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THE EFFECT OF CROP DENSITY ON THE PRODUCT YIELD, YIELD SAFETY AND QUALITY OF SUNFLOWER HYBRIDS

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1. INTRODUCTION

As regards taxonomic category, the classification of sunflower (Helianthus annuus L.) is as follows: Magnoliosida (Dicotyledonea) class, Asterales order, Asteraceae (Compositeae) family, Helianthus genus. In Hungary, the breeding of sunflower started in the 1930s, resulting in varieties of better quality and higher yields. The objective of breeding was to produce varieties that can adapt to different cultivation areas, have high oil content, low stalk and big head diameter. In the 1940s the cultivation area constantly changed. To satisfy the needs of the war economy and the increasing export demand, the growing of sunflower was stipulated, therefore the cultivation area reached 280 000 ha in 1949. At the end of the '50s the cultivation area significantly dropped (75000 ha). In 1975, the domestic production area was 130 thousand ha, which positioned Hungary as the 10th biggest sunflower producer in the world. The institutes realized the importance of genetic research and hybridisation already in the 1960s. Between 1960 and 1970, important achievements were made in sunflower breeding. The first sunflower hybrids generated by the methods of genetic and later on cytoplazmic male sterility were introduced in commercial production in the '70s. In Hungary, farmers joined to the production of sunflower hybrids a few years later, because here the open pollinated hybrids used in commercial production satisfied both the needs for quality and yield. The introduction and spread of sunflower hybrids resulted in increased cultivation area and higher yields.

In Hungary, the variety change has come early, in the beginning of the 80s; therefore, the increase of the yields has grown. Favourable changes in the variety structure of production and in the cultivation technologies lead to the increase of the cultivation area. In 1974, the production area was 113 000 ha, while in 1984 it was 317 000 ha.

The increase of the production area resulted by several factors. The use of sunflower hybrids allowed for the increase of yields. Sunflower is one of the most stable crop of the crop cultures cultivated on big acreages. The export prospects of sunflower seed and oil were excellent and these factors inspired farmers. By the end of 1985, the acreage of domestic sunflower breeds exceeded 25%, and national genotypes together with variety GK 70 were cropped on 39% of the sunflower cultivation area. In the 1990s, due to the EU's agricultural reforms and to extreme climatic conditions the oil crop market was instable. Sunflower production of the world reached 22 million t by the 1990s, which is 40 % increase within 5 years. From 1995 the primary goal of breeders was to produce hybrids with high yields and balanced production to satisfy the requirements of intensive production. In Hungary, the cultivation area of sunflower was 473 000 ha in 1996. Out of the 44 certified hybrids, 70 % of the cultivation area was used by 5 hybrids [(VIKI (32%), U-55-E (16%), Kamil (13%), Iregi HNK-173 (7%), Florakisz (3%)]. Due to high precipitation in the period between 1996 and 1997, stalk diseases had a negative influence on seed production, therefore high amounts of seed had to be imported that changed the domestic variety selection. At that time in Hungary, hybrids developed by the Cereal Research Institute and Fodder Crop Research Institute (VIKI, Albéna, Sonrisa hybrids) were grown on 80 % of the acreage.

Recently, worldwide sunflower production has been increasing. In 2005, 23.4 million ha sunflower was harvested worldwide, while in 2000 the production area was only 21.1 million ha. Similarly, total sunflower seed production has unexpectedly increased. In 2004, total seed production was 26.5 million t. According to 2004 FAPRI (Food and Agricultural Policy Research Institute) predictions, worldwide sunflower production will reach 30 million tons by 2015, however, already in 2005 it exceeded 31 million tons. Former states of the USSR (Russia, Ukraine) are still the biggest producers of the world, but India, Argentina, China, the USA, Romania, France, Spain, Hungary, Turkey and South-Afrika also highly contribute to total sunflower production.

2. TOPIC OF INTEREST

Sunflower is the most important oil crop and is planted on the biggest acreage in Hungary. In has a significant role in Hungary's crop oil production and became one of the major crops in the Hungarian crop production sector. During the last 30 years, the cultivation area increased from 9.2 million ha to 23 million ha. Sunflower is a typical commercial cash crop, which fits well in the structure of arable farming. Because in terms of acreage the most significant crops are corn and cereals, the partial monoculture cultivation cannot be avoided. Sunflower production is a way to eliminate this problem, therefore it has an important role both in planting and ecological points of view.

Sunflower well adapts to Hungary's climatic conditions and sunflower production is easily practicable in our country.

Modern and economical sunflower production can be reached by optimizing several factors that influence production. Genetics, production technology, and agroecological factors have a significant effect on yield and quality. Yield potential (6-7 t ha^{-1}) and oil content (50-55 %) of today's hybrids has increased. The improved yield potential increased the sensitivity to the factors of agroecology and cultivation technology. Being good at adapting to extreme conditions, sunflower was grown on areas of low productivity in Hungary. Today's hybrids cannot be produced in extensive circumstances. To reach sufficient profit, at least average expenditure is needed. Currently the hybrid selection is wide-ranged both in terms of product yield and quality. The biggest problem of hybrids is imbalance production.

Today, to increase the effectiveness of sunflower production it is essential to work out hybrid-specific production technologies. The increase of hybrid selection accounted for genotype tests as regards critical elements and genotype x environment interactions. The effect of crop density change is a complex influencing factor, affecting both the sunflower yield and the characteristics of plant physiology and pathology.

Complying with the technological requirements of cultivation is the basis for successful production. In this regards, significant changes have taken place during the last decade. The objective of the researches was to work out the most suitable technology for the modern hybrids so that producers can make the best of the yield and quality potential at the given cultivation circumstances. Sunflower is a highly technology-sensitive crop; therefore, to increase the safety of production the optimization of these factors is necessary.

Sowing technology suitable for the crop year and the genotype is the base of successful sunflower production. Apparently, examinations regarding the sowing technology (sowing time, crop density) are of high importance. Optimizing these agrotechnical factors is also highly important in terms of increasing the yield and production safety.

Agroecological, biological and agrotechnical factors all influence the crop density of sunflower.

The reaction of sunflower hybrids on crop density change is different. Some hybrids are more some are less sensitive to this parameter. In different crop years, the crop density optimums of the different genotypes are also different. Nutritional value of the soil also influences crop density. On soils with good water and nutritional management, crop density to be increased by 10000-15000 plant ha^{-1}.

In Hungary, the yield and quality is primarily determined by fungal infections, while viruses and bacteria are less important.

The actual production loss is influenced by the resistance of hybrids to diseases, the climatic conditions and the agrotechnical factors. Out of the climatic conditions, the amount of precipitation in the growing season has vital importance, as some of the most dangerous diseases prefer warm weather (Macrophomia phaseolina, Diaporthe helianthi) and some tolerate colder circumstances (Plasmopara halstedii, Sclerotinia sclerotiorum, Botrytis cinerea).

Summarizing, high yield can be expected in warm years with less-than-average precipitation. However, in years with high amount of precipitation, especially if a high amount of rain falls in the time of flowering and maturing, there might be a significant loss due to head rot. This latter occurred in 2005, when except from downy mildew, almost all types of fungal infections emerged in some degree. (Sclerotinia sclerotiorum, Macrophomia phaseolina, Diaporthe helianthi, Botrytis cinerea, Alternaria ssp., Phoma macdonaldii).

In my research, supervised by Prof. Dr. Péter Pepó head of department, I examined the reaction on Plant density change of different sunflower genotypes at Látókép Farm and Regional Research Institute of the University of Debrecen, Centre of Agricultural Sciences between 1999-2005.

The objectives of my research were the following:

- analysis of the effect of the examined sunflower genotypes on the product yield and oil content,
- analysing the crop year on sunflower genotypes,

- analysing the different plant density parameters on the product yield and oil content of sunflower hybrids,
- analysing the plant density change on the stalk strength
- analysing the damage caused by Diaporthe helianthii, Sclerotinia sclerotiorum and head diseases at different plant density levels in different years,

3. MATERIAL AND METHODS

3.1. The soil characteristics and water conditions of the research site

The research was conducted at the Látókép farm and Regional Research Institute of the University of Debrecen, Centre of Agricultural Sciences. The research institute is situated by Road 33, 15 km from Debrecen in the Hajdúság. The soil of the research site is calcareous chernozem developed on loess with deep mould layer. The soil is semi-hard ground (KA=43) loam and is in good condition.

The depth of the fertile layer is 80-90 cm, in which 40-50 cm evenly contains humus. The average humus content is 2.76 %. $CaCO3$ appears in the soil profile in the transition level at 75 cm. Lime is usually visible on the soil particles as calcareous coating, in this layer the lime content ranges from 10 to 13 %. The pH (KCl) in the cultivated layer ranges between 6.3 and 6.5.

Analysing the water management characteristics of the soil of the research area, we found that typically to chernozem soils, it has favourable water management characteristics. According to Várallyay's classification, it belongs to category IV., i.e. soil with good water management and water holding capacity.

The minimum field water capacity (VKmin) ranges between 33.65 and 46 %, the non-available water (HV) ranges between 8.5-15.7 % in the 0-200 cm soil layer.

Soil water table is in 8-10 m depth, the soil can store a substantial amount of water.

3.2. Evaluating the agrotechology of the research

The agrotechnology of the research included the most common soil preparation methods. The acreage was sown by manual precision driller to ensure exact crop density. Harvesting was performed by Sampo plot combine supplied with a special adapter. After harvesting the raw yield and the moisture content were measured. The moisture content of the yields was set to 8 % and the oil content set to dry matter standardized. Depending on the crop year, the sowing was performed between 10-17 April and the harvesting between 9-21 September (table 1.). Table 2 shows the hybrids in the research.

Table 1. **The sowing, harvesting time and forecrops of the experiment (Debrecen-Látókép, 1999-2005)**

Tenyészév	Sowing time	Harvesting time	Forecrop
1999.	april 14	september 9-10.	winter wheat
2000.	april 12.	september 9.	winter wheat
2001.	april10.	september 21.	maize
2002.	április17.	september 12.	maize
2003.	april15.	september 10.	maize
2004.	april16.	september 15.	maize
2005.	april15.	september 16.	maize

Table 2. **Sunflower hybrids used in the research (Debrecen-Látókép, 1999-2005)**

	The analysed sunflower hybrids						
	1999.	**2000.**	**2001.**	**2002.**	**2003.**	**2004.**	**2005**
1.	Alexandra/PR	Alexandra/PR	Alexandra/PR	Alexandra/PR	Alexandra/PR	Alexandra/PR	Alexandra/PR
2.	Aréna/PR	Aréna/PR	Aréna/PR	ArénaPR	Aréna/PR	Aréna/PR	Aréna/PR
3.	Florix	Florix	Diabolo	Diabolo	Diabolo	Diabolo	Diabolo
4.	Rigasol/PR	Rigasol/PR	Rigasol/PR	Rigasol/PR	Rigasol/PR	NK Brio/PR	NK Brio/PR
5.	Hysun 321	Hysun 321	Hysun 321	Floyd	Altesse/RM	Altesse/RM	LG 56.65
6.	Flores	Larisol	Larisol	Larisol	Larisol	Astor	LG 54.15
7.	Natil	Lucil	LG 53.85	PR63A82	Astor	PR63A82	PR63A82
8.	Lympil	Lympil	Lympil	Magnum	PR64A63	PR64A63	PR64A63
9.	Trentil	Fleuret	Fleuret	LG 53.85	LG 53.85	Rumbasol	Rumbasol
10.	Util	Util	PR63A90	Louidor	Louidor	Louidor	PR64A30

3.3. Methodology used for the evaluation of the results

The research plots are arranged randomized in 4 repetitions. The plot size was 15 m^{-2}. 10 hybrids were used in each research year. 5 different crop density levels were used (from 35000 to 75000 plant ha^{-1}). We have documented the data on fenologic, fenometric, shooting and flowering dynamics, as well as the agronomic and pathologic traits in four repetition.

The methodology for the analysis of the infection was as follows:

- As regards Diaporthe, the infection of leafs and the stalk of a given plant exceeded 20%.
- As regards head rot, at least 25% of the head was infected.
- The plant was considered as fallen if the angle of the stalk exceeded 45%.
- We considered plants where the head remained on the stalk, but the connection between the stalk and the stem partially or completely was broken.

To determine the degree of infection, we considered the number of plants in the plot as well as the number of the infected plants.

The statistical evaluation has been done by SPSS 13.0 program.

- The statistical evaluation was done by two-coefficient variance analysis (hybrid, crop density, relationships), furthermore, we summarized the data of the seven years in a three-coefficient variance analysis (hybrid, crop density, year, relationships) with 5% standard error. LSD test was done to compare the mean values and SD was calculated according to Sváb (1981).

During the statistical evaluation we

- conducted Pearson's bilateral correlation analysis to reveal the relationship between the weather and pathological factors,
- conducted quadratic regression analysis to determine the relationship between the crop yield and crop density of Aréna/PR and Alexandra/PR sunflower hybrids,
- conducted Kang's stability analysis for those hybrids being used in the research for 3 or more years, allowing for visual evaluation in the examination of the interaction between the hybrids and the environment. The illustration of the linear functions determined make the determination and the evaluation of the relationships easier.
- determined the standard deviation (CV%) during the analysis of the crop yield.

3.4. Climatic conditions in the research years

The weather of 1999 was favourable for sunflower production both in terms of temperature and precipitation. In the growing season the precipitation exceeded the 30 year average by 27.9 mm and the temperature by 1.2 ºC. The precipitation was of even distribution. The dry and warm weather in 2000 was favourable for sunflower. In the growing season the amount of precipitation was significantly lower than the 30 year average (-158.3 mm), and the average temperature exceeded it by 2.1 ºC. In 2001 the amount of precipitation was average (deviation from the 30 years average was 0.7 mm). The distribution of precipitation was uneven; the highest amount fell in June-July (160.4 mm, 77.7 mm). The average temperature exceeded the 30 year average with 1.3 ºC. In 2002, the amount of precipitation was insufficient. In the growing season the precipitation was 119.5 mm less than the 30 year average. The average temperature exceeded the 30 year average by 0.5 ºC. The weather was warm and dry in 2003. The precipitation was significantly lower than the average in the growing season (-131.1 mm) and the average temperature exceeded the 30 year average (1.7 ºC). In 2004 the precipitation fallen in the growing season was average (311.1 mm), however, of very uneven distribution. The precipitation in July was more than twice the 30 year average (142.2 mm). The temperature was average. The precipitation in the growing season significantly exceeded the 30 year average (133.3 mm). The distribution of the precipitation was uneven. The highest amount of precipitation fell in July and August (99.7 mm, 135.7 mm).

4. RESULTS

4.1. The effect of crop density on hybrid height

The crop height ranged between 142.2 and 247.8 cm. At each level of plant density and in the average of the plants crop height was highest in 1999. Between 2001 and 2005, crop height in the average of the hybrids and of the plants ranged between 161.3-195.6, no significant deviation was experienced. Increasing crop density increased height as well. Crop height in the average of the hybrids and of the years was 158.4 cm at 35000 ha^{-1} and 175.4 cm at 75000 ha^{-1} (Table 3).

The highest hybrids in the research years were *Lympil* (234.1 cm), *PR64A63* (180.4 cm), *PR63A82* (183.4 cm), *PR63A90* (163.6 cm), the lowest hybrids were *Florix* (153.4 cm), *Diabolo* (142.8 cm), *Louidor* (153.8 cm) and *LG 53.85* (152.0 cm).

Table 3. **Relationship between crop density and crop height in the average of hybrids (Debrecen – Látókép, 1999-2005)**

Crop height (cm)									
Plant density ha^{-1}	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**Average**	**LSD 5%**
35000	183,5	155,4	146,6	153,4	160,7	153,1	156,2	*158,4*	**4,60**
45000	188,1	161,0	156,3	158,3	165,0	162,5	162,0	*164,7*	**4,93**
55000	196,5	165,7	164,7	164,2	168,2	166,7	163,3	*169,9*	**4,66**
65000	203,2	169,3	169,3	166,1	168,2	168,2	168,4	*173,2*	**4,91**
75000	207,0	170,2	169,6	168,0	169,2	173,2	170,3	*175,4*	**4,87**
Average	***195,6***	***164,3***	***161,3***	***162,0***	***166,3***	***164,8***	***164,1***	***168,3***	
LSD 5%	**2,91**	**2,43**	**1,90**	**1,94**	**2,25**	**2,44**	**2,73**	***2,48***	

4.2. The effect of plant density on the stalk strength of sunflower hybrids

In years with high amount of rainfall, the rate of disease occurrence, and … is higher. In humid years (1999, 2001, 2004, 2005) the rate of falling over was over 7 % (7.4 %, 13 %, 12.3 %, 15.6 %) in the average of the hybrids and plant density. In contrast, in average and dry years (2000, 2002, 2003) the rate of fallen plants was under 7 % (3.9 %, 6.1 %, 6.8 %). The rate of falling over was lowest at 35000-45000 ha^{-1} plant density levels and highest at 65000-75000 ha^{-1} in the research years. In average and dry years the rate of falling over was lowest with hybrids Util (2.2%), Louidor (2.8%) and PR64A63 (4.2%). In years with high amounts of rainfall, Arena/PR (6%), LG 56.65 (12.0%), PR63A90 (5.8%) and Flores performed best. As an effect of increased plant density (from 35000 ha^{-1} to 75000 ha^{-1}) in 1999, 2001, 2004 and 2005 falling over increased 10 % (10.8 %, 11.0 %, 12.4 %, 16.5 %). In 2000, 2002 and 2003, the increased plant density had a smaller effect on the stalk infections of the hybrids (3.2 %, 5.4 %, 4.5 %). No significant differences were experienced in terms of falling over at low levels of crop density (35000-45000 ha^{-1}), however, at 65000-75000 ha^{-1} plant density level there was a significant difference between the different years in the average of the hybrids. *(Table 4).*

Table 4. **Stem lodging (%) in the average of sunflower hybrids between 1999-2005 (Debrecen-Látókép, 1999-2005)**

Stem lodging (%)									
Plant density ha^{-1}	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**Average**	**LSD 5%**
35000	3,0	2,5	6,9	3,6	4,5	6,7	7,3	*4,9*	**1,01**
45000	3,3	2,7	10,1	4,0	5,4	8,4	10,0	*6,3*	**1,33**
55000	5,3	3,8	14,4	5,9	7,0	10,5	15,6	*8,9*	**1,65**
65000	11,6	5,0	15,8	8,2	8,2	16,6	21,5	*12,4*	**3,73**
75000	13,8	5,7	17,9	9,0	9,0	19,1	23,8	*14,0*	**2,49**
Average	***7,4***	***3,9***	***13,0***	***6,1***	***6,8***	***12,3***	***15,6***	***9,3***	
LSD 5%	**0,62**	**2,05**	**0,70**	**2,81**	**0,54**	**1,20**	**1,14**	***1,27***	

The extent of head rot ranged from 0.7% to 38.6 %. This index was calculated in the average of the hybrids and of the plant density, and was lowest in 2000 (1.6 %). In 2005, which was the coldest year with the highest amount of precipitation, the infection in the average of the hybrids and plant density was significantly higher than in earlier years (14.4 %). In 2003, head rot infection was 3.0 %. In 1999, 2001, 2002 and 2004 in the average of the hybrids and plant density there was no significant difference in terms of head rot (7.7 %, 6.1 %, 6.9 %, 6.1 %). With increasing crop density in the average of the hybrids head rot infections increased every research year. At low plant density levels (35000-45000 ha^{-1}) there was no significant difference. The values calculated in the average of the hybrids and the growing seasons stayed below 6 % at 35000-55000 ha^{-1} plant density levels (3.4 %, 4.3 %, 5.9 %). More dynamic increase was experienced at 65000-75000 ha^{-1} plant density levels (8.8 %, 10.4 %) *(Table 5).*

PR63A90 (2.9 %), *Util* (4.9 %), *Alexandra*/PR (2.0 %) and *LG 54.15* (7.5 %) were most resistant to head rot in years with high amount of precipitation. In terms of resistance, in dry and average years *Lympil* (1.3 %), *Alexandra*/*PR* (2.4 %), and *Rigasol*/*PR* (1.8 %) performed best.

Table 5. **Broken head (%) in the average of sunflower hybrids between 1999-2005 (Debrecen-Látókép, 1999-2005)**

Broken head (%)									
Plant density ha^{-1}	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**Average**	**LSD 5%**
35000	4,7	1,1	3,4	3,8	2,2	3,5	4,9	*3,4*	**0,88**
45000	5,1	1,3	4,7	4,3	2,5	4,9	7,2	*4,3*	**1,20**
55000	7,2	1,6	6,1	7,3	3,2	5,8	9,8	*5,9*	**1,39**
65000	10	1,9	7,9	8,5	3,3	7,5	22,7	*8,8*	**1,96**
75000	11,3	2,0	8,6	10,8	3,9	8,7	27,3	*10,4*	**3,13**
Average	***7,7***	***1,6***	***6,1***	***6,9***	***3,0***	***6,1***	***14,4***	***6,5***	
LSD 5%	**2,62**	**0,11**	**0,42**	**0,53**	**0,30**	**0,63**	**1,16**	**1,13**	

4.3. The effect of plant density on infection by white mold (Sclerotinia sclerotiorum)

The tolerance of hybrids towards Sclerotinia infection was satisfactory. No significant damage was experienced in either research year. Between 1999-2005, infection with Sclerotinia in the average of the hybrids and crop density ranged from 0.6 % to 4.7 %. The amount of precipitation in the growing season and plant density proved to be significant factors in terms of Sclerotinia infection. In years with high amounts of rainfall (1999, 2001, 2004, 2005) the infection was relatively higher (2.6 %, 3.0 %, 2.2 %, 4.7 %). The highest infection occurred in 2005, which was extremely wet, where the increase of plant density increased the infection rate from 2.0 % to 7.8% in the average of the hybrids. In drier years (2000, 2002, 2003) the increase of plant density had a little influence on Sclerotinia infection (0.6 %, 0.3 %, 0.3 %)*(Table 6).*

Relatively higher deviation amongst the cropping years in terms of Sclerotinia infection was experienced only at higher plant density levels.

In dryer and average years *Alexandra/PR* (2.0 %), *Diabolo* (0.5 %) and *Rigasol/PR* (0.4 %) performed best. In years with high amount of precipitation Lympil (1.9 %), *PR63A90* (1.7 %), *PR64A63* (1.4 %), *LG 54.15* (3.2 %) proved to be the best in terms of resistance to Sclerotinia.

Table 6. **White mold *(*Sclerotinia sclerotiorum) (%) infection in the average of the hybrids (Debrecen-Látókép, 1999-2005)**

Sclerotinia sclerotiorum (%) infection									
Plant density ha^{-1}	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**Average**	**LSD 5%**
35000	1,7	1,1	1,9	0,6	0,4	1,4	2,0	*1,3*	**0,21**
45000	2	1,2	2,1	0,6	0,5	1,6	2,7	*1,5*	**0,29**
55000	2,8	1,5	3,0	0,7	0,6	2,0	4,2	*2,1*	**0,55**
65000	3,0	1,5	3,8	0,9	0,7	2,7	6,9	*2,8*	**0,47**
75000	3,4	1,7	4,5	0,9	0,7	3,4	7,8	*3,2*	**0,49**
Average	***2,6***	***1,4***	***3,0***	***0,7***	***0,6***	***2,2***	***4,7***	***2,2***	
LSD 5%	**0,15**	**0,46**	**0,20**	**0,09**	**0,08**	**0,15**	**0,42**	**0,27**	

4.4. The effect of plant density on the development of stalk spots and shredding of the stalk caused by Diaporthe helianthi infection

In terms of hybrids and crop density, more significant deviations were found with Diaporthe infection than was with Sclerotinia in the examined growing seasons. The examined sunflower hybrids are less resistant to Diaporthe, therefore the crop year has a great effect on the emergence and dynamics of Diaporthe infection.

Infection was most serious in 1999, 2001 and 2005 in the average of the hybrids and crop year (73 %, 67 % and 62 %). In dryer years (2000, 2002, 2003) Diaporthe infection was less serious (7

%, 27 %, 18 %). In 2004, Diaporthe emerged relatively late and the average rate of infection was 18%. In years with high amount of rainfall (1999, 2001, 2005) infection was serious even at 35000-45000 ha^{-1} crop density levels (44 %-65 %) and at 75000 ha^{-1} exceeded 80%. In dry and average years (2000, 2002, 2003) and at low plant density levels the infection was less serious (4-22 %) and the change was not significant either (at 75000 ha^{-1} it ranged from 9 % to 34 %) *(Figure 1).*

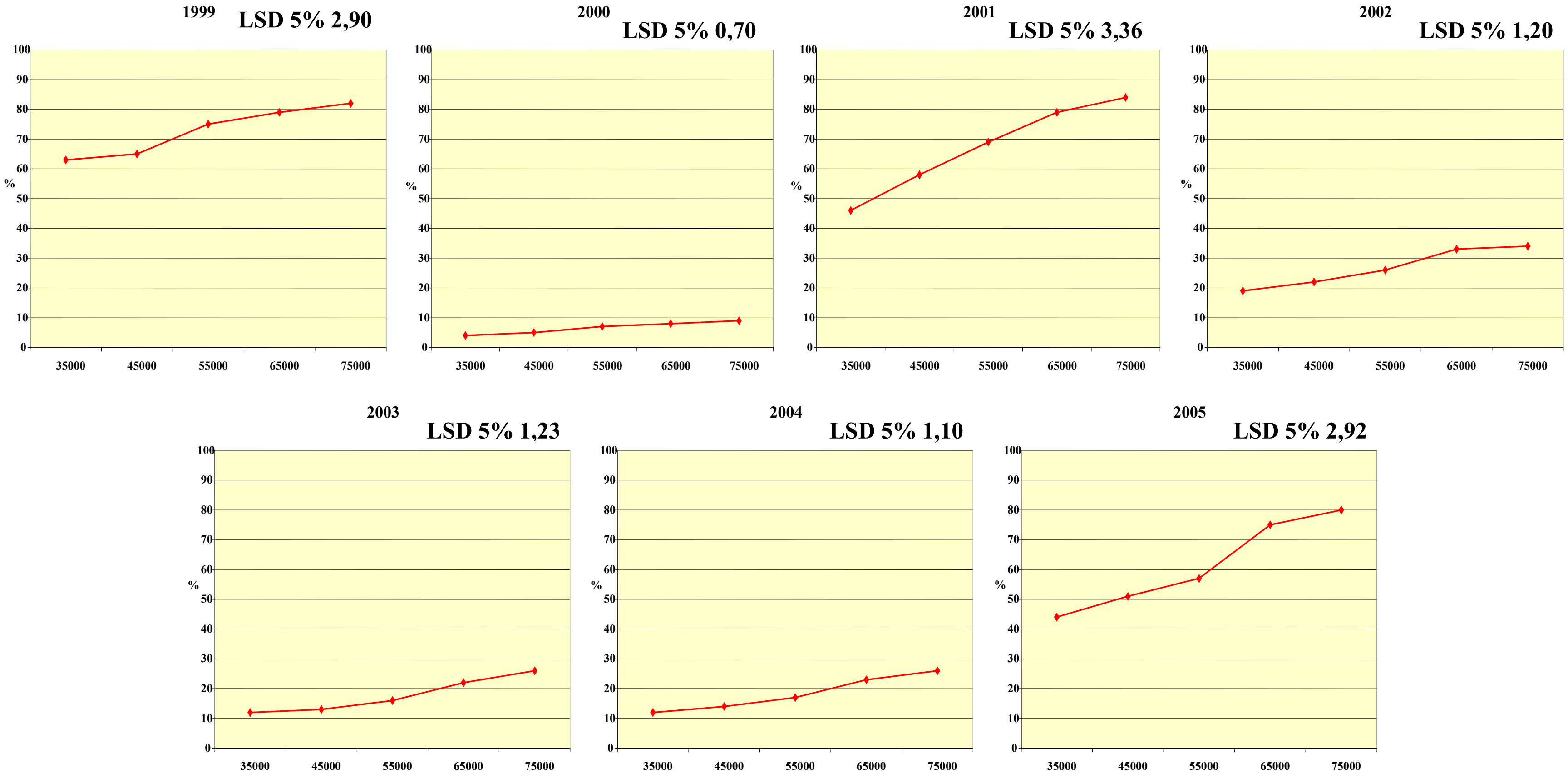
In years with high amount of rainfall, the most tolerant hybrids to Diporthe were Util (43 %), Aréna/PR (54 %) and *LG 56.65* (52 %). In dry and average years *Uti*l (3 %), *Magnum* (18 %), *Alexandra/PR* (9 %) and *Aréna/PR* (12 %) were the most tolerant hybrids.

4.5. The effect of plant density on head infections of sunflower hybrids

Head infection ranged from 0.9 % to 42.2 % in the research years. The infection was greatest in 2003, 2004 and 2005 in the average of the hybrids and crop density (9.3 %, 13.0 %, 20.6 %). Lower infection rates were experienced in the average of the hybrids and the crop years in 1999, 2000, 2001 and 2002 (6 %, 1.7 %, 7.7 %, 5.8 %). In years with high amount of rainfall *Natil* (3.1 *%), Alexandra/PR* (5.6 %), *PR63A82* (1.6 %) and *LG 56.65* (14.2 %) were most resistant to head infection. In dry and average years *Alexandra/PR* (5.1 %), *Rigasol/PR* (3.9 %) and *Hysun 321* (1.2 %) performed the best.

Examining head disease infections at different plant density levels in the average of hybrids, we found that at lower levels of plant density (35000-45000 ha^{-1}) the infection was relatively low (1.3 %-7.6 %), except from 2005. In 2005, the infection rate was 12.5 % already at 35000 ha^{-1} plant density level, and at 55000 it exceeded 20 %. Due to increased plant density level, the increase of infection was smallest in 2000 and 2002 (0.6 % and 3,9 %). In2004 and 2005, increasing the plant density level from 35000 ha^{-1} to 75000 ha^{-1} increased head infections by 15.5

Figure 1. **Trends of Diaporthe infection in the case of different plant density in the hybrids average (Debrecen – Látókép, 1999 – 2005)**



%. In the average of the hybrids and the crop years, increasing the plant density levels increased the infection rate from 5.8 % to 12.5 %. *(Table 7).*

Table 7. **Head infections (%) in the average of sunflower hybrids (Debrecen-Látókép, 1999-2005)**

Head infections (%)									
Plant density ha^{-1}	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**Average**	**LSD 5%**
35000	4,1	1,3	4,3	4,0	6,7	8,0	12,5	*5,8*	**1,14**
45000	4,4	1,4	4,8	4,2	7,6	9,6	16,6	*6,9*	**1,41**
55000	6,3	1,6	7,3	5,8	9,6	12,4	20,7	*9,1*	**1,67**
65000	7,3	2,1	11,1	7,1	10,5	16,3	25,3	*11,4*	**2,22**
75000	7,9	1,9	11,1	7,9	12,0	18,8	28,0	*12,5*	**2,37**
Average	***6,0***	***1,7***	***7,7***	***5,8***	***9,3***	***13,0***	***20,6***	***9,2***	
LSD 5%	**0,28**	**0,11**	**0,48**	**0,38**	**0,65**	**0,62**	**1,36**	**0,99**	

4.6. The effect of plant density on sunflower yield

The agrotechnical factors all influence the product yield of sunflower hybrids. In years with high amounts of rainfall, because the attacks and damages of pathogens were more severe, the product yield significantly decreased. Due to the extreme precipitation in 2005, the product yield in the average of the hybrids and the plant density was the lowest among the research year (2821 kg ha^{-1}). The highest product yields (4237 kg ha^{-1}, 3927 kg ha^{-1}, 4304 kg ha^{-1}) were obtained in dry, warm years (2000, 2002, 2003). In years with higher amount of precipitation (1999, 2001, 2004) average or lower than average yields were harvested (3616 kg ha^{-1}, 3169 kg ha^{-1}, 3658 kg ha^{-1}).

Between 1999-2004, the highest product yields were obtained at 45000-65000 ha^{-1} plant density levels. Both increasing and decreasing plant density caused the product yield to decrease. Evaluating the product yield at different plant density levels in the average of the hybrids, we found that because of the precipitation in 2005, the highest yield was obtained at 35000 ha^{-1} plant density level, and increasing the plant density level resulted in decreased product yield. Due to the favourable weather conditions for sunflower in 2003, the product yield in the average of the hybrids (4626 kg ha^{-1}) was highest among the research years and was reached at 45000 ha^{-1} plant density levels. In 1999 and 2001-2004 the highest average yield was obtained at 45000-55000 ha^{-1} plant density levels *(Table 8).* In the average of the crop years and the hybrids the highest yield was obtained at 45000 ha^{-1} plant density level. The highest average yield at 65000 ha^{-1} plant density level was harvested in 2000. In years with high amount of rainfall, Lympil (4680 kg ha^{-1}), PR63A82 (4156 kg ha^{-1}), LG 56.65 (3372 kg ha^{-1}) gave the highest yield. In dry years *Lympil*

(4856 kg ha^{-1}), *PR63A82* (4540 kg ha^{-1}), *Alexandra/PR* (4583 kg ha^{-1}) and *Louidor* (4601 kg ha^{-1}) performed best.

Table 8. **Crop yield (kg ha^{-1}) at different plant density levels in the average of the hybrids (Debrecen-Látókép, 1999-2005)**

	Crop yield (kg ha^{-1})								
Plant density tő ha^{-1}	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**Average**	**LSD 5%**
35000	3504	3697	2919	3783	4372	3466	3031	*3539*	**197,60**
CV %	*17,50*	*12,12*	*11,81*	*12,84*	*9,69*	*12,64*	*10,81*		
45000	3846	4123	3277	4025	4626	3742	3010	*3807*	**226,80**
CV%	*16,02*	*10,89*	*11,17*	*12,23*	*15,75*	*11,04*	*14,50*		
55000	3736	4406	3356	4016	4322	3866	2900	*3800*	**192,39**
CV%	*16,46*	*9,85*	*10,37*	*8,41*	*8,67*	*12,05*	*14,55*		
65000	3605	4632	3220	3929	4215	3712	2698	*3716*	**226,12**
CV%	*18,03*	*14,86*	*7,88*	*9,54*	*9,95*	*16,86*	*15,65*		
75000	3390	4326	3073	3882	3986	3505	2465	*3518*	**202,00**
CV%	*21,71*	*10,01*	*10,74*	*10,56*	*8,85*	*12,33*	*16,05*		
Average	*3616*	*4237*	*3169*	*3927*	*4304*	*3658*	*2821*	*3676*	
LSD 5%	**122,13**	**149,27**	**91,07**	**106,51**	**146,58**	**109,79**	**82,17**	**99,85**	

4.7. The effect of crop yield on the oil content and oil yield of sunflower hybrids

The oil content ranged from 40.39 % to 61.28 % in the research years. The oil content was highest in 2002 (46.31-61.28 %), and lowest in 2005 (40.63- 51.38 %). The oil content in the average of the hybrids and the crop year in years with higher amounts of precipitation (1999, 2001, 2004, 2005) was lower (49.92 %, 48.27 %, 49.01 %, 46.73 %), while in dry and warm years (2000, 2002, 2003) it was higher (50.29 %, 54.16 %, 51.31 %). Examining the oil content in the average of the hybrids we found that increasing plant density resulted in higher oil content and was highest in 1999 at 55000 ha^{-1} plant density level (52.24 %).

The oil content was the highest in 2000 and 2001 at 75000 ha^{-1} plant density level (51.97 %, 49.47 %), while in 2002 – 2005 at 65000 ha^{-1} crop density level. In the research years in the average of the hybrids and the crop years between 35000-75000 ha^{-1} plant density the oil content increased (48.17-50.91 %) *(table 9).*

In years with high precipitation, the oil content of *Util* (52.91 %), *Diabolo* (52.31 %), *Astor* (52.04 %) was highest. In average and dry years *Florix* (53.85 %), *Magnum* (58.57 %), and *LG 53.85 (54.87* %) performed best.

Table 9. **The relation of the oil content (%) and different crop density levels in the average of hybrids**
(Debrecen – Látókép, 1999 – 2005)

	Oil content (%)							
Plant density ha^{-1}	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**Average**
35000	48,28	47,85	47,33	51,01	49,61	48,18	44,91	*48,17*
45000	49,17	48,92	47,44	52,88	52,35	47,94	45,21	*49,13*
55000	52,24	51,24	48,38	55,38	50,89	49,46	47,02	*50,66*
65000	49,93	51,46	48,45	56,25	51,91	49,84	48,51	*50,91*
75000	49,95	51,97	49,74	55,29	51,79	49,60	48,02	*50,91*
Average	49,92	*50,29*	*48,27*	*54,16*	*51,31*	*49,01*	*46,73*	*49,95*

The major determining factor of oil yield was crop yield, at the same time, oil content modified it. The oil content in the research year ranged between 841-2771 kg ha^{-1}. The lowest maximum oil yield was obtained in 2005 (1544 kg ha^{-1}). The highest oil content was obtained in 2000 (2771 kg ha^{-1}). In dry growing seasons (2000, 2002, 2003) the oil yield in the average of the hybrids and the plant density was higher (1970 kg ha^{-1}, 1958 kg ha^{-1}, 2032 kg ha^{-1}). In years with higher amount of precipitation (1999, 2001, 2004, 2005) oil yield was smaller (1670 kg ha^{-1}, 1408 kg ha^{-1}, 1648 kg ha^{-1}, 1210 kg ha^{-1}). In 2005, oil yield was far behind those of the other research years; because due to the wet and cold weather both oil yield and product yield were smaller (1210 kg ha^{-1}). Between 1999 and 2004 the oil yield in the average of the hybrids was highest between 45000 ha^{-1} to 65000 ha^{-1} plant density levels (1800 kg ha^{-1}, 2200 kg ha^{-1}, 1496 kg ha^{-1}, 2046 kg ha^{-1}, 2226 kg ha^{-1}, 1758 kg ha^{-1}). In 2005 the maximum average oil yield was obtained at 35000 ha^{-1} plant density level (1255 kg ha^{-1}), which was smaller than in earlier years.

In the average of the examined growing seasons and hybrids, in 2005 the maximum oil yield was obtained at 55000 ha^{-1}(1779 kg ha^{-1}) *(Table 10).*

Table 10. **Oil yield of sunflower hybrids at different crop density levels**
(Debrecen – Látókép, 1999 – 2005)

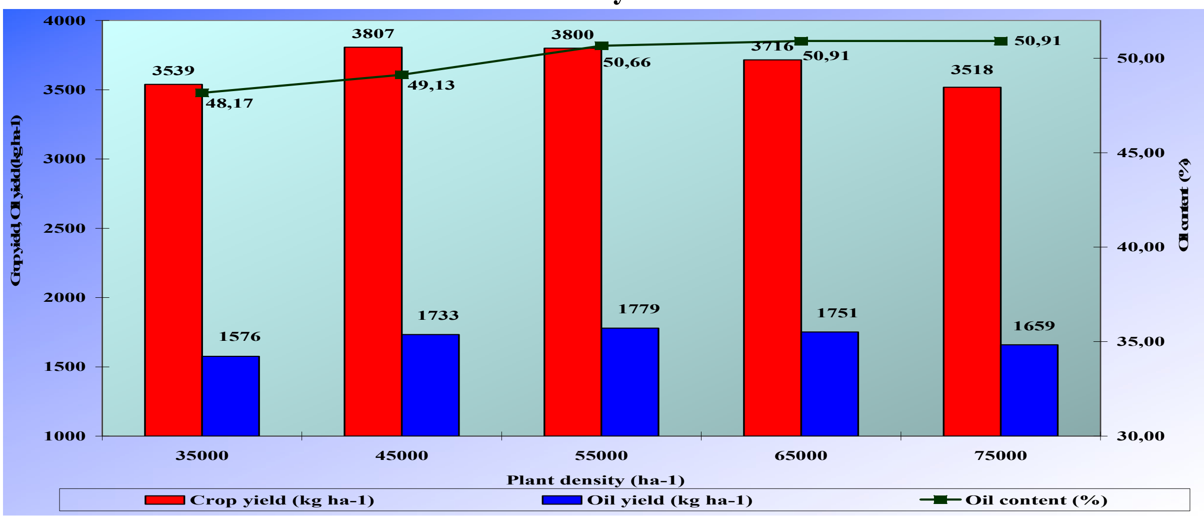
	Oil yield (kg ha^{-1})							
Plant density ha^{-1}	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**Average**
35000	1565	1635	1272	1775	1997	1535	1251	*1576*
45000	1748	1860	1432	1962	2226	1649	1255	*1733*
55000	1800	2082	1496	2046	2020	1758	1254	*1779*
65000	1668	2200	1436	2034	2015	1699	1204	*1751*
75000	1568	2074	1406	1973	1903	1598	1090	*1659*
Average	1670	1970	1408	1958	2032	1648	1210	*1700*

In years with high amount of precipitation the oil content of *Lympil* (2314 kg ha^{-1}), *NK Brio/PR* (1387 kg ha^{-1}) and *Diabolo* (1700 kgha^{-1}) was highest.

In dry years *Lympil* (2314 kg ha^{-1}), *Magnum* (2274 kg ha^{-1}) and *Louidor* (2298 kg ha^{-1}) performed best.

The interactive analysis of the product yield, oil content and oil yield shows that in the average of the hybrids and the plant density, product yield was highest between 45000-55000 ha^{-1} levels (3807 kg ha^{-1}, 3800 kg ha^{-1}), and increase or decrease of plant density both decreased the yield. Increasing the plant density improved the average oil content from 48.17 % to 50.91 %. Increasing plant density had a same effect on oil content than on product yield, however, the highest oil yield was obtained at 55000 ha^{-1} plant density level (1779 kg ha^{-1}), because oil content at 55000 ha^{-1} plant density level was 1,53 % higher than at 45000 ha^{-1}, which modified oil content at a relatively higher degree.

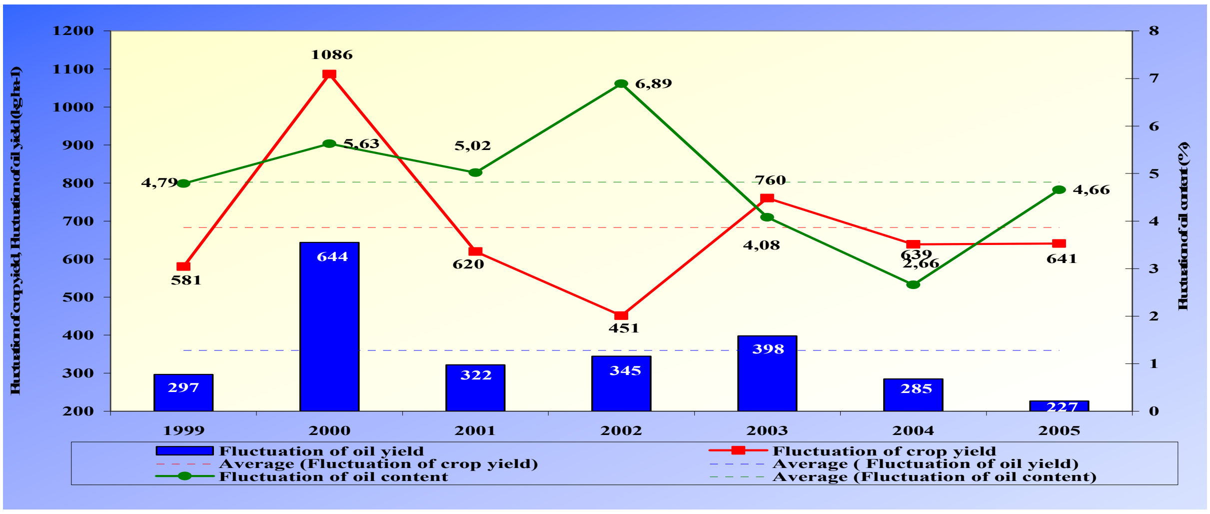
Figure 2. **Crop yield, oil content and oil yield at different plant density levels in the average of the hybrids**



The lowest crop yield was obtained at 75000 ha^{-1} plant density level, while oil yield was lowest at 35000 ha^{-1} plant density level *(Figure 2).*

Fluctuation of crop yields and oil yields in the average of the hybrids was highest in 2000 and 2003 (1086 kg ha^{-1}, 760 kg ha^{-1}, 644 kg ha^{-1}, 398 kg ha^{-1}), because crop yield was highest in these years, therefore the differences between the hybrids were higher regarding the examined plant density levels. Fluctuation of oil yield values was smaller in 2004 and 2005. The average fluctuation of oil yield was highest in 2000 and 2002. *(Figure 3).*

Figure 3. **Fluctuation of yields, oil content and oil yield in the average of the hybrids**



4.8. Examining the relation between agrotechnical and meteorological parameters by Pearson's correlation

The statistical correlation between the different factors in the research was evaluated by Pearson's correlation analysis. Positive and medium correlation was found between plant density and stalk strength (0.470**), broken head (0,392**), Diaporthe infection (0.263**), Sclerotinia infection (0.377**) and head infections (0.327**). Negative medium and strong correlation was found between product yield and lodging (-0.412**), head rot (-0.439**), Diaporthe infection (-0.571**), Sclerotinia infection (-0.501**) and head infections (-0.468**). Positive medium and strong correlation was found between the amount of precipitation in the growing season and broken head (0.442**), head rot (0.487**), Diaporthe infection (0.683**), Sclerotinia infection (0.644**) and head infections (0.572**). Positive medium and strong correlation was found between the amount of precipitation in the first half of the growing season (April – June) and leaning (0.329**) head rot (0.370**), Diaporthe infection (0.869**), Sclerotinia infection (0.574**) and head infections (0.344**). Positive strong correlation was found between the amount of precipitation in the second half of the growing season and leaning (0.421**), broken head (0.456**), Diaporthe infection (0.282**), Sclerotinia infection (0.518**), head infections (0.628**). Negative weak and medium correlation was found between the average temperature in the growing season and leaning (-0.355**), broken head (-0.431**), Diaporthe infection (0.243**), Sclerotinia infection (-0.314**), and head damage (-0.491**). "**" indicates that there is a 1 % significant correlation.

4.9. Analysing the production stability of sunflower hybrids by Kang's stability analysis

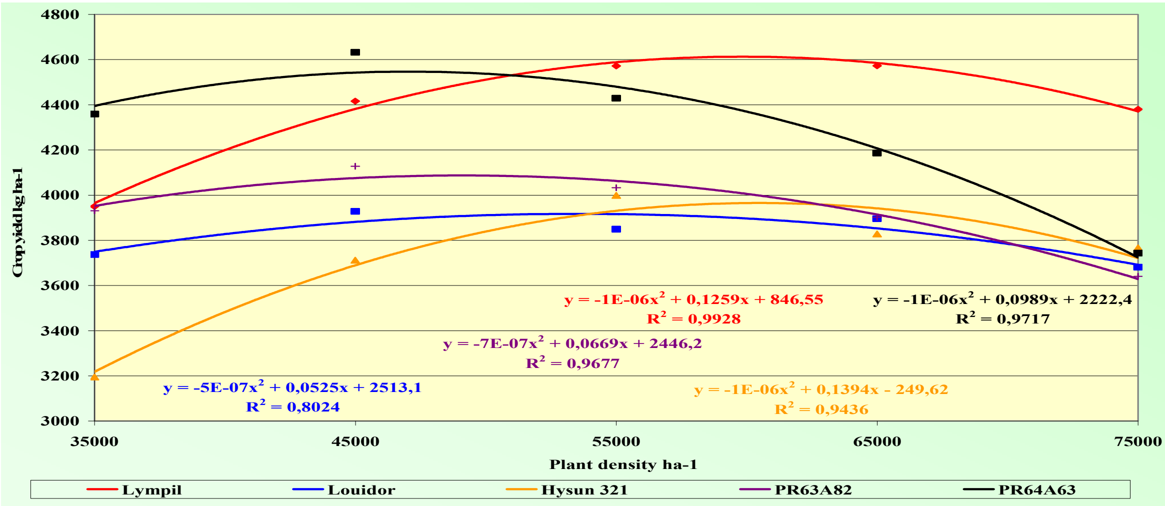
The hybrids used every year, *Aréna/PR* and *Alexandra/PR* hybrids were tested by Kang's stability analysis. We found that *Alexandra/PR* was most balanced at every levels of plant density. Both hybrids performed most balanced at 65000 ha^{-1} plant density level and less balanced at 35000 ha^{-1} plant density level. As a result of improved environmental conditions, the yield increase of *Aréna/PR* was higher than *Alexandra/PR*.

4.10. Regression analysis between crop yield and plant density

The change of plant density levels influences the product yield of sunflower hybrids. The plant density level required to the highest product yield is regarded optimal. Any divergence from the optimum level of plant density (increase or decrease) causes yield losses. At different sunflower hybrids, changes in plant density level cause different levels of yield loss. The reaction to plant density change of hybrids can be described by a quadratic regression function, and can be graphically illustrated by a polynomial trend line in a frame of reference. The maximum of the parabolic function shows the maximum yield. The rise of the curve shows the yield stability of the hybrid. If the rise of the curve is increasing, it means that change in plant density level causes higher deviation in product yields.

The crop density reaction of *Lympil*, *Hysun 321* (from 1999 to 2001), *Louidor* (from 2002 to 2004) *PR63A82* and *PR64A63* (from 2003 to 2005) was analysed in three consecutive years. The results of the regression analysis showed that *Lympil* and *Hysun 321* had maximum product yields at 60000 ha^{-1} plant density levels. The optimal plant density levels of the other hybrids was lower (*Louidor* – 54000 ha^{-1}; *PR63A82* – 49000 ha^{-1}; *PR64A63* – 47000 ha^{-1}). According to the statistics, the highest product yield was obtained by *Lympil* and *PR64A63*. The optimal interval of plant density levels, where product fluctuation is not significant was at lower plant density levels at *Lympil* and *Hysun 321*, while in case of *Louidor*, *PR63A82*, *PR64A6,* this rate was higher. The most stable hybrids were *Louidor* and *Lympil (Figure 4).*

Figure 4. **Correlation of crop yield and crop density of sunflower hybrids (Debrecen, 1999 – 2005)**



Rigasol/PR (from 1999 to 2003) and *Diabolo* (from 2001 to 2005) was used in 5 research years, while *Larisol* (from 2000 to 2003) was used in 4 research years.

Regression analysis showed that the optimal plant density level of *Rigasol/PR* and *Larisol* (58000 ha^{-1}) is higher than *Diabolo* (46000 ha^{-1}). At optimal plant density level the product crop of *Larisol* was the highest. As regards product yield, Diabolo proved to be the most stable. Fluctuation of the product yield of *Larisol* and *Rigasol/PR* caused by changing plant density levels was higher. The optimal interval of crop density levels was widest at *Diabolo* (21000 ha^{-1}) (Figure *5).*

Aréna/PR and *Alexandra/PR* were used in every research year (from 1999 to 2005). Product stability of *Aréna/PR* was better than that of *Alexandra/PR*, however, the product yield was lower. The optimal plant density level of *Aréna/PR* was smaller than that of *Alexandra/PR*. *Aréna/PR* has a wide interval of plant density level (22000 ha^{-1}). This rate is smaller at *Alexandra/PR (Figure 6).*

Figure 5. **Correlation of crop yield and plant density of sunflower hybrids (Debrecen, 1999 – 2005)**

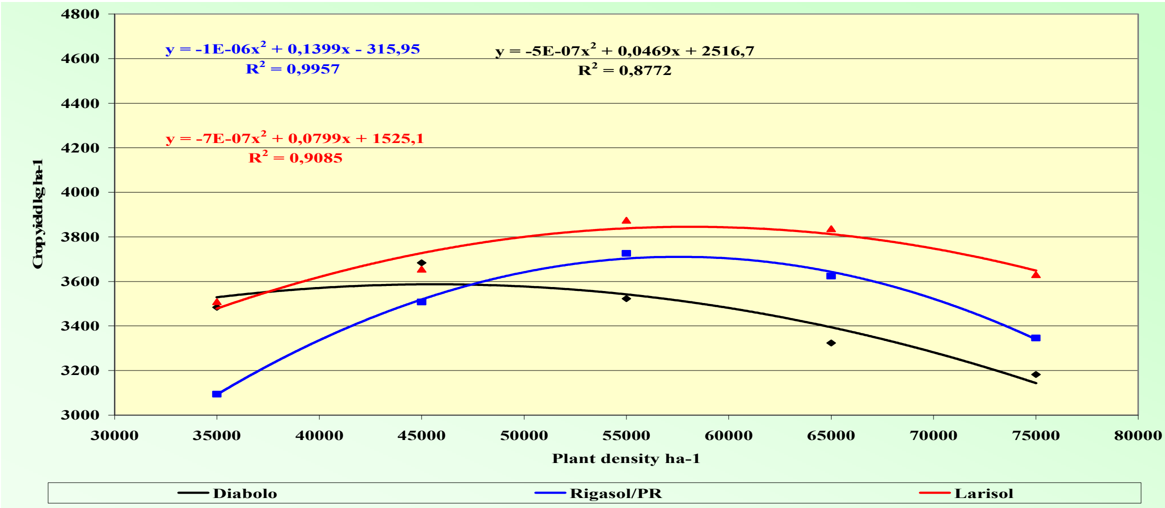
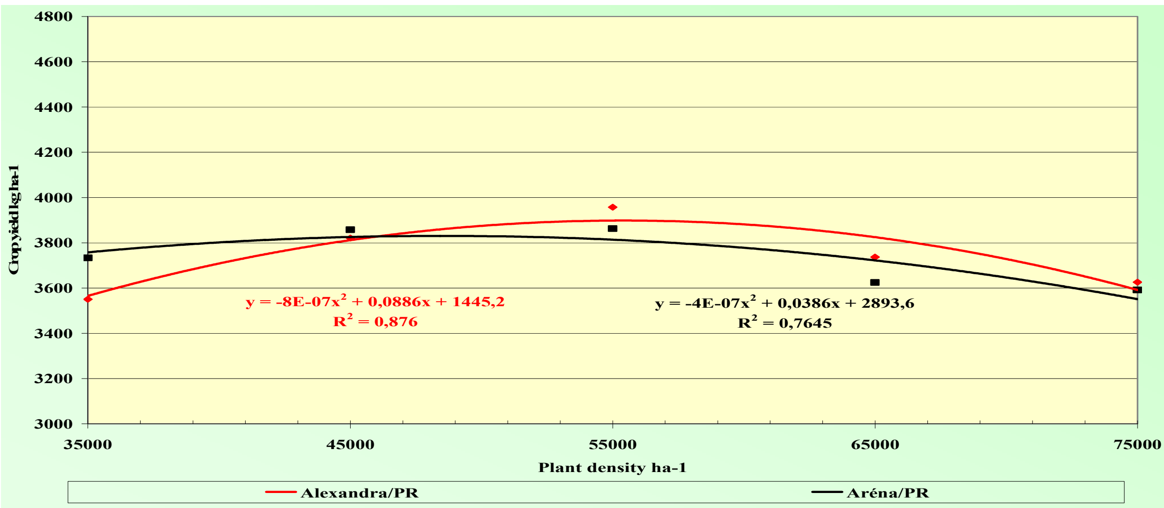


Figure 6. **Correlation of crop yield and plant density of sunflower hybrids (Debrecen, 1999 – 2005)**



5. NEW AND UP-TO-DATE SCIENTIFIC RESULTS

1. Parameters regarding sunflower stalk strength (falling over, head rot) were influenced by crop year, genotype and crop density. If the weather in the vegetation period was wet, the year also had an effect on this parameter. The differences between the hybrids emerged under stress conditions (high crop density level, wet weather). In wet years the degree of falling over and head rot infections was higher the in dry and average years.
2. The degree of stalk and head infections was primarily determined by the year, and was partially modified by the crop density and the hybrids. Under the research conditions Diaporthe helianthi was the most important disease. The degree and dinamics of the Diaporthe infection was primarily determined by the year (in dry years the infection was 4-34 %, in wet years it was 44-84 %). The Diaporthe infection was significant at 65000-75000 tő ha^{-1} crop density level.
3. Except from 2005 (2,0-7,8 %), the stalk damage caused by Sclerotinia was moderate (06-4,5%) in the research years. The degree of head rot infections depended on the weather in August and September. Increasing crop density increased both Sclerotinia (1,9 % in the average of the hybrids and the years) and head rot infections (6,7 % in the average of the hybrids and the years).
4. The crop yield of sunflower was determined by the interactive relations between the year, the hybrid and the crop density. The crop yield was highest (4237 kg ha^{-1}, 3927 kg ha^{-1} 4304 kg ha^{-1} in the average of the hybrids) in moderately dry years with favourable distribution of rainfall and good temperature conditions (2000, 2002, 2003). The crop year was lowest in years wetter then the average (1999, 2001, 2004, 2005) (3616 kg ha^{-1}, 3169 kg ha^{-1}, 3658 kg ha^{-1}, 2821 kg ha^{-1} in the average of the hybrids).
5. As regards crop yield, in dry weather conditions the higher (55000-65000 plant ha^{-1}), in average and wet years the lower (35000-45000 plant ha^{-1}) crop density level proved to be optimal. The hybrids influenced the optimal crop density level (hybrid specific production technology).
6. The interaction of the year, the hybrid and the crop density level influenced the oil content and oil yield. The oil content increased with the increase of the crop density level (48,17-50,91%) in the average of the hybrids. The oil yield was primarily determined by the seed yield and modified by the oil content.
7. The results of the parabolic regression analysis determine the optimal crop density level and interval of the hybrids. The crop density optimum of the following hybrids is small (35000-45000 plant ha^{-1}): *Louidor*, *PR64A63*, *Diabolo* and *Aréna*/*PR* and the crop density optimum of the

following hybrids is high (45000-55000 plant ha^{-1}): *Lympil*, *Hysun 321*, *Rigasol/PR*, *PR63A82* and *Alexandra/PR*. We determined the hybrids of narrow (*Lympil*, *Hysun 321*) and wide crop density interval (*Alexandra/PR*, *Diabolo*, *Aréna/PR*).

8. Kang's stability analysis showed that the yield safety of *Aréna/PR* and *Alexandra/PR* highly depends on the crop density level. The crop safety of *Aréna/PR* was better than that of the *Alexandra/PR*. The production stability of the hybrid of higher yield potential was smaller, and vice versa.
9. Based on the results of Pearson's correlation analysis we found that the Diaporthe and Sclerotinia infection was significantly influenced by the precipitation in the first half of the growing season (correlation coefficient: 0,869**, 0,574**). As regards head rot infections, the precipitation in the second half of the growing season was of high importance (correlation coefficient: 0,628**). The crop yield was primarily influenced by Diaporthe infection (-0,571**). There was a negative strong correlation between the precipitation in the growing season and the crop yield (-0,649**).

6. RESULTS CAN BE USED IN PRACTISE

1. The optimal crop density level has to be determined according to the specific hybrid.
2. The crop density optimum ranges between 45000-55000 plant ha^{-1} in the Hajdúság reagion according to the year.
3. In the Hajdúság loess soil the productivity of *Lympil*, *PR63A82*, *LG 56.65*, and *Alexandra/PR* was the best. The crop yield was smaller in wet years.
4. We found that increasing the crop density had an increasing effect on the oil content. Extreme weather conditions (high precipitation, low temperature in the growing season) decreased the oil content. *Lympil*, *Diabolo*, *Astor*, *Magnum* and *Louidor* had the highest oil content.
5. The oil yield per hectare of the hybrids was primarily determined by the yield, while the oil content moderately changed it. Therefore, the highest oil yields could be obtained in the range of 45000 ha^{-1} – 55000 ha^{-1} crop density levels. In dry, warm weather with evenly distributed precipitation the oil yield of the hybrids was higher than in cold years with high amounts of rainfall. On the basis of the results we found that *Lympil*, *PR63A82*, *Louidor, Magnum, Diabolo and NK Brio/PR* gave the highest oil yield per hectare.
6. *Alexandra/PR*, az *Aréna/PR*, az *Util*, a *Louidor*, a *Lympil*, az *LG 54.15*, az *LG 56.65*, a *Rigasol/PR* és a *PR63A90* had the best stalk strength parameters.
7. In the research years, out of the examined stalk and head infections the hybrids proved to be most tolerant towards Sclerotinia infection. The infection pressure was highest at the Diaporthe helianthi infection. As regards Sclerotinia, the infection rate was lowest at *Alexandra/PR*, *Diabolo*, *Rigasol/PR*, *Lympil*, *PR63A90*, *PR64A63*, and *LG 54.15*.
8. The rate of infection with Diaporthe helianthi was lowest at *Util*, *Aréna/PR*, *LG 56.65*, *Magnum* and *Alexandra/PR*.
9. *Natil*, *Alexandra/PR*, *PR63A82*, *LG 56.65*, *Rigasol/PR* and *Hysun 321* proved to be most tolerant towards head infections.
10. The complex analysis if the hybrids proved that in the Hajdúság region the most suitable hybrids are *Alexandra/PR*, *PR63A82*, *Aréna/PR and NK Brio/PR* .
11. The use of the results in practice implied that in wet years the crop safety was apropppriate at lower crop density levels (45000 plant ha^{-1}), while in average and dry years the use of higher crop density levels (55000-65000 plant ha^{-1}) resulted in the highest seed and oil yield, as well as crop safety.

List of publications in the topic of dissertation

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