2012-2014, in the case of 70 thousand plants per ha, the starch yield of 2013 (4,83 t/ha) was significantly lower than that of 2012 (5,69 t/ha) and 2014 (6,08 t/ha). Therefore, the average for extreme dry years (2012, 2013) remained below the average starch yield of the favorable year (2014). In the average of three years, we estimated that the highest starch yield was achieved in the year 2014 (6.13 t/ha), with 50 thousand plants per hectare. The starch yield of 4,50 t/ha in 2013 was significantly lower than that of 2012 (5,84 t/ha) and 2014 (6,13 t/ha). Therefore, the crop year effect was crucial also from the aspect of starch yield.

(3) *Analysis of the effects of tillage methods on yield during the examined years;*

The results of the maize yields showed that there were significant differences between the yields of the examined years, and in particular the yields achieved through the various tillage systems.

Based on the post hoc test, it can be concluded that in spring 2014, spring cultivation resulted in significantly higher yields than the yields achieved during the autumn ploughing and spring ploughing, with 50 thousand plants per hectare. In the case of the 70 thousand plants per hectare, in the year 2014, the highest yield resulted from autumn ploughing, i.e. autumn ploughing had a statistically significant effect on yield per hectare.

Based on the repeated measurement ANOVA, it was determined that, averaged over 2012-2014, and applying 50 to 70 thousand plants per hectare, both spring tillage methods resulted in the highest yield.

(4) *Analysis of the effects of tillage methods on starch yield during the examined years;*

In a favorable crop year - as in 2014 - tillage had a statistically significant effect on starch yield.

According to the post hoc test, the highest starch yield was obtained at 70 thousand plants per ha and autumn ploughing. In the case of applying a plant density of 50 thousand plants per hectare, spring shallow tillage resulted in the highest starch yield. Averaged over 2012-2014 and applying a plant density of 70 thousand plants per hectare, the highest starch yield can be obtained in the case of spring shallow tillage.

Based on the repeated measurement ANOVA, it was concluded that, averaged over 2012-2014, and applying 50 to 70 thousand plants per hectare, the spring tillage method resulted in the higher starch yield. We have found that under the changing weather conditions, a water-saving soil cultivation process results in the highest starch yield.

The statement made by *Makra* (2012) - i.e., the highest starch yield is linked to the highest yield -, has been certified in our research.

(5) *Analysis of the effects of fertilisation methods on yield during the examined years;*

The effect of fertilisation on the yearly crop yield could not be proven statistically by using the Post Hoc test.

Based on a repeated measurement variance analysis averaged over 2012-2014 and applying 50 and 70 thousand plants per hectare, the highest yield was obtained in the case of applying N 240 kg/ha + P₂O₅ 180 kg/ha + K₂O 212 kg/ha. The statement of various researchers, i.e., the amount of nitrogen applied has the highest role in achieving maize yield surplus (*Győrffy and I'só, 1966; Balláné, 1968; Latkovicsné and Krámer, 1968; Bocz, 1974; Bocz, 1976; Anda, 1987; Nagy, 1986; Ahmad, 2000; Berzsenyi, 2009a*) was confirmed by the performed measurements.

With regard to the applied dose, *Széll and Kovácsné (1993)* reported 200 kg/ha of nitrogen and *Werner (1983)* reported 214 kg/ha of nitrogen in non-irrigated conditions in monoculture to result in the highest yield. The fertiliser dose for the maximum yield achieved by us approximates these two literature data.

(6) *Analysis of the effects of fertilisation methods on starch yield during the examined years;*

The effect of fertilisation on starch yield could not be verified using a post hoc test. Based on a repeated measurement variance analysis averaged over 2012-2014 and applying 50 and 70 thousand plants per hectare, the highest starch yield was obtained in the case of applying N 240 kg / ha + P₂O₅ 180 kg / ha + K₂O 212 kg / ha.

We confirmed the conclusion of several scientists, i.e, nutrition, including nitrogen supply as an agrotechnical element, determines to the largest extent the size of the crop and, as a result, grain quality (*Genter et al., 1956; Veress, 1973; Jellium et al., 1973; Lásztity, 1975; Sarkadi, 1975; Getmanets és Klyavzo, 1981*).

Bocz (1976) obtained the same data as, i.e., nitrogen and phosphorus are the main factors which affect the nutritional value of the grain. Compared to the control, nitrogen alone was able to increase the crude protein content, but the combination with NPK resulted in the the highest amount of crude protein in the crop. This finding was later also shown by *Ványiné et al., (2012)*.

In the case of extreme crop years (2012, 2013), when the influence of various factors is greatly influenced by the weather, elevated amounts of nitrogen result in the highest amount of starch yield in the case of both plant density values (50 and 70 thousand plants/ha).

However, the highest amount of starch yields we have achieved and the corresponding nitrogen fertiliser dose of 240 kg / ha are largely different from that proposed by *Sárvári and Boros (2011)*, i.e., 80-90 kg/ha nitrogen dose is required to achieve maximum starch yield.

(7) Analysis of the effects of plant density on yield during the examined years;

Based on the performed measurements, the statement of *Pepó et al.*, (2002) was proved and confirmed by post hoc test that 50 thousand plants per hectare is considered to be justified in dry years, and 65-73 thousand plants per hectare is appropriate in average years. In the examined years, 11,61 t / ha was obtained in the case of spring shallow tillage and 50 thousand plants/ha. *Árendás et al.*, (2013) also suggested a similar plant density value, also in the case of growing FAO 300 hybrids.

However, the yield-increasing effect of 70 thousand plants per hectare was measurable in the case of autumn ploughing primary tillage (10,21 t/ha).

By applying the repeated measurement variance analysis, it was also proved that the choice of 50 thousand plants per hectare value is more favourable for dry years and it is advisable to apply spring shallow tillage to achieve the highest crop yield.

(8) Analysis of the effects of plant density on starch yield during the examined years;

As regards starch yield, there was no significant effect that could be justified by the use of a Post hoc test in the case of the extreme drought years (2012, 2013).

During the more favorable weather conditions in 2014, most of the starch yields were reached at 50 thousand plants per hectare, applying spring grass tillage (7,29 t/ha). Based on the repeated measurement ANOVA, it was concluded that, averaged over 2012-2014, the spring shallow tillage method resulted in the higher starch yield (6.03 t/ha) when applying 70 thousand plants per hectare, the

(9) Complex analysis of factors and the quantification of their interactions.

Considering the complex analysis of the applied factors (tillage, fertilisation, hybrid, plant density), it can be concluded that the post hoc test showed interaction between only in 2014 with respect to tillage and hybrid due to their effect on yield in the case of 50 thousand plants / ha. In the other experimental years, the interaction between each agrotechnical element was not statistically significant.

Following the performance evaluation with repeated measurement variance analysis, the following statements are made:

With regard to the average yield per hectare and 50 thousand plants per hectare, the interaction between crop year and tillage was significant averaged over 2012-2014.

In relation to the yield per hectare, there is a significant correlation between crop year and tillage, when averaged over 2012-2014 and applying a plant density of 50 thousand plants per hectare.

NEW SCIENTIFIC FINDINGS

(1) On the basis of the tillage method results, it was found that the highest amount of yield and the highest starch content were achieved by applying autumn ploughing at 70 thousand plants per hectare and spring shallow tillage at 50 thousand plants per hectare on mid-heavy calcareous chernozem soil in the case of non-irrigated conditions.

(2) On the basis of the plant density experiments, it was concluded that on mid-heavy, calcareous chernozem soil and under non-irrigated conditions, RENFOR achieved the highest yield and, therefore, the highest starch yield in the case of 70 thousand plants per hectare, while NEFFEL reached the highest respective values in the case of 50 thousand plants per hectare.

(3) The highest yield and yield safety was obtained on mid-heavy calcareous chernozem soil in dry years when applying water-preserving spring shallow tillage.

(4) The effect of the weather on yields and on starch yields in drought years in non-irrigated conditions exceeds the effect of all other agrotechnical factors.

FINDINGS TO BE USED IN PRACTICE

1. In accordance with the climate change, we recommend to the growers, under irrigated conditions, to reach the maximum yield, for spring cultivation in the case of 50 thousand plants per hectare, and in the autumn cultivation of 70 thousand plants per hectare as basic cultivation.

2. The extreme weather conditions, it is important to reduce the production risk that our research can access by using different FAO hybrids.

3. Based on our results, we recommend the use of water-saving spring grasses for medium-sized calcareous chernozem soil farms for the purpose of maintaining crop safety.

4. Our research results contribute to maximizing the starch content of maize, which helps producers to make decisions about the specific use of the final product.

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List of publications related to the dissertation

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