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„SUMMARY OF THE DOCTORAL (PHD) THESIS"

THE IMPACT OF IRRIGATION ON THE YIELD QUANTITY AND QUALITY OF POTATO (SOLANUM TUBEROSUM L.) CULTIVARS

By:

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1. INTRODUCTION

Potato (*Solanum tuberosum L.*) is one of the most important basic food crops. It is grown in about 140 countries with a total growing area of 18.6 million ha. Countries with the largest growing area are Russia, Poland, Ukraine and China. The highest yields in Western-European countries are obtained in Great-Britain, France, the Benelux states, Germany and Denmark. (Figure 1). The Hungarian yields are lower than those of the EU countries.

Yields, t/ha

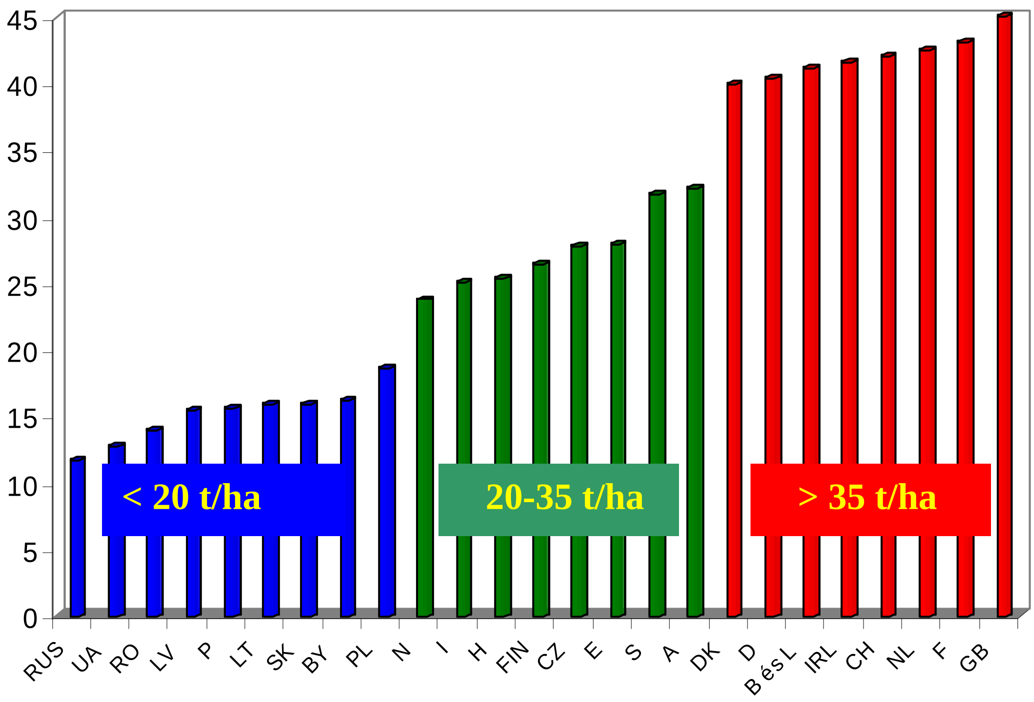

Figure 1: The position and role of Hungary among the major potato producing countries

Between 1920 and 1965, the potato growing area in Hungary was 220–290 thousand ha with average yields of about 10 t/ha. As a result of the spread of the cultivars introduced from abroad (mainly from the Netherlands) due the necessary change in the cultivars because of the Y virus in the 1970s, the national average yield in the 1980s exceeded 18 t/ha (Figure 2).
By the 1980s, the size of the growing area had reduced to 50 thousand ha, then it started to increase gradually during the 1990s and reached 63 thousand ha by 1997 (Figure 2).
The reduction of the potato growing area has been continuous since 2000. In 2006, the area was only about 24 thousand ha.
With Hungary’s EU accession, the customs for potato were abolished and we could not compete with the cheap import potato successfully.
Many farms were forced to cease potato growing.
In order to improve our competitiveness, special emphasis should be laid on all technological elements which can enhance the effectiveness of potato production. We can achieve a high yield-increasing effect by irrigation in addition to a better utilization of the possibilities in technology and biological bases. Profitable potato production is hardly possible without irrigation in Hungary. By irrigation, the temporary water deficiencies can be prevented,

thereby, yield quality and quantity can be improved. In Hungary, all the lands that can be irrigated should be utilized in order to achieve higher yields.

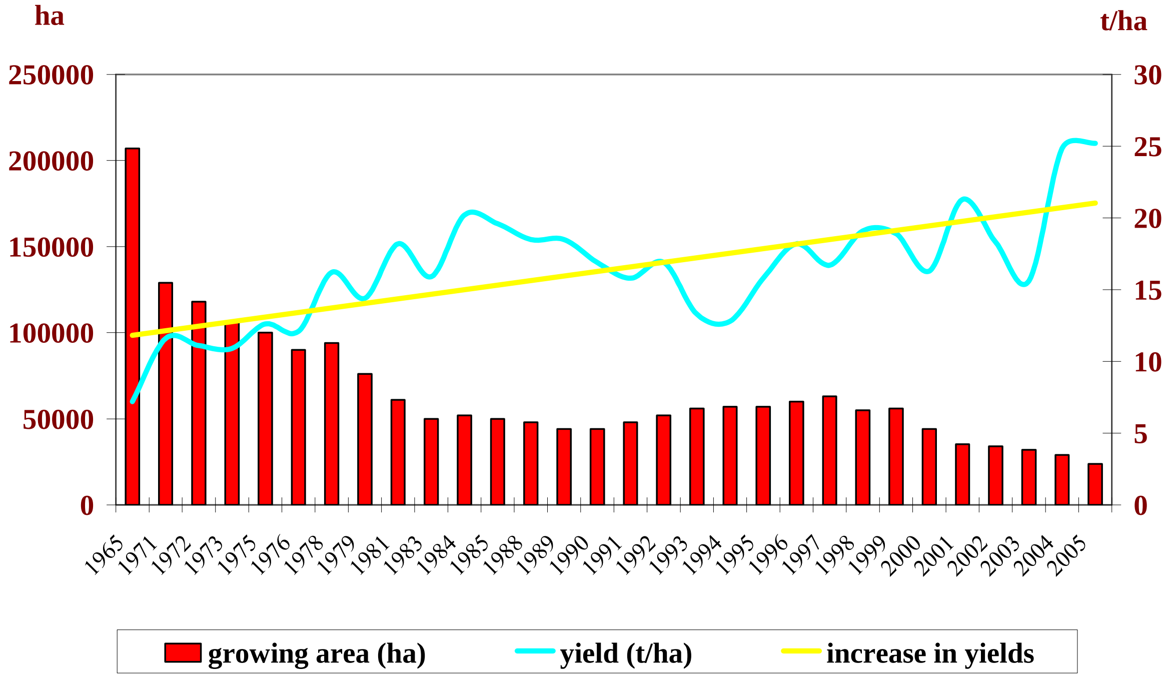

Figure 2: Changes in the growing area and yield of potato in Hungary in the period of 1965-2005 (Source: data of the Central Statistical Office)

The experiment was carried out at the Látókép Experimental Station of the University of Debrecen, Centre of Agricultural Sciences, Debrecen Farm and Regional Research Institute.
The aim of our research was to give more information about the growing experiences and thereby contribute to a more successful potato production by studying cultivars of Hungarian and Dutch breeding with different utilization purposes on calcareous chernozem soil.

2. BACKGROUND OF THE TOPIC

Potatoes originate from South-American regions of 2000-4000 m height above sea level. During the vegetation period of potato, there is a considerable amount of precipitation in these areas and the temperature is not high. However, the great adaptability of potato enables the production of potato under conditions very different from the above.
The geographical location and climatic conditions of Hungary are less favourable for potato production (especially for seed tuber propagation) than those of countries with a more northern, north-western location. Our climate is drier and warmer and the impact of pests is more severe.
Further problems are caused by ***viral diseases***, which can result in severe yield losses. Although the protection against them and methods for the mitigation of damages caused by them have been studied since their finding, we do not have yet a uniform, effective protection procedure against them. Forcing, defoliation and weed killing can be recommended as passive protection methods, the only solution as an active protection is breeding for resistance.

For the last 40 years, domestic seed tuber requirements were satisfied from import, but growing potato directly from import seed tuber is not economical in Hungary due to the high costs of seed tuber. The annual import of seed tuber in the last five years was around 6800-7600 t, which is enough only for a small portion of the growing area. The cultivars imported mostly from the Netherlands are susceptible to viral diseases, they quickly deteriorate. This results not only in a significant yield loss, but it also maintains the contagious viral environment. This is due to the reinfestation resulting from that, that although we have imported annually 4000-13500 t of healthy seed tuber since 1973, potato deterioration has not been reduced at a national level, therefore, the national yield average is just half of the potential yield under our climatic and soil conditions.

In the National cultivar registry of Hungary, 62 ***potato cultivars*** were included in 2005, out of which 28 are very early and early (consisting of 22 table, 5 chips and 1 mash-flake cultivars), and 34 cultivars of early-mid and medium ripening cultivars (22 multi-purpose table cultivars (for fresh consumption and winter storage), 3 chipped potatoes, 6 chips cultivars, 3 cultivars for use as salad and dessert). 27 cultivars are of Dutch breeding, while 15, 12, 3, 2, 1, 1 and 1 are of German, Hungarian, Austrian, British, Czech, American and French origin.
Foreign cultivars, mainly Dutch (*Desirée*, *Kondor*, *Cleopatra*) were planted on 75% of the growing area in 2001, this ratio was only 58% in 2005. Hungarian cultivars were planted on 6% of the propagation area, while in 2005, this ratio was already 17%, which seems to be increasing based on the trend of the last years.
In 2006, seed tuber was produced from the three major cultivars (Desirée, Kondor, Cleopatra) on 51.7% of the total propagation area. With the reduction of the ratio of the three major cultivars, the ratio of other cultivars has increased, thereby, the ***cultivar assortment*** has improved. Hungarian traders and consumers start to request some yellow-skinned cultivars with excellent taste (e.g. the ratio of *Agria* this year is 6.6% in the propagation area) in spite of the baseless preference of pink (red-skinned) cultivars.
Among the registered Hungarian cultivars, there are such which are competitive with foreign cultivars in yielding capacity, utilization value and other qualities. They have a high resistance to viral diseases causing deterioration, stable yields and their propagation has started, they can have a role in increasing the cultivar assortment in the near future.
In Hungary, there are several registered cultivars resistant to the Y, X and leafroll viruses (e.g. Keszthely cultivars). The spread of these cultivars is the economic interest of the growers primarily, however, they should first fight with the conservative attitude of the market.

The second limiting factor after deterioration is ***the lack of water***. The amount and distribution of precipitation during the vegetation period do not satisfy optimally the biological water requirement and do not ensure the soil moisture content necessary for the harmonic nutrition of potato. Proper water supply can be ensured, if the water requirement of potato is satisfied continuously during the season and the lack of water is compensated by irrigation. An essential precondition of irrigation is therefore, the knowledge of the plant's water requirement and the characteristics of the growing site and their harmonization.
When selecting the time of irrigation, the phenophase (development stage) of the plant, soil moisture content and meteorological factors should be considered. It is recommended to start the first irrigation at tuber set, if the moisture content of the soil reduces below 75 % of the natural water capacity. This can reduce also the degree of scabbing. Irrigation enables the prevention of temporary water deficiencies and thereby, the improvement of yield quality and quantity. The irrigation period of potato is usually between mid-May and end of August. Under average weather conditions, 200-300 mm water should be irrigated in several small

dosages of 20-40 mm. More frequent irrigation has a more favourable effect on quality. In dry years, 400-600 mm of irrigation water should be applied.
There are gaps in the literature available regarding the effect of irrigation on certain inner content parameters. It is well known that foreign results can only be evaluated under Hungarian conditions if comparative results are available. Therefore, we consider it important to provide further data by presenting the results of the first three years of a multi-year experiment in this study.

In my PhD thesis, I have summarized the results of my research work performed under the supervision of Dr. Mihály Sárvári, associate professor at the Látókép Experimental Site of the University of Debrecen Centre of Agricultural Sciences, Farm and Regional Research Institute between 2002 and 2004.
In my research, I studied the effect of irrigation on the yield, major exterior and inner parameters of 9 potato cultivars of mid-early and medium maturing. We studied:

- the yielding capacity of potato cultivars,
- size distribution of tubers,
- changes in certain inner content parameters:
    - under water weight,
    - dry matter content,
    - starch content,
    - reducing sugar content,
    - transformation of macro-, mezo-, and microelements in the tubers,
- fry colour index.

We have carried out our research with the conviction that the obtained results can be successfully utilized in areas with similar ecological conditions, and new information can be gathered which help in:

- determining the effect of the region's climatic factors on the yield of potato in multi-year experiments,
- determining the effect of irrigation, one of the most important elements of economical potato production, on the yield quantity and quality of potato,
- determining adaptable potato cultivars that can be grown successfully in the region for the different utilization purposes following the evaluation of year effects and the effect of the above production factors,
- developing and adjusting cultivar-specific technologies, by growing such cultivars, seed tubers can be obtained at a lower cost, thereby, the large input costs per hectare can be reduced.

By utilizing the results on yield quantity and quality, and by transferring this knowledge to the growers, a more successful quality potato production can be realized that adapts to the ecological conditions of the region.

3. MATERIALS AND METHODS

3.1. Location and soil conditions of the experimental site

The experiment was carried out at the Látókép Experimental Station of the University of Debrecen Centre of Agricultural Sciences, Farm and Regional Research Institute, which is situated on the loess region of Hajdúság at 15 km from Debrecen along road no. 33.
The experiment was carried out on calcareous chernozem with deep humus layer formed on loess. The soil was in good cultural condition, of medium heaviness (plasticity according to Arany: 42), physical type: medium-heavy loam. The pH value of the cultivated layer was (KCl pH) between 6.3-6.5.
The total nitrogen content was 0.12-0.15 %. Based on the total nitrogen content, the N supply of the area is medium, the potassium supply is good (240 mg/kg), the phosphorus supply is medium (133 mg/kg) (P_2O_5 and K_2O content determined by the ammonium-lactate method).
When evaluating the water management characteristics of the experimental soil, it can be stated that it has good water management qualities. Ground water is found at 8-10 depth. The soil can store 600 mm water until 200 cm depth, 50 % of which is non-available water, and 50 % is available water.

3.2. Applied agrotechnique

In the experiment, the production technology generally applied in the growing region was used.
The basic autumn cultivation in all three years was deep ploughing (in September) of 35 cm depth, followed by disc cultivation in October. In the spring, harrowing and smoothing was done (March) followed by multitilling.
Planting was performed with a 2-row Cramer planting machine on 3-4 April 2002, 23-24 April 2003 and 21-22 April 2004. The forecrop was winter wheat in 2002 and corn in 2003 and 2004.
Parcel sizes: 102 m^2 in 2002, 49.5 m^2 in 2003 and 2004.
In all three years of the experiment 165 kg N, 120 kg P_2O_5, and 220 kg K_2O active ingredients were applied per hectare. The general plant protection practice was applied.
Harvest was performed on 3 October 2002, 25-26 September 2003 and 22 September 2004. Plant density was uniformly 51 thousand plants/ha in all three years.

3.3. Studied cultivars

6 domestic (Góliát, Hópehely, Kánkán, Lilla (Lorett), Százszorszép (Rioja), White Lady) and 3 Dutch cultivars (Desiée, Kondor, Kuroda) were included in the experiment.
Major characteristics of the studied cultivars:
Desirée: High yields, medium dry matter content. Red-skinned, medium susceptibility to viral diseases.
Kondor: High yields. Red-skinned, susceptible to Y virus.
Kuroda: High yields. Medium susceptibility to viral diseases. Red-skinned.
Kánkán: Very high yields. Moderately high starch content. Red-skinned High resistance to Y virus. Dry matter content 19-20%.
Százszorszép (Rioja): High yields. Both its dry matter content (22-23 %) and starch content are high. Highly resistant to Y virus. Red-skinned.

Góliát: High yields. Dry matter content: 18-20 %. Highly resistant to Y virus. Red-skinned.
Hópehely: Very high yields. Medium starch content. Dry matter content: 19-20% . Immune to Y virus. Yellow-skinned.
White Lady: High yields. Dry matter content: 20-21%. Immune to Y virus. Yellow skinned.
Lilla (Lorett): Medium starch and dry matter content (17-19%). Immune to Y virus. Red-skinned.

3.4. Timing of irrigation

The experiment was irrigated four times in all three years, 4 x 40 mm in 2002, 3 x 30 mm and 1x35 mm in 2003, while in the wet year of 2004 1x15, 1x25 and 2x30 mmm dosaged were applied.(Table 1).

Table 1: Dates and dosages of irrigation in the different years

	2002	2003	2004
Irrigation 1	19. VI. (40 mm)	12. V. (30 mm)	22. V. (15 mm)
Irrigation 2	28. VI. (40 mm)	24. V. (30 mm)	5. VI.(25 mm)
Irrigation 3	18. VII. (40 mm)	6. VI. (30 mm)	11. VI. (30 mm)
Irrigation 4	24. VIII. (40 mm)	25. VI. (35 mm)	8. VII. (30 mm)

3.5. Experimental design

It was a two-factor experiment, one of the studied factors was the cultivar, the other was irrigation. The experimental design was a randomized block design with four repetitions, with two irrigated and two non-irrigated repetitions. The number of treatments for the cultivars was 9 and for irrigation it was two (irrigated and non-irrigated).

3.6. Weather during the years of the experiment

Weather varied between the experimental years. Regarding precipitation, 2002 (-140 mm) and 2003 (-143 mm) were dry years. In 2004, the amount of precipitation was slightly higher than the average of 30 years (+ 36 mm).
2002 and 2003 are considered dry years, while 2004 was a wet year based on the amount of precipitation.

3.7. Laboratory examinations

In the examinations, samples from all cultivars from the irrigated and non-irrigated treatments were included. The examinations were carried out by Dr. Zoltán Győri and his colleagues at the Agricultural Central Laboratory of the University of Debrecen, Centre of Agricultural Sciences. Samples were taken from each parcel for the inner content examinations and were stored in Raschel-sacks until performing the examinations. The original dry matter content and total nitrogen content of the potato samples were determined according to the method published in 1955 in the MNOSZ. The starch content of the samples was measured with a

Reimann scale. Under water weight was determined according to the method of Arends et al. (1999). Dry matter content and starch content were determined according to the standards MSZ 6369-4:1987 and MSZ 6830-18:1988, respectively. Fry colour and reducing sugar content were determined also according to the method of Arends et al. (1999). The element content of seed tubers was examined based on MSZ 08-1783-4:1983. Nitrogen content was determined according to MSZ 6830-66 5,23 by Wagner-Parnas Mikrokjeldahl method. Potassium content was measured by flame photometer, calcium, magnesium and zinc content were determined by atomabsorption procedure. Phosphorus content was measured by the molibdovanate method.

3.8. Methods of evaluation

For testing the differences between the irrigation treatments and between cultivars $SD_{5\%}$ values were used calculated according to SVÁB (1981), the values were calculated for irrigation, cultivar, and irrigation x cultivar interaction. For claryfing the irrigation x cultivar interaction, linear regression analysis was used, and a two-sided Wealson correlation analysis was performed. The obtained data were processed with one-factoral and two-factoral variation analysis (SVÁB 1981), and LSD-test. Before the variation analysis, a homogeneity test was also performed. Data were processed using an SPSS 13.0 statistical evaluation program.

4. RESULTS

4.1. The effect of treatments on yield quantity

Since the weak root system of potato can exert only a small suction force, water deficiency can become a limiting factor in the development of plants in dry periods. The effect of irrigation is dependent upon the degree of natural water supply and the development stage of the plant at the time of water deficiency. Potato is very sensitive to the lack of water, its yield decreases if there is not enough water. However, it responds with a considerable yield increment to good water supply, especially in dry areas.

Table 2: The effect of irrigation on the yield of potato cultivars

Cultivar	Non-irrigated				Irrigated			
	2002	2003	2004	Average	2002	2003	2004	Average
Desirée	21.89	17.03	17.27	**18.7**	53.28	28.65	17.35	**33.09**
Góliát	23.88	19.90	17.13	**20.3**	41.64	30.27	22.02	**31.31**
Hópehely	18.67	20.61	55.37	**31.6**	39.47	37.68	53.61	**43.59**
Kánkán	21.25	19.70	24.40	**21.8**	36.07	28.82	25.58	**30.16**
Kondor	28.32	23.17	25.68	**25.7**	52.80	41.60	27.30	**40.57**
Kuroda	29.16	23.26	34.14	**28.9**	54.71	35.00	36.85	**42.19**
Lilla	0.00*	20.86	33.97	**18.3**	0.00*	36.92	38.25	**25.06**
Százszorszép	21.45	13.71	37.29	**24.2**	28.90	29.71	44.87	**34.49**
White Lady	34.11	24.36	46.00	**34.8**	52.54	35.15	45.98	**44.56**
Average	**24.84**	**20.29**	**32.36**	**25.8**	**44.92**	**33.75**	**34.64**	**37.77**

***** Cv. Lilla was not yet included in the experiment in 2002

$SD_{5\%\ (irrigation)}$ 6.79 t/ha $SD_{5\%\ (cultivar)}$ 6.88 t/ha $SD_{5\%\ (irrigation\ x\ cultivar)}$ 9.73 t/ha

2002 was a dry year for potato. The average yield of the 8 studied cultivars without irrigation was 24.84. t/ha. The average yield of irrigated treatments was 44.92 t/ha, which is about 80% higher than the average of non-irrigated treatments.

Under non-irrigated conditions, the highest yields were measured for cvs. Kondor (28.32 t/ha), Kuroda (29.16 t/ha) and White Lady (34.11 t/ha), while under irrigation, the highest yields were obtained for these cultivars and Desirée (53.28 t/ha).

Under irrigated conditions the lowest yield was obtained for cvs. Százszorszép (28.9 t/ha), Kánkán (36.07 t/ha) and Hópehely (39.47 t/ha).

The amount of yield increment as a result of irrigation varied among the 8 cultivars.

Summing up the yields of *2002,* it can be stated that the yield-increasing effect of irrigation could be verified statistically, it significantly ($SD_{5\%}$= 13.42) increased the yield of cvs. Desirée, Góliát, Hópehely, Kánkán, Kondor, Kuroda and White Lady.

Yield was not increased significantly by irrigation only in the case of cv. Százszorszép.

Irrigation increased the yield by 80% on average, varying between 70-90% as compared to non-irrigated repetitions. Yield increments were high for cvs. Desirée (140%) and Hópehely (110%). The smallest increase of 35-55% was observed for cvs. Százszorszép and White Lady.

Significant differences were found among the cultivars in yield ($SD_{5\%}$=13.38): yields of cvs. Desirée, Kondor, Kuroda and White Lady were higher than those of Kánkán, Százszorszép and Hópehely. The irrigation x cultivar interaction did not have a significant ($SD_{5\%\ (irrigation\ x\ cultivar)}$ 18.92 t/ha) effect on yield.

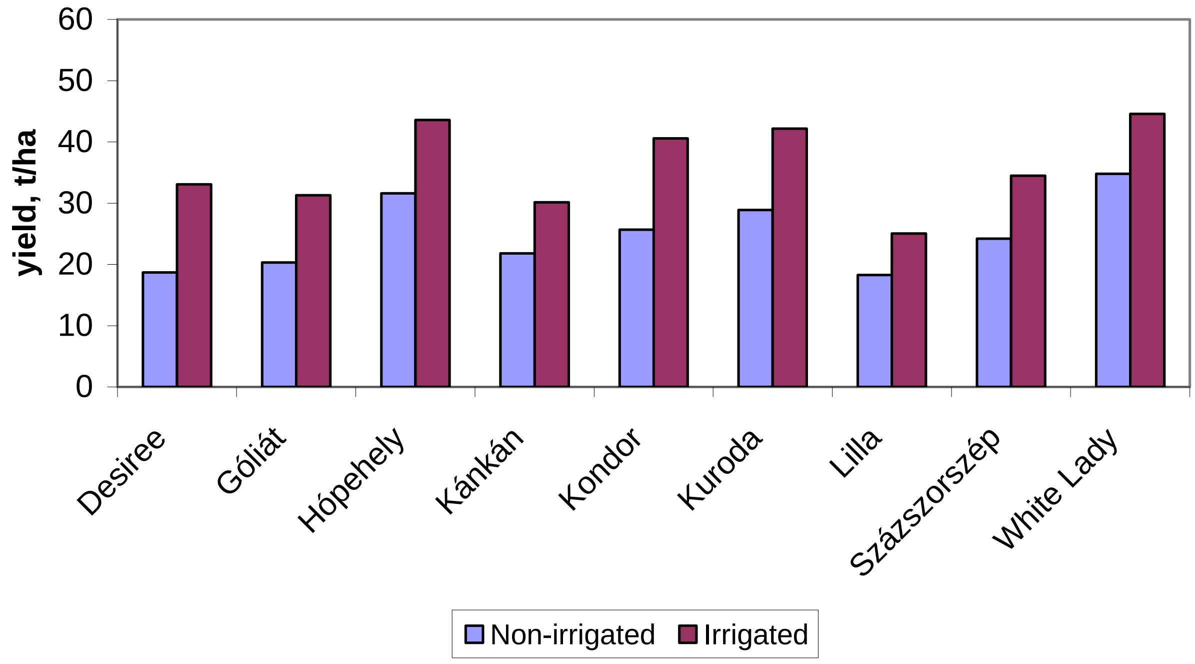

Figure 3: The effect of treatments on the yield of potato in the average of 3 years

2003 was a very dry year for potato. The period between May-July was especially dry.
In this year, a newly registered cultivar, Lilla, of Keszthely breeding was also included in the experiment.
When evaluating the results of 2003, the average yields were 20.29 t/ha and 33.75 t/ha in the non-irrigated and irrigated treatments, respectively. The yield increment due to irrigation was 70% on average.
In 2003, cvs. White Lady, Kuroda and Kondor had the highest yields in the non-irrigated treatment. Under irrigation, outstanding yields were obtained for cvs. Kondor (41.60 t/ha), Hópehely (37.68 t/ha), Lilla (36.92 t/ha), Kuroda (35.00 t/ha) and White Lady (35.15 t/ha).
Without irrigation, low yields (< 20 t/ha) were measured for cvs. Százszorszép (13.71 t/ha) and Desirée (17.03 t/ha). Under irrigation, the lowest yields were obtained for cv. Desirée (28.65 t/ha), Százszorszép (29.71 t/ha), Kánkán (28.82 t/ha), and Góliát (30.27 t/ha), which was partly due to the phytophthora infection.
It was the first year, when the newly registered cultivar, Lilla, of Keszthely breeding was included in the experiment, its yield performance was above the average both under irrigated and non-irrigated conditions. Without irrigation, its yield was 20.86 t/ha, while under irrigation the yield was 76 % higher, 36.92 t/ha on average. However, it should be noted, that the yield per parcel was quite variable, that is it did not have a balanced yield among the repetitions, its yield safety was variable.
In 2003, irrigation significantly ($SD_{5\%\ (irrigation)}$ 2.64 t/ha) increased the yield of all the 9 cultivars. There were significant differences among cultivars in yield ($SD_{5\%\ (cultivar)} = 2.76$): cvs. Góliát, Hópehely, Kondor, Kuroda, Lilla and White Lady had higher yields than cvs. Százszorszép and Desirée. Unlike in the previous year, the irrigation x cultivar interaction was also significant ($SD_{5\%\ (irrigation\ x\ cultivar)} = 3.90$), irrigation had a greater effect as verified by the value of the regression coefficient, which was b=13.46 for irrigation (y=13.46x + 6.83, r=1), that is higher than the effect of cultivars (b=1.28) (y=1.28x + 20.58, r= 0.94).

2004 was more abundant in precipitation than the previous two years, therefore, less obvious results were expected as a result of irrigation. The average yield of the non-irrigated treatment repetitions was 32.36 t/ha in 2004, while the yield of irrigated repetitions (34.64 t/ha) increased only by 7 %. Among the studied three years, irrigation had the smallest effect on the yield in this year.
Under non-irrigated conditions in 2004, cvs. Hópehely (55.37 t/ha) and White Lady (46.00 t/ha) gave the largest yields. Cvs. Kuroda (34.14 t/ha) and Lilla (33.97 t/ha) had yields similar to the average yield of all cultivars.
Yields of cvs. Desirée (17.27 t/ha), Góliát (17.13 t/ha), Kánkán (24.4 t/ha) Kondor (25.68 t/ha) had the lowest yields without irrigation.
The average yield of the 9 cultivars under irrigation was 34.64 t/ha. Outstandingly high yields were obtained for cvs. Hópehely, (53.61 t/ha), White Lady (45.98 t/ha) and Lilla (38.25 t/ha), while Desirée had the smallest yield (17.35 t/ha). Cv. Góliát also gave low yields: non-irrigated 17.13 t/ha, irrigated 22.02 t/ha.
When comparing the results with those of the previous two years, we observed that while irrigation increased the yields of cultivars by 70-80% in 2002 and 2003, the yield increment was only 7 % in the wet year of 2004.

Summing up, it can be stated that 2002, 2003 and 2004 were dry, dry and warm and wet years for potato, respectively, as compared with the average of 30 years. The yield-increasing effect of irrigation was between 70-80% in the dry (2002 and 2003) years, while it was considerably smaller, 7 %, in the wet year (2004).
The statistical evaluation confirmed that ***irrigation significantly increased***

- a./ the yield of all studied (9) cultivars in the dry, warm year (2003).
- b./ the yield of cvs. Desirée, Góliát, Hópehely, Kánkán, Kondor, Kuroda and White Lady (7 cultivars) in the dry year (2002).
- c./ the yield of cvs. Góliát and Százszorszép (2 cultivars) in the wet year (2004).

There were significant differences in yield **among the cultivars,** the yield of cvs. *Hópehely, White Lady, Kondor and Kuroda* was significantly higher in the average of three years.

The irrigation x cultivar interaction increased yields significantly only in the dry, warm year, and the yield-increasing effect of irrigation had a greater role in the changes in yields than the differences between the cultivars.

Combined evaluation of the yields of the three years (Table 2, Figure 3):
- *Under non-irrigated conditions* cvs. White Lady (34.8 t/ha), Hópehely (31.6 t/ha) and Kuroda (28.9 t/ha) had the highest yields.
- *Under irrigated conditions*, the yields of cvs. ***White Lady*** (44.56 t/ha), ***Hópehely*** (43.59 t/ha), ***Kuroda*** (42.19 t/ha) and ***Kondor*** (40.57 t/ha) were higher than 40 t/ha in the average of three years, therefore, they can be suggested for intensive production in areas with similar conditions to that of the experiment.

Irrigation had a yield-increasing effect of 46 % in the average of three years.

4.2. The effect of treatments on the size distribution of tubers

The lack of water in the period of tuber setting and development has a disadvantageous effect on the size distribution of tubers (the ratio of more expensive tuber categories reduces) in addition to its effect on the number of tubers.

Irrigation significantly increased the ratio of large-sized tubers in the dry years of 2002 and 2003 in the case of cvs. Góliát, Hópehely, Kondor, Kuroda and White Lady (by 15-20%), while it was decreased for cv. Desirée in both years. In the case of cv. Kánkán, which produced a surprisingly high ratio of small tubers (35%), the ratio of small tubers was halved and the ratio of large tubers increased by 15% due to irrigation.

In the wet year of 2004, the ratio of size categories was the opposite, since the ratio of large tubers decreased and increased for Hópehely and Desirée, respectively, as a result of irrigation. The too wet weather had a favourable effect on the ratio of size categories for Desirée and Kuroda and an unfavourable effect on that of cvs. Hópehely, Góliát, Kánkán and Lilla.

Summing up the effect of irrigation on the size distribution of tubers (Figures 4 and 5), the following can be observed in 2002:

- Irrigation had the greatest impact on cvs. ***Hópehely*** and ***Kuroda***, in which it increased the ratio of large tubers by 24 % and 26 %, respectively. If we consider, that irrigation increased the average yield of *Hópehely* from 18 t/ha to 39 t/ha, then it cannot be questioned that it had a positive effect in increasing the amount of yield. The yield of cv. *Kuroda* was also very high under irrigated conditions, 54 t/ha.

- As a result of irrigation, the ratio of small tubers reduced for most of the cultivars (Kánkán, Hópehely and Százszorszép) (by 3-13 %), it remained stable for certain cultivars (e.g. White Lady and Kuroda), and increased for cv. Desirée by 4 %. The reason for this is probably that it set more tubers as a result of the irrigation, which could not develop fully.

- Without irrigation, the largest ratio of small tubers was produced by cv. Kánkán (35 %) which ratio was halved as a result of irrigation. Consequently, irrigation should also be carried out in the case of Kánkán, since its yield increase from 21 t/ha to 36 t/ha as a result of irrigation, which represents a 70% increase in yields.

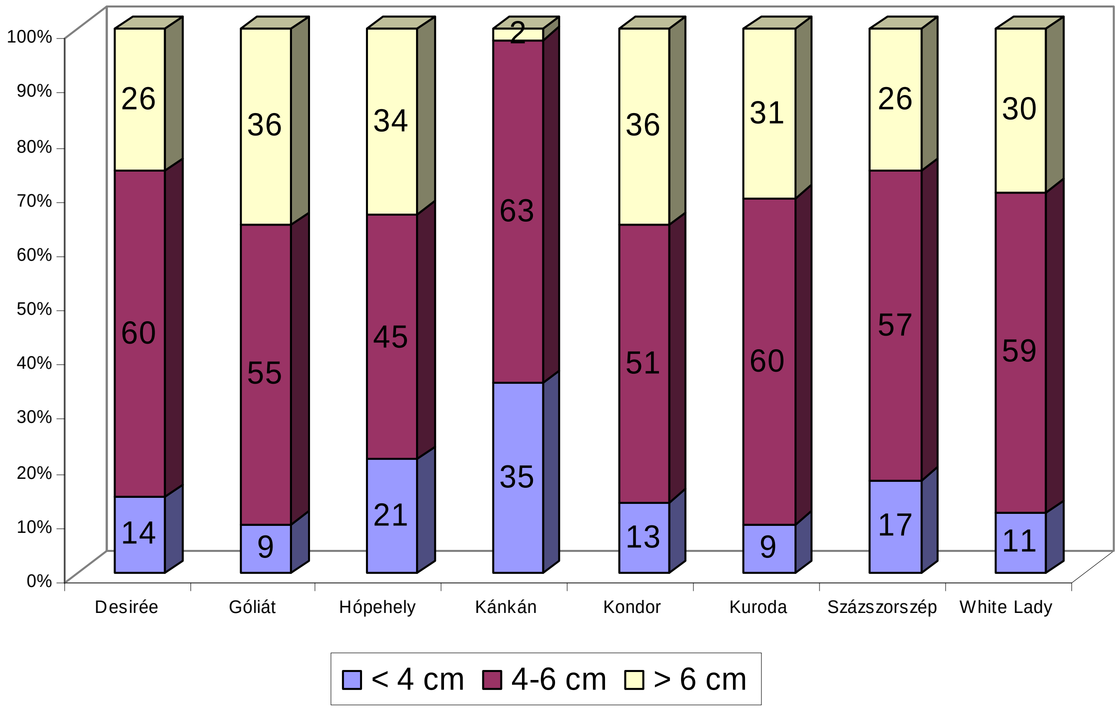

Figure 4: Size distribution of tubers in non-irrigated treatments in 2002

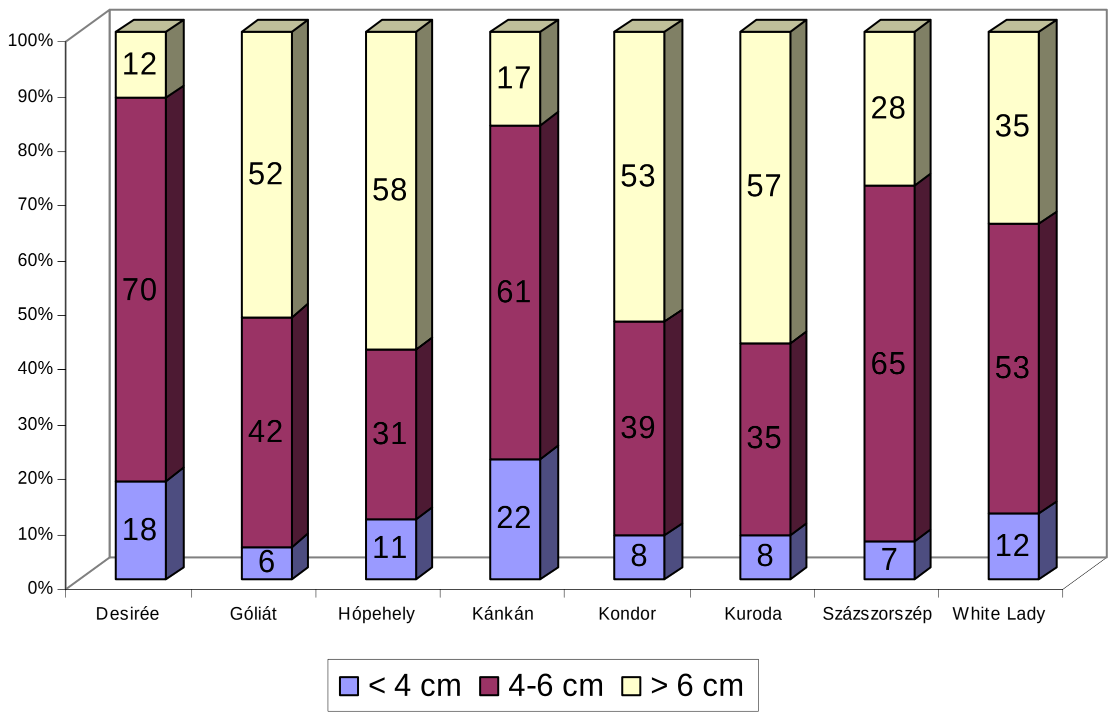

Figure 5: Size distribution of tubers in irrigated treatments in 2002

In the dry, warm year of 2003, cultivars responded differently to the additional water supply:

- Irrigation increased the ratio of large tubers in most of the cultivars (Góliát, Hópehely, Kánkán, Kondor, Kuroda, Lilla, Százszorszép and White Lady) by 5-20 %.
- The ratio of large tubers reduced only in the case of one cultivar, Desirée as a result of irrigation, similarly to that in 2002, but the reduction was smaller.
- As a result of irrigation, the ratio of medium-sized tubers increased considerably in the case of cvs. Desirée and Százszorszép, it did not change for cv. White Lady, but it was reduced for all the other cultivars (Góliát, Hópehely, Kánkán, Kondor, Kuroda, Lilla) (by 9-15 %).

2004 was a wet year for potato:

- The largest ratio of large tubers (> 6 cm átmérőjű) was measured for cvs. Lilla (54 %), Hópehely (45%) and Kondor (42%) without irrigation.
- Irrigation had a favourable effect on the size distribution of tubers of cvs. Desirée and Kuroda, while it affected unfavourably cvs. Hópehely, Góliát, Kánkán and Lilla, while it did not cause a significant change in the case of cvs. White Lady, Százszorszép and Kondor.

4.3. Changes in the inner content parameters

Water affects not only the quantity, but also the quality of potato yield (draught at the beginning of summer accompanied by high temperatures is becoming frequent, the distribution of precipitation is not balanced and its amount varies between years).
There are marketed plant products, where special attention has been paid to quality control (e.g. winter wheat, sugar beet, sunflower), while in the case of others the objective qualification was considered less important (corn, potato). However, due to the fact that the amount of potato and processed potato products sold at supermarket chains is increasing, the importance of quality control is also increasing in the case of this crop (moisture content, starch content, under water weight, frying quality, reducing sugar content).
Changes in the inner content parameters are especially important in the case of cultivars produced for different utilization purposes, but inner content also has a great influence on the storability of potato.

4.3.1. The effect of treatments on under water weight

Under water weight of potato is influenced by numerous factors, e.g. cultivar, water and nutrient supply, light intensity, etc.
Generally, it is true that those factors which promote the development of foliage reduce the under water weight, while those enhancing tuber development increase it.
During the season, under water weight increases continuously. The larger the ratio of mature tubers by harvest, the largest the under water weight of potato. In dry years, the under water weight of potato is usually larger than in wet years.
Processing industry requires a high under water weight. Depending on the processing, it should be higher than 400 gramm (370-450 g) for pommes frites, 430 gramm (400-470 g) for crisps, 400 gramm felettit (400-450 g) for mashed potato and flakes.
In our experiment we found that

- irrigation increased significantly the under water weight of tubers in 2003 and 2004.
- in the dry year, the under water weight of potato was higher than in the wet year.
- the under water weight of cultivars was significantly different in all three years, the under water weight of Kuroda was significantly higher in all years than that of other cultivars.
- higher under water weight was accompanied by higher starch content

4.3.2. The effect of treatments on dry matter content

High dry matter content has a positive effect both on the product ratio and product quality. The dry matter content of potato tubers is usally between 18 and 24%, which corresponds to about 325 and 450 g under water weight.
If the dry matter content is too low, then the pommes frites or chips will be soft. Potato with higher dry matter content, however, absorbs less oil during frying. However, if the dry matter content of the tuber is too high, then the pommes frites will be too hard and dry.
The differences in the dry matter content of cultivars due to the irrigated and non-irrigated treatments are presented in Figures 6 and 7.

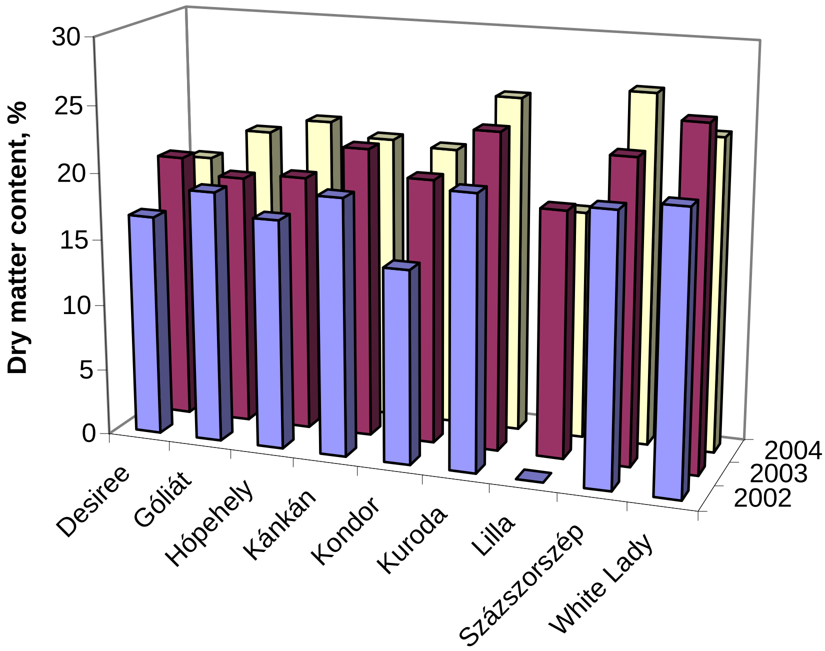

Figure 6: Changes in the dry matter content in non-irrigated treatments in the period of 2002-2004
$SD_{5\%}$ *(cultivar)* 2.14 %

- The dry matter content of potato was less strongly influenced by irrigation in the wet year than in the studied years, but the effect of irrigation was not significant in either year.
- The dry matter content of cultivars was significantly different in all the three years, the dry matter content of Góliát and Kondor was smaller than that of the other cultivars ($SD_{5\%\,(cultivars)}$=2.14).
- High dry matter content was accompanied by high under water weight. In 2002, the correlation was very close (r=0.99), while in 2003 and 2004, it was medium (r= 0.6).
- Negative correlation was found among dry matter content and fry colour (r= 0.7), and dry matter content and manganese content in all three years (r= 0.4-0.55).

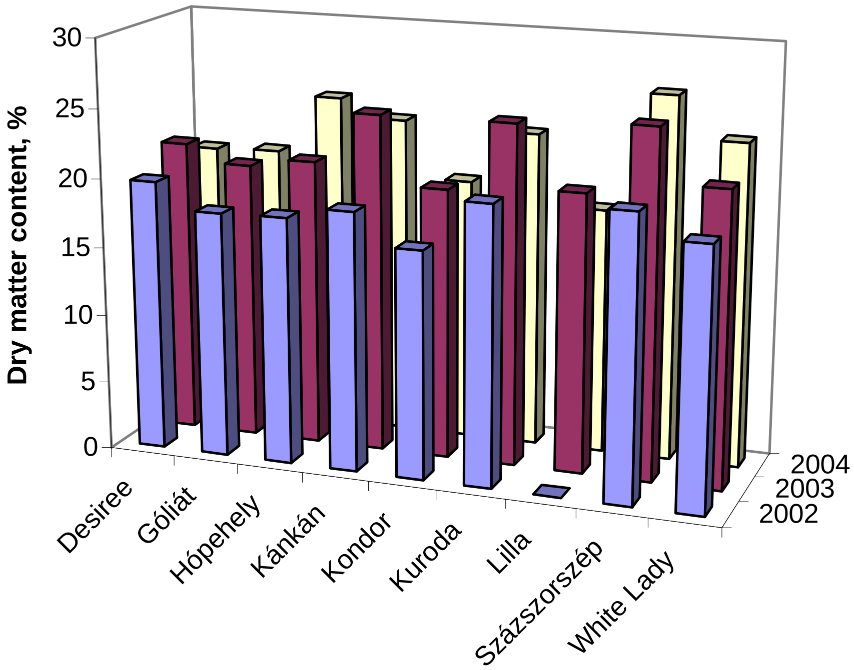

Figure 7: Changes in the dry matter content in irrigated treatments in the period of 2002-2004
$SD_{5\%}$ *(irrigation)* 2.07 % $SD_{5\%}$ *(cultivar)* 2.14 % $SD_{5\%}$ (irrigation x cultivar) 3.03 %

4.3.3. The effect of treatments on starch content

The most important indicator of quality is the starch content, which is usually 75% of the dry matter content and ranges between 12 and 20 %.
When studying starch content, we found that

- Irrigation did not have a significant effect on starch content which is primarily dependent upon the cultivar and is not influenced significantly by irrigation.
- There were significant differences among cultivars: the starch content of cvs. Százszorszép and White Lady, and Kondor was higher and lower as compared with other cultivars (Figure 8).
- There is a negative correlation between starch content and fry colour (r=0.6), and starch content and manganese content (r=0.58).
- There is a positive correlation between starch content and under water weight (r=0.5).

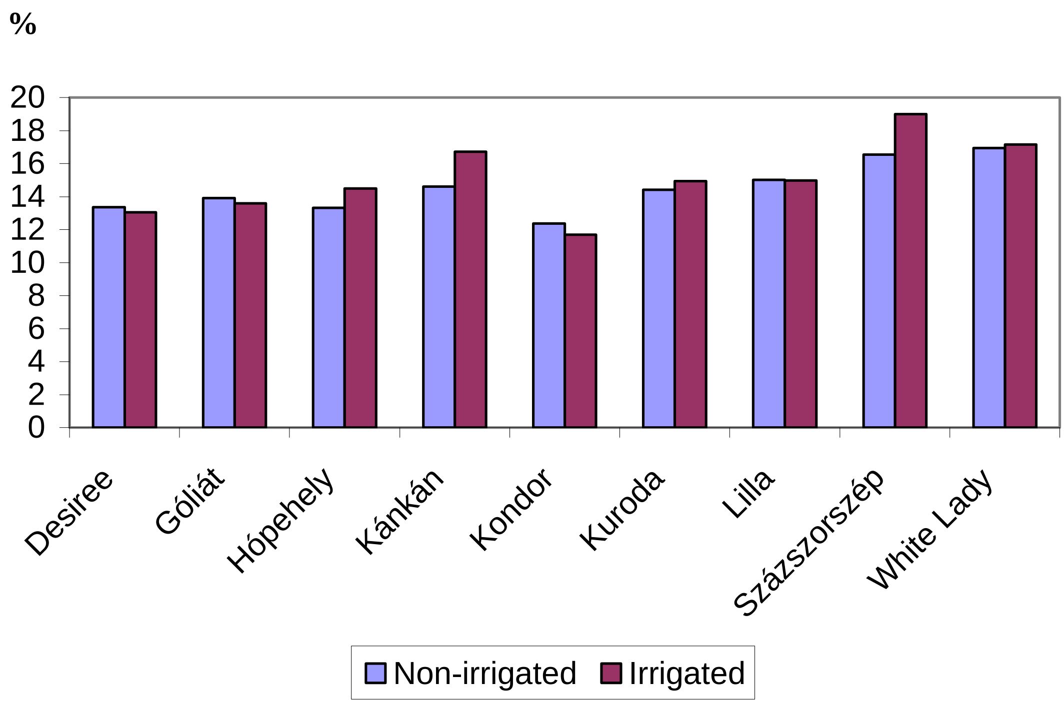

Figure 8: The effect of treatment on starch content in the average of three years

$SD_{5\%}$ *(irrigation)* 2.53 % $SD_{5\%}$ *(cultivar)* 2.59 % $SD_{5\%}$ (irrigation x cultivar) 3.67 %

4.3.4. The effect of treatment on reducing sugar content

The quality of table potato is influenced by the reducing sugar content, since it has an effect of the taste and colour of fried potato. During the frying process, the reducing sugars react with the free amino acids (Maillard-effect) result in a brown colouration of the product.
Since free amino acids are always available in great amounts in the tubers, therefore, the reducing sugar content determines the colour of the end product. If it is too high, then a bitter taste of the product will also be caused in addition to the dark brown colouration.
The processing industry accept reducing sugar content values of maximum 0.4% for pommes frites and flakes, and 0.2% for chips (calculated for fresh weight).
Cultivar and storage temperature have the largest influence on the reducing sugar content of tubers.
When evaluating reducing sugar content results, it should be taken into account, that it is determined by a subjective examination.
When studying the reducing sugar content, we found that:
- Irrigation did not have a significant effect on reducing sugar content in either year.
- There were significant differences among the cultivars in all three years: the reducing sugar content of cv. White Lady was significantly higher than that of cvs. Desirée, Góliát, Kánkán and Kondor, but it was still below the limit accepted by the processing industry.

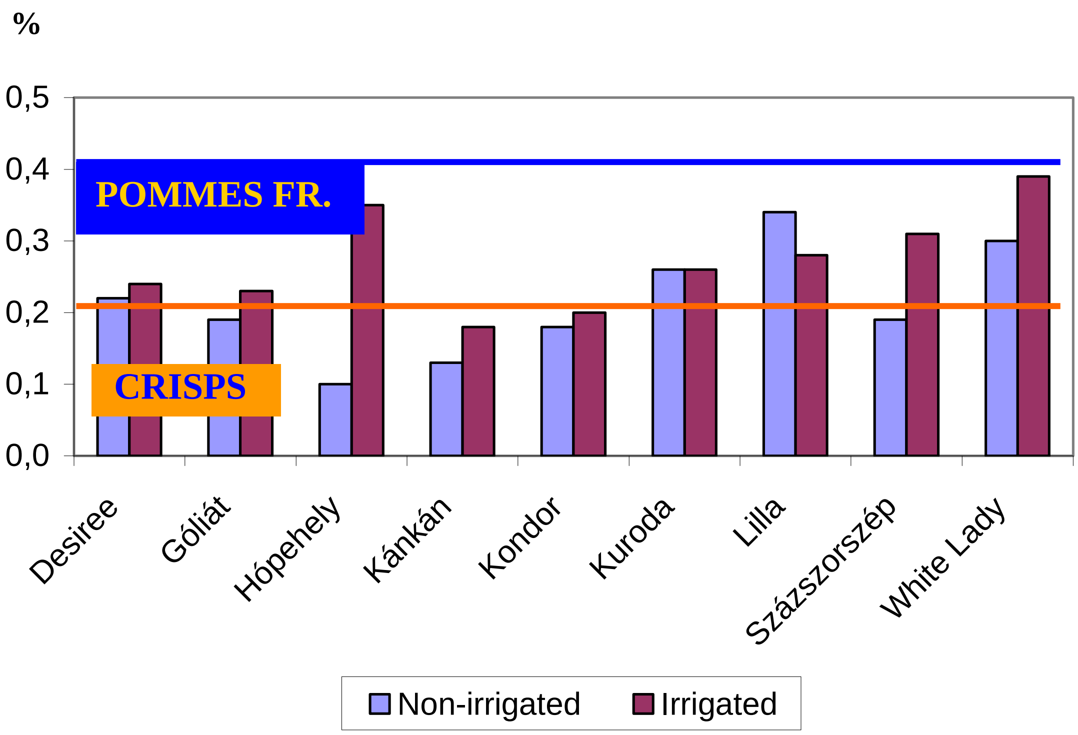

Figure 9: The effect of treatments on the reducing sugar content in the average of three years
$SD_{5\%}$ *(irrigation)* 0.16 % $SD_{5\%}$ *(cultivar)* 0.16 % $SD_{5\%}$ (irrigation x cultivar) 0.226 %

In order to clarify the relationships, we consider it meaningful to continue the experiment, since longer data series enable us to obtain more precise relationships and the ratio of mistakes is reduced.

4.4. The effect of treatments on fry colour

Fry colour expresses the degree of the browning of potato as a result of frying. In the case of pommes frites, this value should be low, which means that it does not brown during frying but it remains uniformly yellow.
Processing industry accepts the following values: fry colour under 3.00 is considered very good, values between 3.00-4.00 are acceptable, while the acceptance of lots with a fry colour above 4.00 depends upon the processing firm (maximum 4.5 in general).
Our experiments have verified that

- irrigation did not have a significant effect on the fry colour in either of the studied years.
- there were significant differences among cultivars: the fry colour of Lilla was significantly higher than that of cv. Százszorszép. Both with and without irrigation, the fry colour of cv. Százszorszép was the most favourable in all three years.
- higher fry colour was accompanied by a lower under water weight (r=0.6).

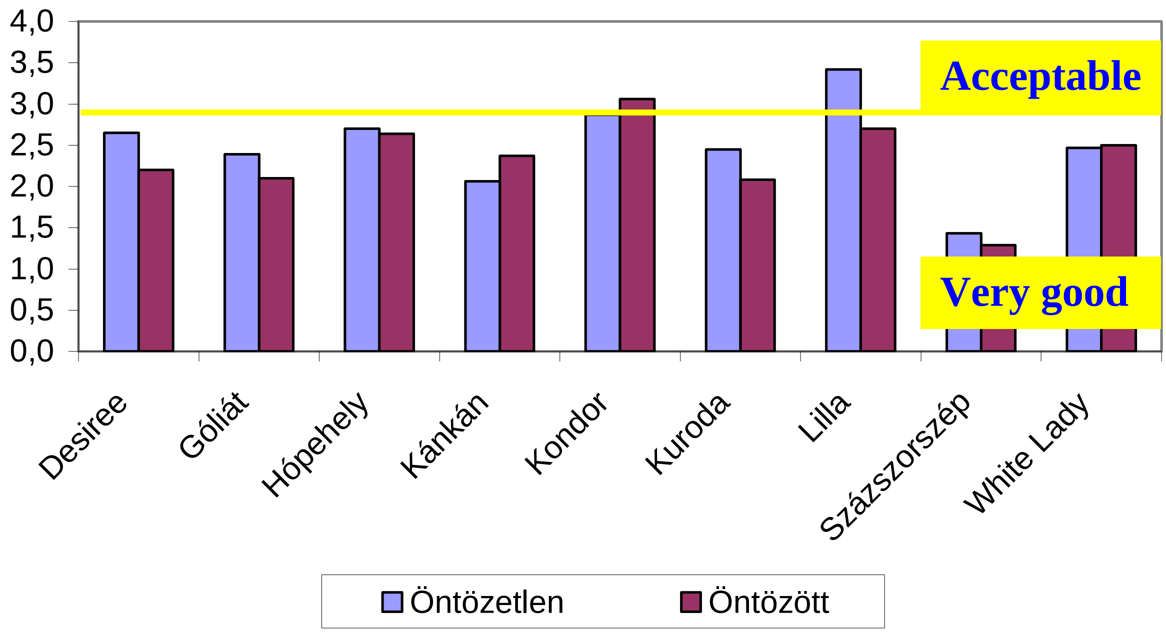

Figure 10: The effect of treatments on fry colour in the average of three years
$SD_{5\%}$ *(irrigation)* 0.653 $SD_{5\%}$ *(cultivar)* 0.566 $SD_{5\%}$ (irrigation x cultivar) 0.8

4.5. The effect of treatments on the element content of tubers

The results of the examinations on element content were variable:

- *Irrigation did not have a significant effect on the K, P, Ca, Mg, S, Mn, Na, Cu, Fe content.*
- The *K content* of Hópehely and Kánkán was significantly higher than that of other cultivars.
- The *P content* was the highest for cvs. Százszorszép and Desirée in the irrigation treatments.
- The high *magnesium content* of tubers was accompanied by a high *copper content* (correlation coefficient r=0.8).
- The *S content* of cv. Százszorszép was higher than that of other cultivars.
- The *Mn content* of cvs. Desirée, Góliát and Kondor was significantly higher than that of cvs. Hópehely and White Lady.
- The *Na content* of cvs. Góliát and Hópehely, and Kuroda and White Lady was significantly higher and smaller, respectively, than that of other cultivars.
- The *Cu content* of cvs. Desirée, Góliát, Kondor, Kuroda and Százszorszép was significantly higher.
- There was a positive correlation between the manganese and copper content of tubers (r= 0.66), similarly to that between manganese and zinc content (r= 0.49).
- The *Zn content* of cv. Desirée was significantly higher in all three years than that of most other cultivars.
- The *iron content* of cvs. Kánkán and Hópehely, and Százszorszép and White Lady was significantly higher and lower, respectively, than that of other cultivars.

4.6. Evaluation of the studied cultivars

Considering the results of the three-year cultivar study, those cultivars can be suggested to more rainy areas or areas that can be irrigated which responded well to irrigation both regarding quantity and quality. In those areas where irrigation is not possible, those cultivars should be preferred the yield of which is high even without irrigation.

Among the studied cultivars, only *Desirée* and *Kondor* are grown on large areas in Hungary. During the experiment, the yield of Desirée increased considerably due to irrigation, but it was mostly inferior to cultivars of Hungarian breeding regarding the quality parameters. Its dry matter content was low under irrigation, moreover, its resistance characteristics are also unfavourable.

Kondor produces high yields even under non-irrigated conditions, as a result of irrigation it produces more large tubers, its dry matter content is low. **Therefore, we recommend Kondor to those areas where irrigation is not possible.**

The yield of *Kuroda* is high both with and without irrigation, the ratio of tuber size categories is also favourable for this cultivar. The yield of ***Százszorszép*** was lower than that of other cultivars both under irrigated and non-irrigated conditions. Its resistance qualities are favourable, based on its high dry matter content and reducing sugar content we suggest it for **food processing.**

White Lady has favourable characteristics both regarding quality and quantity Without irrigation, its yield was above 30 t/ha, it responded well to irrigation, its yield was considerably higher. Based on the results of our experiments, **this cultivar is the most suitable for table use** among the studied cultivars **in the region characteristic to the experimental site.** Its industrial utilization can be limited by the fact that it has a high reducing sugar content.

Góliát produced average yields, had a low dry matter and highe reducing sugar content in the experiment. As a result of irrigation, the ratio of its large-sized tubers increased greatly.

Yields in the irrigated repetitions were the smallest in the case of *Kánkán*. As a result of irrigation, it produced more small and less large tubers. Probably, it set more tubers which could not fully develop. Its dry matter content is average, its reducing sugar content was low even under irrigation.

If there is no possibility for irrigation, then the best cultivars can be **Hópehely and White Lady,** since they gave 31-34 t/ha yield without irrigation in the average of the three years of our experiment.

Under irrigation, we recommend cvs. **Hópehely, White Lady, Kondor and Kuroda** to be grown in areas with similar conditions to that of the experimental site.

5. NEW AND NOVEL SCIENTIFIC RESULTS

I. Yield, size distribution of tubers

1. There is a tight relationship between year, irrigation and yield of potato cultivars. In the dry year (2002) the yield of the studied 8 cultivars was 24.84 t/ha without irrigation and 44.92 t/ha under irrigation. The yield-increasing effect of irrigation was 80%.
2. In the dry, warm year (2003), the average yield of the 9 cultivars was 20.29 t/ha without irrigation and 33.75 t/ha under irrigation. The yield-increasing effect of irrigation was 70 %. There were large differences among cultivars in the yield increment due to irrigation. Irrigation had a great role in increasing the yields of cvs. Kondor (80 %), Hópehely (90 %) and Százszorszép (115 %). The yields of cvs. Góliát (30 %) and Kánkán (45 %) were increased by a smaller extent by irrigation. By irrigation, the harmful effect of draught can be prevented, irrigation reduced the yield loss and thereby increased yield safety.
3. In the wet year (2004), the average yield of the 9 cultivars was 32.36 t/ha without irrigation and 34.64 t/ha under irrigation. The yield-increasing effect of irrigation was 7 %.
4. The impact of irrigation on tuber size varies greatly depending on the year and cultivar. As a result of irrigation, the ratio of small and large tubers reduced and increased, respectively. In dry years, irrigation had a favourable effecr on the size distribution of tubers of cvs. Kondor, Kuroda, Hópehely and Góliát (it increased the ratio of large tubers by at least 10 %).

II. Quality, inner content (UWW + dry matter content and starch content)

5. Irrigation significantly increased the under water weight of tubers in 2003 and 2004. Higher under water weight was accompanied by higher starch content. The under water weight of cvs. Kánkán, Kuroda, Százszorszép and White Lady was significantly higher than that of the others. There were also significant differences among the cultivars in starch content: the starch content of cvs. Százszorszép and White Lady was significantly higher than that of other cultivars.
6. A positive correlation was found between dry matter content and under water weight (in 2002 r =0.99; in 2003 and 2004 r=0.64-0.67). There was a tight positive correlation between dry matter content and starch content, r = 0.8. A negative correlation exists between the dry matter content and fry colour of tubers (correlation coefficient: r =0.7). There is a negative correlation between fry colour and starch content (r = 0.6).
7. Irrigation did not have a significant effect on dry matter content, fry colour and reducing sugar content in either year.
8. At higher starch content, the fry colour and manganese content of tubers were lower. There was a negative correlation between starch content and manganese content in all three years (r = 0.4-0.55).

III. Quality, inner content (element content)

9. Irrigation did not have a significant effect on the K, P, S, Ca, Mg, Cu, Fe and Na content. As a result of irrigation, there was a slight decrease and increase in K and P content, respectively. There were significant differences among the cultivars in P and K content: the potassium content of cvs. Hópehely and Kánkán and the phosphorus content of cvs. Százszorszép and Desirée were significantly higher than those of other cultivars.
10. Positive correlations were found between magnesium content and zinc content (r = 0.49), and manganese content and copper content (r = 0.66).

6. SCIENTIFIC RESULTS APPLICABLE IN THE PRACTICE

1. The yield of potato can be greatly increased by irrigation especially in years with lower precipitation. Accordingly, the yield-increasing effect of irrigation is about 70-80%.
2. The yield-increasing effect of irrigation is significantly larger in dry years (70-80 %), than in normal or wet years (7 %).
3. The size distribution of tubers can be influenced via irrigation, the ratio of undersized tubers can be reduced, which results in lower selection and peeling costs.
4. There is a tight relationship between irrigation and certain inner content parameters. Irrigation does not reduce significantly the dry matter content and starch content of cultivars.
5. There are large differences among cultivars in yield quality and quantity which should be considered at determining the aim of production and in cultivar-specific technologies.
6. Cultivars with better adaptability should be preferred when selecting the cultivars, due to the increase in weather extremes. Under irrigation, we recommend cvs. **Kondor, Kuroda, Hópehely és White Lady** for areas with similar conditions to those of the experimental site, since their yield was above 40 t/ha in the average of three years under irrigated conditions.
7. If irrigation is not possible, then cvs. **Hópehely and White Lady** can be recommended, since their yields were 31-34 t/ha in the average of the three years of the experiment without irrigation. However, their yield varied between the years.

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