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THESES OF DOCTORAL (PhD) DISSERTATION

EVALUATING THE CORRELATION BETWEEN SPAD VALUES AND THE YIELD OF MAIZE (*Zea mays* L.) ON DIFFERENT NUTRITIVE AND WATER SUPPLY LEVELS

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1. INTRODUCTION

> *„There is no case which a clever*
> *man could not take advantage of"*
> *(Jókai)*

Agriculture has been the basis of human civilisation since the beginning of historical times. Agricultural production process is based on crop production, during which economically profitable crops use the energy of sunlight to produce carbohydrates indispensable for the nutrition of people and farm animals. The amount of food produced by crop growing and animal husbandry serves the nourishment of the Earth's population. The population is continuously growing, therefore we need more and biologically valuable food.

At the beginning of our chronology, the population of Earth was assumed to be around 150 million people. After 1000 years, this number doubled, whereas it reached 6.2 billion in 2000. Based on predictions, the Earth's population will increase to 7.2 billion in 2015 and 8–9 billion in 2050. The wasteful and harmful utilisation of natural resources and the energy, food and drinking water demand increases even more than the incredibly growing population.

The worldwide production rate of crop growing and animal husbandry grew from 1.9% (in the period 1986–1995) to 2.4% (in the period 1996–2005), therefore it outran the growth rate of population. Consequently, the growth rate per capita showed an increasing tendency. This value was 0.3 and 1.1% in the above mentioned two periods, respectively. A significant part of the increase of production is the consequence of the yield increase. For example, the yield of cereals increased by 17% between the two periods.

Nevertheless, intensive crop nourishment is indispensable for the increase of yields and this process needs energy. Fertilisers (especially nitrogen fertilisers) demand considerable fossile energy that has a limited availability. In the light of this, it is important to not use more fertiliser than absolutely necessary in order to get a yield surplus that can be produced economically.

In the future, the practical application of the basic principles of sustainable crop nourishment should be paid more attention to. It is the only way to meet the dual requirements formulated by *Stefanovits* (1977) in his „Ten commandments of soil protection": 1: *Do not apply more fertiliser than what the crop needs."* and 2: *„Maintain the fertility of soil and if possible, increase it!"*

As agriculture was becoming more intensive, human activities – and anxiety concerning the damages caused by agricultural production (nitrogen leaching, eutrophication, etc.) – got more and more emphasised. Nevertheless, agriculture and more specifically, crop growing does not only produce food, but it rationally recreates its resources, while carrying out environmental sustaining and atmosphere protection activities.

The change of oil prices will have a more significant impact on the world's agriculture than before. On one hand, permanently high oil prices will increase the costs of agricultural production and it will really imply the wider application of bioenergy (biofuels, biomass) on the other. This latter can increase the demand for maize as feedstock.

Maize is produced on a huge area in the world. It is grown south from 45^0 northern latitude in North America, whereas it is produced generally up to the 50th latitude in Europe, where the vegetation period provided by temperature is at least 140 days. Although mainly maize for silage is produced to the North from the Carpathians, maize can be found up to the 60th latitude in Norway. It is grown to the 42nd latitude on the Southern Hemisphere (New Zealand). The altitude limit on our continent is 1300 m (Tirol), whereas it is 3000–3900 m in Peru and Mexico.

Hungary lies in the middle of the temperate zone of the Northern Hemisphere, „halfway" between the Equator and the North Pole (NL: 45°48'–48°35'; EL: 16°05'–22°58'). According to the climate classification by Trewartha, it can be characterised by a cold, moderate climate with long warm periods.

The climate and soil of the country is outstandingly appropriate for maize production. *Carter et al.* (1991) found that one degree change in the annual mean temperature modifies the northern border of maize production by 300–330 km. This border has been continuously moving to the North by 50 km per year.

Maize is of outstanding importance worldwide. As regards both the production area and the amounts of yield, it is in the first place. As for maize production of maize, its total yield was 483 million tons in 1990. This value increased to 766 million tons in 2007. The 59% increase of production is the most dynamic among cereals. Due to the cautious prognosis of the maize production in the future, the rate of production – depending on the population growth – will slowly increase.

The importance of maize production in Hungary is indisputable. Its production area has been continuously growing since it has spread. It amounted to 20% of the sowing area in the 1930s–1940s. Intensive animal husbandry made its production area increase even more. Average yield was also growing with the increase of the sowing area of maize. After the second World War, yield increased from 2.2 t/ha to more than 6 t/ha (early 1980s) in a country average (*Nagy* 2007). Due to its high productivity and versatile utilisation, producers try to grow maize on higher and higher areas. Meanwhile, we also have to consider that we have to recover the energy of the soil used up by production. We should also improve the structure of soils. We have to apply environmental friendly production technologies. In order to be able to do all this, we have to be more acquainted with the correlation among soil, crops and the environment. Hybrids with outstanding genetic features are also needed for success.

It is important to know what production technology we should use on the given soil, within the given macro- and micro-climatic conditions, while also considering economic and environmental protection aspects and human needs.

2. OBJECTIVES

> *„To invent something it to see*
> *what everyone sees and think*
> *what no-one has ever done."*
> *(Szent-Györgyi)*

The nutriment demand of crops can be roughly estimated on the basis of the nutriment content of yield. The nutriment supplying capacity of soils varies, therefore the fertiliser need of maize will be different on different soils, even when yield levels are the same.

The nutriment uptake of crops calls for a significant amount of energy. This energy is generated in the cells and is released by respiration. It also happens that the nutriment needed is present in the soil solution in the amount needed, still, crops cannot take them up, because their nutriment reserves are low, or the respiration of the root is hindered by the lack of air. In cases like this, we have to cease the hindering conditions, instead of fertilising the crop. Even if we are exactly aware of the phenomena in the soil and the factors affecting the nutriment supply of the soil, we still cannot get a comprehensive view about the nourishment status of the crop in question. The direct answer will only be given by the crop itself. This is why the analysis of crops is also indispensable.

There are several methods to determine the nourishment status of crops: visual, cell sap analysis, leaf and crop analysis, instrument measurement (SPAD).

Visual diagnostics

The analysis of the nourishment status of crops is done on the basis of the outward form of the whole crop or certain crop organs (color, habit, growing abnormities). The one-sided and overdosed macroelement fertilisation can result in the relative lack of important microelements. The advantage of visual method is that it is quick, cheap and it has no instrument or laboratory need. Nevertheless, there can be several reasons for a symptom, as also agrotechnical factors and weather can affect the development of a crop, besides nutriment supply. The practical application of crop diagnosis calls for a notable experience and versatile skills.

Besides this method, crop analysis has also been carried out.

Cell sap analysis

It is a local field analysis that makes it possible to determine the nutriment supply of the green crop tissues. After adding a reagent the change of the colour of the cell sap is compared to a standard colour scale. Its alternative using the principle of threshold dilution is quick and it can be carried out on the spot. It is not very widespread, due to its unreliability.

Leaf and crop analysis
Determination of the nutriment content of a well-developed photosynthesising green leaf in a specific development stage of a crop, or that of another part of the crop using laboratory analyses. Results enable us to calculate nutriment proportions.

Instrument measurement (SPAD-502)
Owing to the Soil Plant Analysis Development (SPAD-502) chlorophyll meter, we have an instrument at hand that can measure the degree of N supply of crops. The meter carries out immediate measurements on the leaf without destruction.

During our examinations, we applied SPAD-502 chlorophyll meter to determine the nourishment status of the crop. In this current study, we evaluated the results we gained.

Nitrogen is one of the most important nutritive that greatly affects the growing and yield of maize. Quickly tracking the development of nitrogen shortage and the finding its correlations is not an easy task, as nitrogen moves easily within soil, therefore it will not be accumulated in the cultivated layers of soil. Nevertheless, determining the optimal amount of N is indispensable from the aspect of efficient fertiliser utilisation and the prevention of soil and underground water contamination.

I would like to fulfil a dual task with my doctoral (PhD) dissertation. On one hand, I want to reach a more exact determination of the degree of N supply in crops even in early development stages of maize.
On the other hand, based on analysis data, I would like to get an a view on how fertilisation and irrigation – two important production factors – affect maize yield in our experimental areas, the correlation between yield and SPAD values and I would also like to get to know whether the results gained can be used in maize fertilisation consultancy.

3. MATERIAL AND METHODS

> *„Measure what is measurable and*
> *make measurable what is not so."*
>
> *(Galilei)*

Examinations were carried out between 2003–2007 within a multifactoral long-term field experiment established in 1984 on calcareous chernozem soil with loam texture at the Látókép experimental site of the University of Debrecen, Centre of Agricultural Sciences and Engineering.

The constant active ingredient proportion of NPK fertilizer doses was 1 N : 0.75 P_2O_5 : 0.88 K_2O. The basic nitrogen dose was 30 kg ha^{-1}. We used treatments of 1, 2, 3, 4 and 5 times the basic dose, plus a control treatment without fertilisation. (*Table 1*). Irrigated and non-irrigated treatments were used and the quantity of irrigation water applied in the former is shown in *Table 2*. Irrigation was applied by Valmon linear irrigation equipment. The population was 70,000 plants ha^{-1}.

Table 1. *Fertiliser treatments*

Treatment	Fert. act. ingr. kg ha^{-1}		
	N	P_2O_5	K_2O
non-fertilised	-	-	-
N_{30}	30	23	27
N_{60}	60	45	53
N_{90}	90	68	80
N_{120}	120	90	106
N_{150}	150	113	133

Table 2. *Amount of irrigation water and the time of applying it* (Debrecen, 2003, 2004, 2006 and 2007)

Time of irrigation	Amount of irrigation water (mm)
16th June 2003	45
26th June	40
08th June 2004	25
07th July	25
13th July 2006	25
26th July	25
27th April 2007	25
16th May	30
10th June	30
26th June	25

Geographical location of the experimental site. Debrecen, Hungary (N: 47°33’, E: 21°27’, 113–118 metres above sea level). The size of the experimental plot was 190 ha. Based on the results of a soil analysis conducted in 2002, the average pH value of the soil was 6.6, which is optimal from the aspect of crops’ nutrient uptake. The physical characteristic of the soil can be classified as a medium-heavy loam. The upper (0.2 m) layer of soil had a soil plasticity in Arany number of 3.7 and a total salt content of 0.05% m/m. The carbonic chalk content in the upper 0.8 m of soil is 0% m/m (i.e. there is a chalk deficiency), but it steeply increases between 1 m and 1.6 m, reaching 11% m/m (i.e. moderately chalky). Compared to the soil analysis results in 1984, the carbonic chalk content appears in deeper and deeper layers. Even the humus layer of the soil has been decreasing due to intensive cultivation during the last 23 years; currently it is 2.4% m/m in the upper 0.2 m of soil, whereas it does not exceed 1% m/m at a depth of 1.2 m. The soil nitrogen and potassium supply was good and the phosphorous supply was average.

Weather. Environmental parameters were continuously measured and logged by an automatic measurement and data-logging station. Air temperature (°C) at heights of 0.5, 1 and 2 m, relative humidity (%) soil temperature (°C) at depths of 50, 250 and 500 mm, incoming radiation (W/m^2) and the amount of precipitation (mm) were measured every sixth second. The statistical parameters derived from the data (average, standard deviation) were stored every 15 minutes. Basic data are accompanied by pheno- and phytometric observations and soil analyses.

We used the following equation to calculate heat units – one of the most important criteria in maize growing – related to the entire growing season:

$$\text{heat unit} = \sum_{i=1}^{n} \frac{(T_{\max} - T_{\min})}{2} - T_{basis}\text{, where} \qquad (1)$$

$T_{\max}$ indicates maximum daily temperature, $T_{\min}$ stands for minimal daily temperature and T_{basis} indicates the base temperature for crop development, which is 10°C in the case of maize. We calculated the potential evapotranspiration using the method of *Szász* (1973), which is widely used in Hungary. It considers the atmospheric elements and processes that mainly influence the evaporation of water – the temperature of air, the relative moisture content of water steam, wind speed and microadvection effects.

The evaporation of a water-filled bathtub having a volume of 3 m^2:

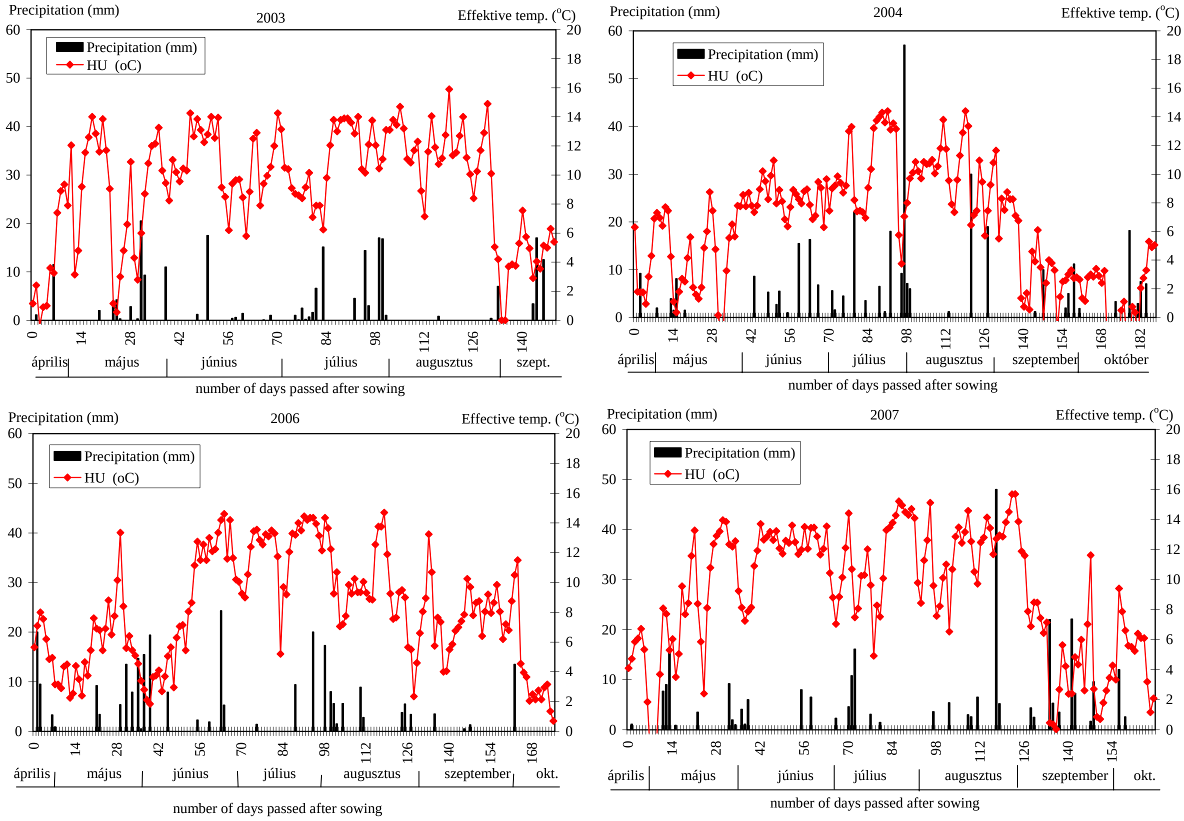
$$PET=\beta[0{,}0095(T-21)^2(1-R)^{2/3}f(v)] \qquad (2)$$

where:

PET: potential evapotranspiration [mm day^{-1}]
T: daily mean temperature [°C]
R: degree of saturation
$f(v)$: effect function of wind speed
β: coefficient for the expression of the oasis effect

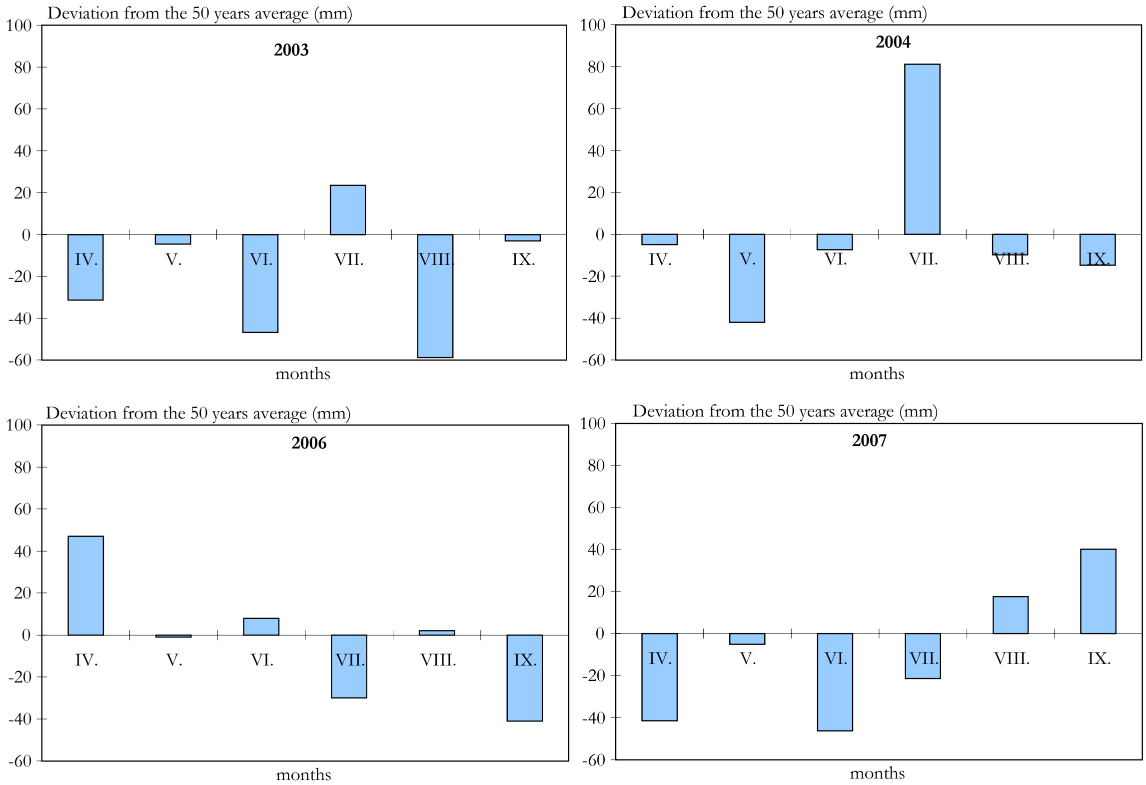
The growing period of *2003* started with a significant precipitation deficiency (-56 mm). The total effective heat units were 1406 °C and the potential evapotranspiration (PET) was 826 mm. The difference between the amount of precipitation and potential evapotranspiration was -389 mm. The amount of precipitation during the growing season (215 mm) was lower than the PET value of the same period (585 mm). From the aspect of precipitation over a 50 year period, 2003 was a favourable year (*Figures 1–2*).

Figure 1: *Amount of precipitation (mm) and effective temperature (°C) in the growing period* (Debrecen, 2003, 2004, 2006 and 2007)



In *2004*, there was sufficient precipitation for maize both in the winter half year (258 mm) and in the growing season (351 mm). The distribution of precipitation was also favourable and the amount of precipitation during the months critical from the aspect of the development of maize (July and August) was sufficient. The total amount of precipitation during the two months was 192 mm. This year was even wetter than average. Maize utilised 1181 °C for yield formation during the growing season. The potential evapotranspiration was 794 mm in 2004, i.e. 190 mm higher than the amount of precipitation of the same year (604 mm). The PET value (604 mm) of the growing season exceeded the amount of precipitation of the same period. The extent of precipitation supply of the year 2004 only slightly differed from the 50 year average (*Figures 1–2*).

Figure 2: *Deviation of precipitation in the growing period from the 50 years average* (Debrecen, 2003, 2004, 2006 and 2007)



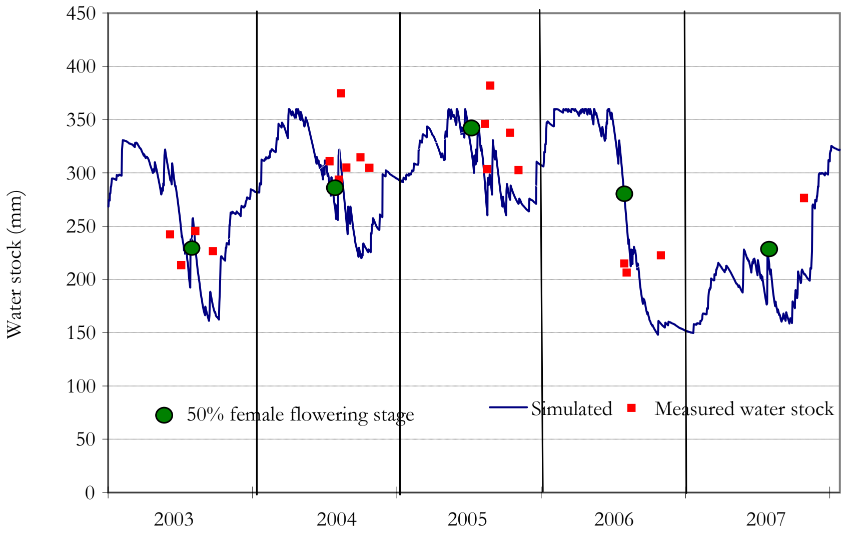
Note: 50 years average is 340 mm.

The weather during the winter half of *2006* was average. The spring was significantly moister than average, especially in April (92 mm). The total effective heat units were 1441 °C during the growing season. The amount of precipitation in 2006 was 522 mm, whereas the PET value was 845 mm, i.e. a difference of -323 mm. The PET value of the growing season was 632 mm, higher than the precipitation from April to October (277 mm). Altogether, the weather during 2006 can be considered average (*Figures 1–2*).

The weather during *2007* was extreme for maize. In July, a temperature of 40 °C lasting for several days set back maize strongly. This heat was accompanied by a persistent precipitation deficiency. The mean temperature of every month between September 2006 and August 2007 was higher than many years' average for a whole year. The total effective heat units was the highest in this year (1519 °C) amongst the years examined. The potential evapotranspiration in 2007 was 899 mm, of which 651 mm would have been needed for the evaporation from crops. As with the previous years, this amount exceeded the quantity of precipitation from April to September, by 370 mm. The difference between the precipitation and PET value in 2007 was -453 mm. Altogether, 2007 can be considered a drought year unfavourable for maize growing (*Figures 1–2*).

The amount of maize yield is determined not only by precipitation, but also the water stock of soil. *Figure 3* indicates that the water stock of soil in the droughty years 2003 and 2007 was much less in the period between the 50% female flowering stage and the end of the vegetation period, than in years with average precipitation supply.

Figure 3: *Water stock of soil, mm*
(at a depth of 1.2 m)
(Debrecen, 2003–2007)



Maize has been grown in monoculture with the application of traditional agrotechnics since the establishment of the experiment in 1984. At harvesting, we determined the moisture content of the grain and yields were converted to 15% moisture content.

The relative chlorophyll concentration of maize leaf was measured with a SPAD-502 portable chlorophyll meter and we evaluated the degree of nitrogen supply of maize during the growing season. Measurements were carried out for each N treatment and their irrigated and non-irrigated versions. The hybrids we used for the analysis were: Debreceni 377, DK 391, Mv 277 and Szegedi SC 352.

Younger crops are the most suitable for the determination of degree of the nutritive supply of soil, because intensive dry matter accumulation and growing does not start in this period yet. As for maize, this starts after the total development of the sixth lead. The nutritive uptake per one unit of root surface is relatively stable and high. Generally, the concentration of nutritives is the highest in young tissue, the insufficiencies of the degree of nutritive supply are intensified. The possible insufficiencies of nutritive supply can be made up for by top-dressing or by foliar application of fertilisers. These additionally applied nutritives can still by taken up by crops in order to increase their yield or its quantity (*Elek* and *Kádár* 1980). Therefore, we started to carry out measurements every year at the six-leaf stage. Further measurements were implemented at the 12-leaf stage and 50% female flowering stage of maize. The number of days between sowing and harvesting varied during the years in the average of hybrids: it was 84 in 2003, 80 in 2004, 78 in 2006 and 71 in 2007, that can be brought into connection with the annual value of heat units. Grain yields were measured at harvest on the following dates: 18/09/2003, 27/10/2004, 16/10/2006 and 08/10/2007.

SPAD-502 chlorophyll meter. The principle of measurement is based on the process of leaves absorbing light of different wavelengths to different extents. The extent of the light attenuation of chlorophyll is in direct correlation with the chlorophyll content of the leaf. The light attenuation peak of chlorophyll can be found in the blue and red wavelengths. The attenuation is low in green, yellow ranges and practically it is zero in the infrared range. Therefore, it is worth taking the infrared range as a basis for comparison and using either the blue, or the red range for measurement. SPAD-502 uses red light for measurement, as the absorption of this range is not affected by the carotene content of the leaf.

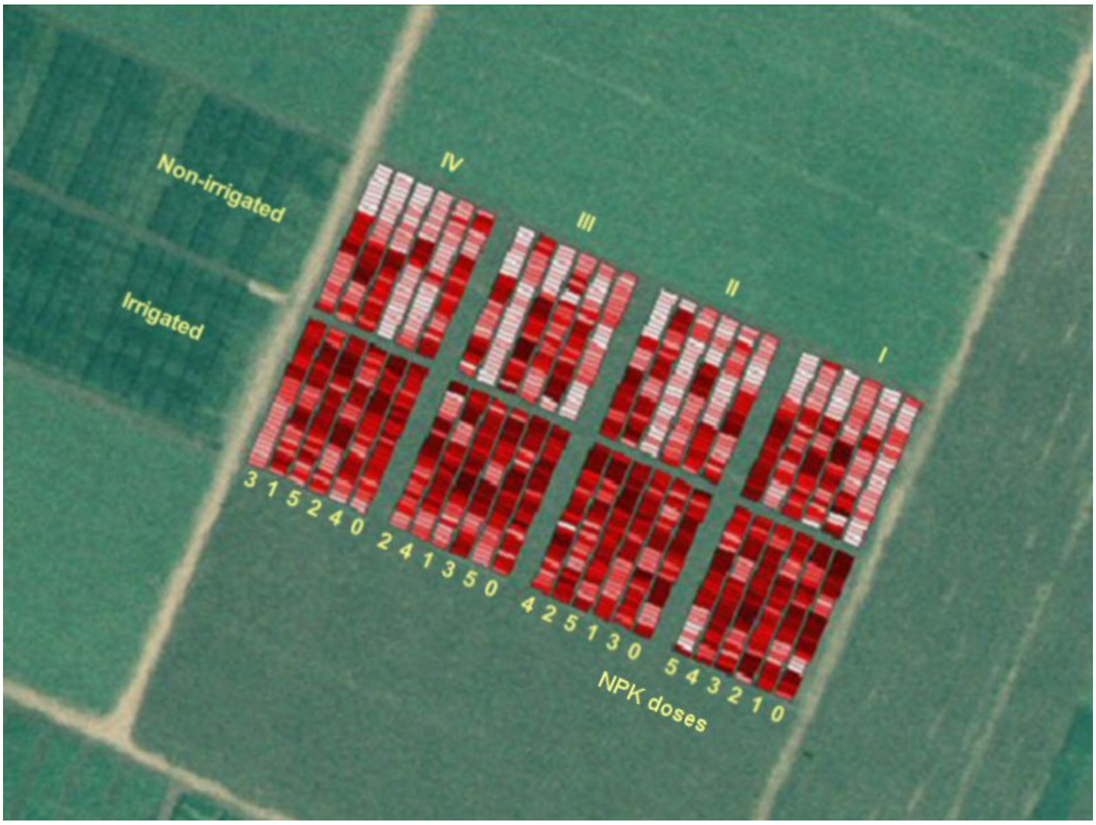
The basis of the calculation is constituted by the ratio of the strengths of infrared and red light going through the leaf. The more light gets absorbed in the leaf, the higher this ratio is, thereby showing a close correlation with the chlorophyll content of the leaf. SPAD values are between 0 and 100 (*Minolta Camera Co. Ltd.* 1989).

Statistical method. The correlation between the SPAD values of maize and the production factors, as well as yield and production factors was evaluated by a *general linear model* (GLM). The comparison of SPAD values and SPAD chlorophyll concentrations, as well as the mean values of yield was done using *Duncan's test*. We examined the correlation between N fertiliser and SPAD values and that of between N fertiliser and yield using a *logarithmic function*. We evaluated the correlation between SPAD values and yield by a *linear function*. Fitting the functions was done by regression analysis, the minimalisation of the residual sum of squares. The reliability of fitting the functions was indicated by the value of R and MSE. Evaluation was done by SPSS for Windows 13.0 statistical software package.

Three-factorial strip plot design. The three-factorial – factor A is irrigation (2 versions), factor B is fertilisation (6 fertiliser active ingredient treatments), whereas factor C represents hybrids (28 cultivars) long-term field experiment had four repetitions and a strip plot design (*Figure 4*).

Here, block is equal to repetition. Fertilisation and hybrid treatments can be found in the main plots, both in irrigated and non-irrigated versions. Therefore, the impacts of treatments placed across each other (fertiliser, hybrid) could be determined with the same accuracy. As the evaluation of SPAD values did not cover the differences between hybrids during the examination, the three-factorial experiment was evaluated as a two-factorial one with strip-plot design.

Figure 4: *Three-factorial long-term field experiment, Debrecen*
(genotype x irrigation x nutritive)



During the evaluation of crop years, the impact of the given years was evaluated using a repeated measurement model. This way, the impact of crop year affected every single treatment, therefore the requirement of independence was not met. The impact of years can be considered a treatment placed on the main plot of a split-plot design. The differences between years were not our primary aim, but we wanted carry out the evaluation of the correlation between years and treatments as accurately as possible.

4. RESULTS

> *„No amount of experimentation can ever prove me right; a single experiment can prove me wrong."*
>
> *(Einstein)*

4.1. The impact of fertilisation on the SPAD value of maize

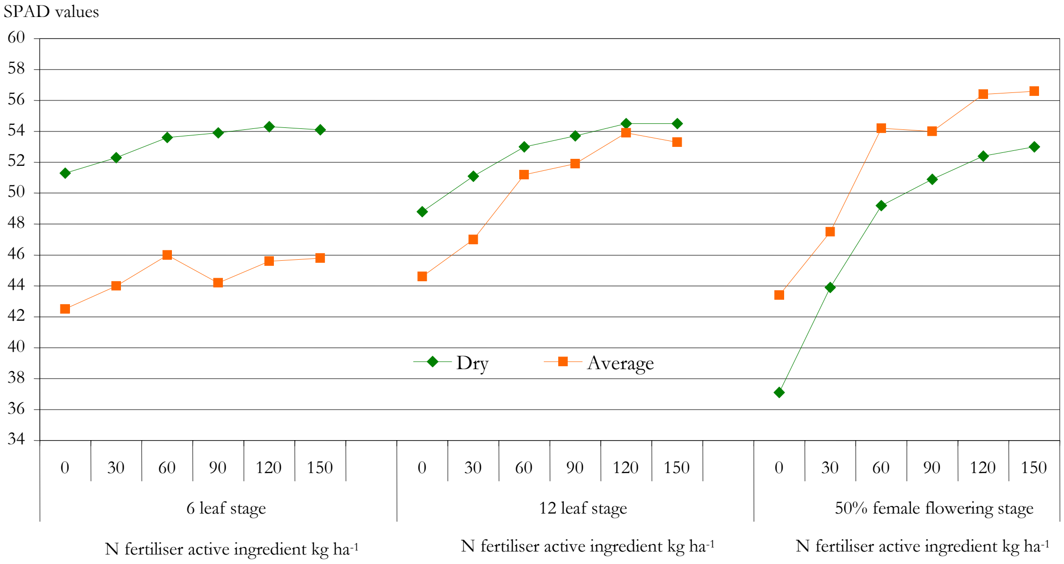
During the research we wanted to know the impact of fertilisation, irrigation, crop year and the interactions of these three factors on the SPAD value and yield; their correlation and it was also our objective to find out whether the results we gained by the chlorophyll meter could be used in the maize fertilisation consultancy network.

4.1.1. Effect of fertilisation within non-irrigated conditions

We analysed the effect of fertilisation in the *non-irrigated treatments* of the long-term field experiment in Debrecen annually. The results of the variance analysis show that fertilisation significantly ($P<0,001$) increased SPAD values in all three measurement times. The correlation between year x NPK was significant on a level of 0.1%. This correlation indicates that the impact of fertilisation changed from crop year to crop year and that the impact of crop year is getting stronger when the time of 50% female flowering stage comes closer. The modifying effect of crop year increases until 12 leaf stage in years with average precipitation supply, whereas this effect decreases at the time of flowering (*Figure 5*). Using Duncan test at a 5% significance level, we justified that – in both dry and average years – 60 kg N ha^{-1} fertiliser active ingredient was needed in 6 leaf stage within non-fertilised conditions, whereas this value was 120 kg N ha^{-1} in 12 leaf stage and at 50% female flowering stage.

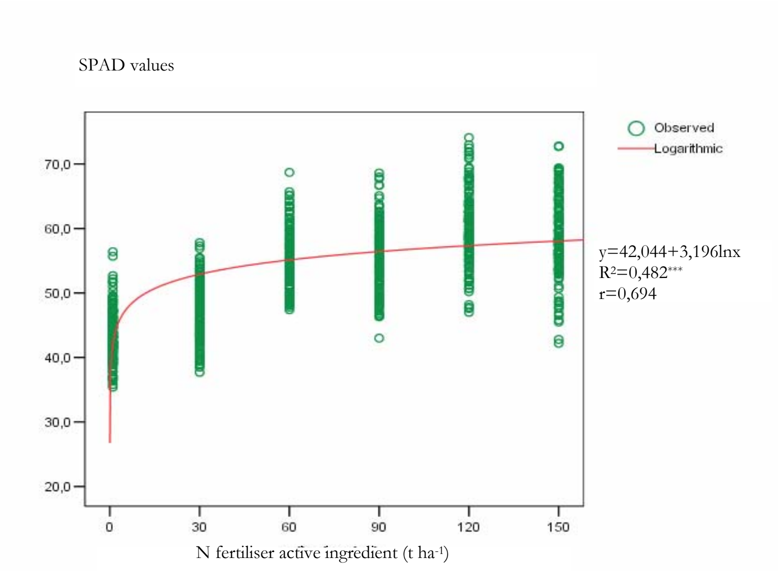
At all three measurement occasions, the lowest SPAD values were measured on plots that have not been fertilised since 1984. In these plots, as a result of nitrogen deficiency, there was little chlorophyll generated in leaves and yellow pigments (carotene and xanthophyll) were predominant. The highest SPAD value (60.3) was measured in 2004. The average SPAD values of fertilised parcels were significantly higher at 6 and 12 leaf stage in a droughty year (53.6 and 53.4, respectively), than in an average one (45.1 and 51.5, respectively). At the 50% female flowering stage, we measured a higher SPAD value (53.7) in the average crop year than that of the droughty one (49.9). The difference was significant ($P<0.001$) in every case. Fertiliser effect was decreased the most by water shortage in 2007. In a dry year, the SPAD value increasing effect of fertilisation compared to that of the control treatment was smaller at 6 and 12 leaf stage, whereas it was higher at 50% female flowering stage than in an average year.

Figure 5: *SPAD values depending on the development stage of maize crop, crop year effect and N fertiliser doses*
(non-irrigated version)
(Debrecen, 2003, 2004, 2006 and 2007)



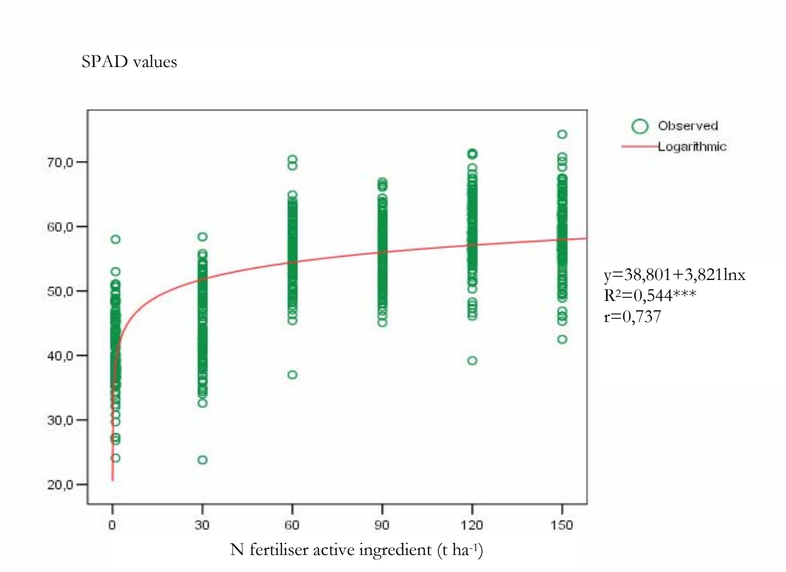
We examined the correlation between fertilisation and SPAD values by using regression analysis. In 2004, there was a close correlation between the two factors at 12 leaf stage (r=0.694) and 50% female flowering stage (r=0.737) (*Figures 6–7*). The weakest correlation during the years examined was found in 2007 – the driest year.

Figure 6: *Correlation between fertilisation and SPAD values, results of the logarithmic regression*
(12 leaf stage, non-irrigated version)
(Debrecen, 2004)



***P=0,1%

Figure 7: *Correlation between fertilisation and SPAD values, results of the logarithmic regression*
(50% female flowering stage, non-irrigated version)
(Debrecen, 2004)

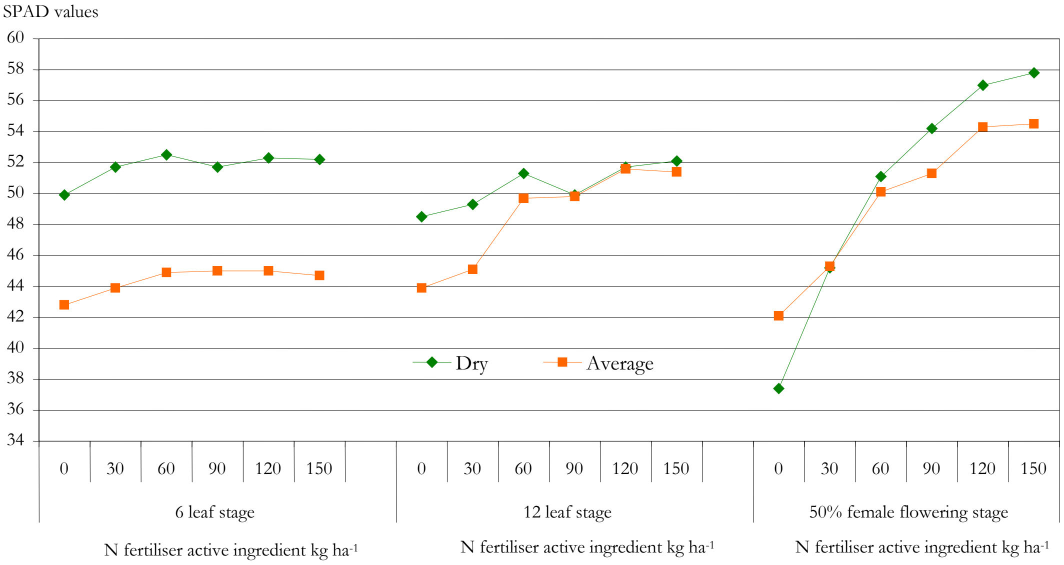


4.1.2. Effect of fertilisation within irrigated conditions

The impact of fertilisation in *irrigated treatments* was also statistically proven (P<0.001) in all four years and at all three measurement occasions.

The correlation between year x NPK was significant at a level of 0.1%, that is the impact of NPK on SPAD values changed from year to year. Similarly to the non-irrigated treatments, the SS value of the correlation between year x NPK in years with average precipitation supply was increasing until 12 leaf stage, then started to decrease. At 6 leaf stage, the fertiliser dose 30 kg N ha^{-1} reliably increased SPAD value in comparison with the control treatment. The further increase of N is not justified. As for 12 leaf stage and 50% female flowering, only 120 kg ha^{-1} N active ingredient caused significant increase in the SPAD value in comparison with the control treatment. The effect of fertilisation was more significant in the irrigated version at the time of 50% female flowering, than it was in the non-irrigated version. The averages of fertiliser active ingredient treatments differed from each other both in years with dry and average precipitation supply at 6 leaf stage, whereas the two crop years were similar in the case of 12 leaf stage and 50% female flowering stage (*Figure 8*). Based on the result of regression analysis, we found that there is a significant correlation (P<0,001) between the two factors at all three measurement occasions. In the case of measurement occasions taken at 50% female flowering stage, the closest correlation (r=0.728) was gained in 2003. In all of the examined years, data of 50% female flowering showed closer correlation, than those gained at 6 and 12 leaf stage.

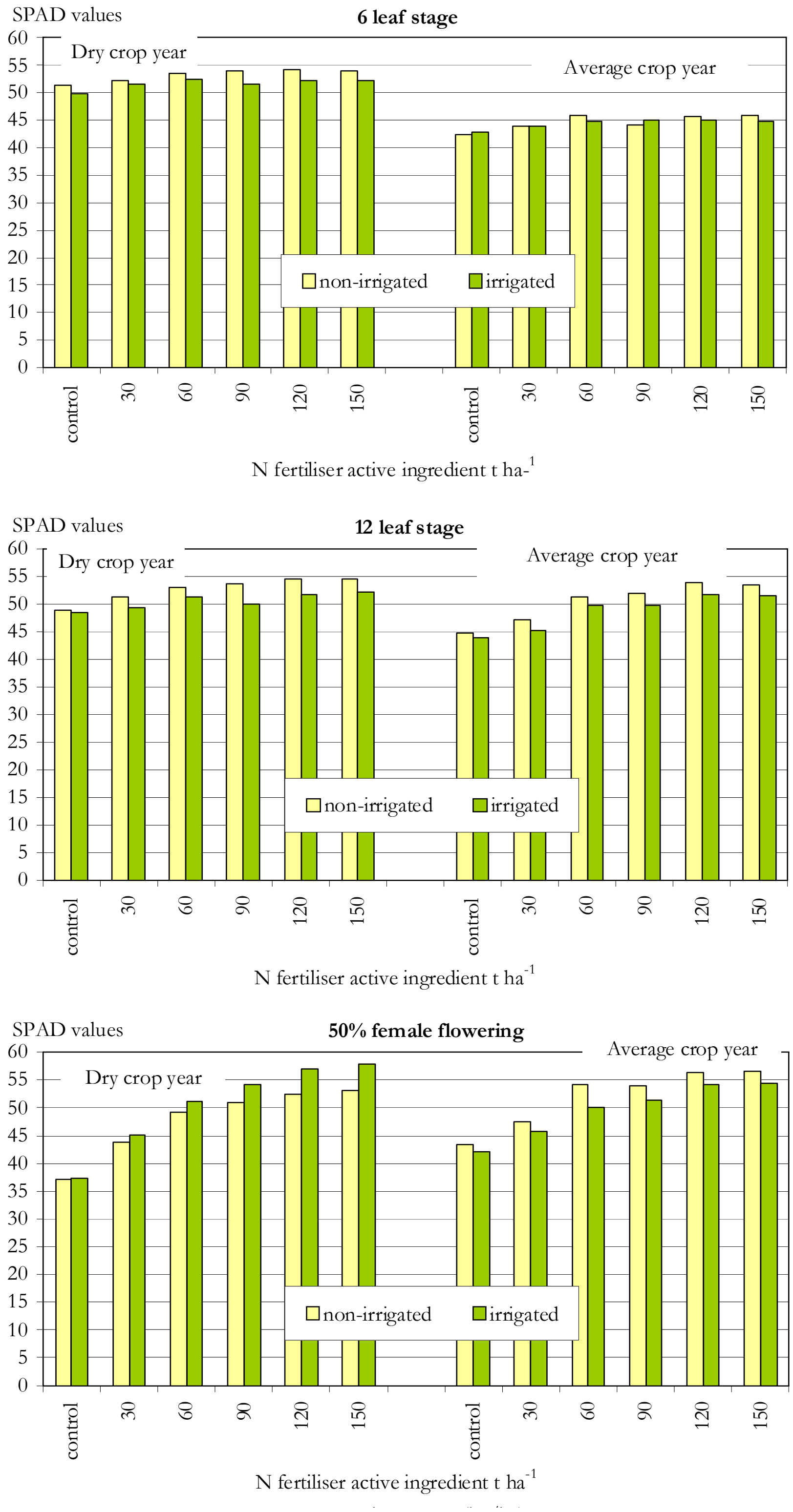
Figure 8: *SPAD values depending on the development stage of maize crop, crop year effect and N fertiliser doses*
(irrigated version)
(Debrecen, 2003, 2004, 2006 and 2007)



4.2. The effect of irrigation on the SPAD value of maize

Irrigation affected the SPAD value of maize reliably with the exception of 6 leaf stage. Its level was $P<0.001$ in the dry year, whereas this value was $P<0.05$ in the year with average precipitation supply. Nevertheless, its quantified impact is lower than that of fertilisation. With the exception of 50% female flowering stage, irrigation decreased SPAD values in non-irrigated treatments and the extent of this decrease was significantly higher in years with average precipitation supply. The effect of irrigation was the highest in the droughty year of 2007 – at 50% female flowering stage. Conforming to Hungarian and foreign research projects, our research data also proved that irrigation decreases chlorophyll concentration and thereby the concentration of nitrogen as well. When examining and analysing the impact of irrigation on SPAD values, we found that irrigation reliably increased ($P<0.01$) SPAD values in the dry year at 50% female flowering stage in the average of fertiliser active ingredient treatments, whereas in years with average precipitation supply it decreased them ($P<0.05$) at all three measurement occasions. We examined the impact of irrigation at all three measurement occasions with the help of a t-test. We ran the test for each active ingredient treatment separately. We found that irrigation decreased the SPAD values of maize (*Figure 9*) at every nutritive level in both crop years – with the exception of 50% female flowering, dry crop year.

Figure 9: *Impact of irrigation and fertilisation on the SPAD values of maize* (Debrecen, dry years and years with average precipitation supply)



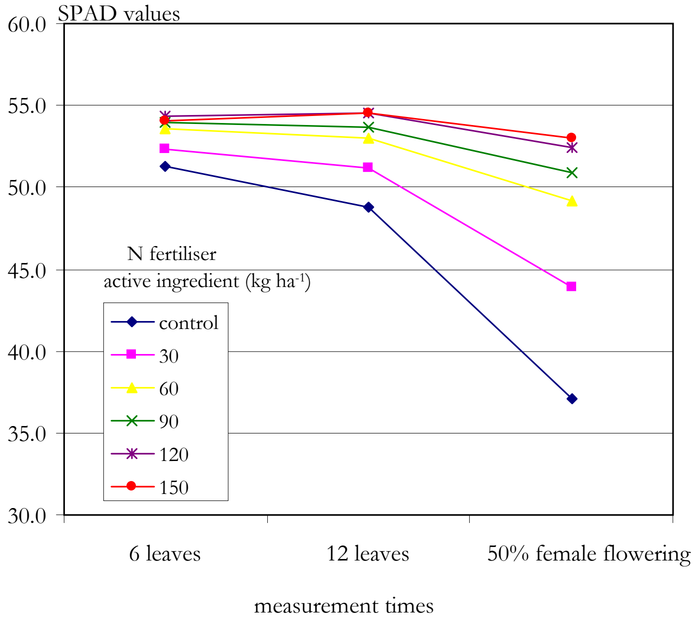
The significant correlation between irrigation and fertiliser justified – at all three measurement occasions and in both crop years – hat the impact of fertilisation on

SPAD values was changing in accordance with irrigation. From the results of variance analysis (cumulated evaluation) of the years' data, we concluded that fertilisation was the only independent variable among the three (fertilisation, year, irrigation) that had a significant impact ($P<0.001$) on the dependent variable (SPAD value). Among first-rate correlations, year x irrigation and year x NPK was significant at all three measurement occasions, whereas irrigation x NPK showed reliable difference only at 50% female flowering.

4.3. The dynamics of SPAD values in the vegetative phase

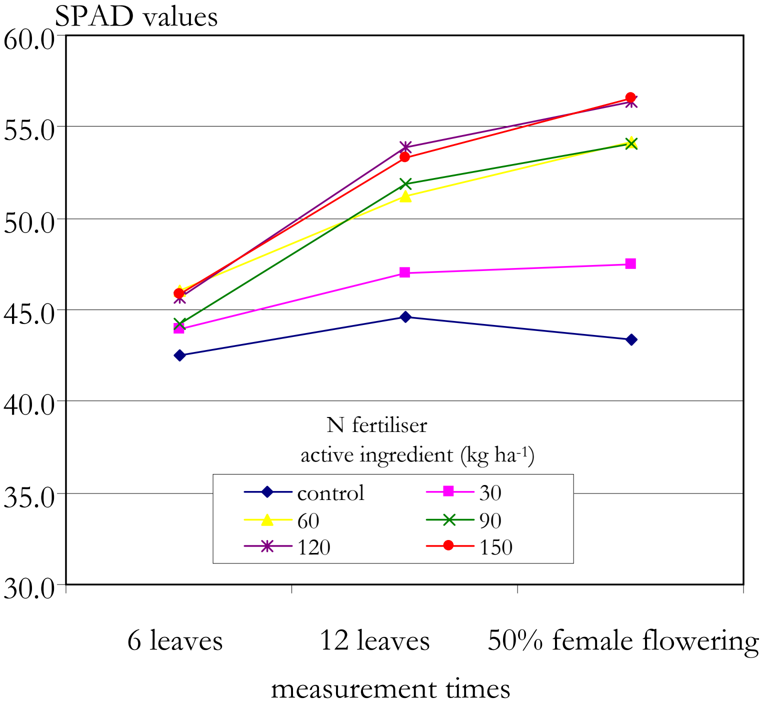
SPAD values were the highest at 6 leaf stage *in non-irrigated treatments* in the dry year – in the average of fertiliser treatments – that decreased during the development (*Figure 10*). By the time of 50% female flowering, the amount of decrease was 3.7 SPAD units in 77 days. The biggest decrease in SPAD values was measured on the control plot in both dry years. Compared to the 6 leaf stage, the decrease of the leaf's SPAD values was 17.5 in 2003 and 9.8 in 2007.

Figure 10: *SPAD values of maize during the growing season in the average of dry crop years* (non-irrigated version)
(Debrecen, 2003, 2007)



In crop years of average precipitation supply (2004, 2006) – in the average of fertiliser treatments – the lowest SPAD values (44.7) were measured at 6 leaf stage. As the growing period progressed, SPAD values also increased by 6.3 at 12 leaf stage and a further 2.3 at 50% female flowering stage. The N concentration of the leaf became abundant by the time of 50% female flowering (*Figure 11*). The highest increase in SPAD values until the time of flowering was shown by the fertiliser active ingredient treatment 120 kg ha^{-1}. When examining the two years separately, we found that in the growing period of 2004, - in the average of fertiliser active ingredient treatments - SPAD values increased by a relatively smaller extent (2.4) than they did in 2006 (5.3). Nevertheless, among fertiliser active ingredient treatments, the increase of SPAD values was smoother in 2006 than in 2004.

Figure 11: *SPAD values of maize during the growing season in the average of crop years with average precipitation supply*
(non-irrigated version)
(Debrecen, 2004, 2006)



In *irrigated treatments*, SPAD values – similarly to the non-irrigated version – decreased in every fertiliser active ingredient treatment by the 12 leaf stage in the dry year of 2007, in comparison with the 6 leaf stage. The biggest decrease (-2.4) could be measured in the case of 30 kg ha^{-1} fertiliser active ingredient treatment. There were further decreases in SPAD values at 50% female flowering in non-fertilised (-7.7) and 30 kg ha^{-1} fertiliser active ingredient treatments (-2.5) (*Figure 12*). In years with average precipitation supply, SPAD values increased when the time of 50% female flowering was getting closer (*Figure 13*). The extent of increase was smaller at both measurement occasions than in the case of non-irrigated treatments. As the growing period was progressing in 2004, SPAD values decreased in non-fertilised and low (30 kg ha^{-1}) fertiliser active ingredient treatments, whereas we measured an increase in 2006 at every nutritive level. The biggest increase in SPAD values could be reached by 150 kg ha^{-1} fertiliser active ingredient treatment by the time of 50% female flowering in both crop years.

Figure 12: *SPAD values of maize during the growing period*
(irrigated version)
(Debrecen, 2007)

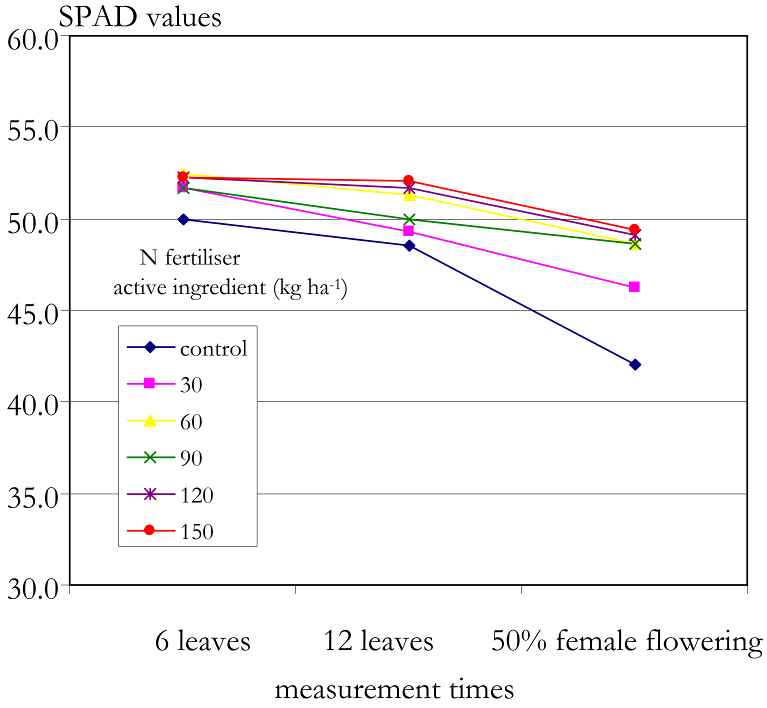
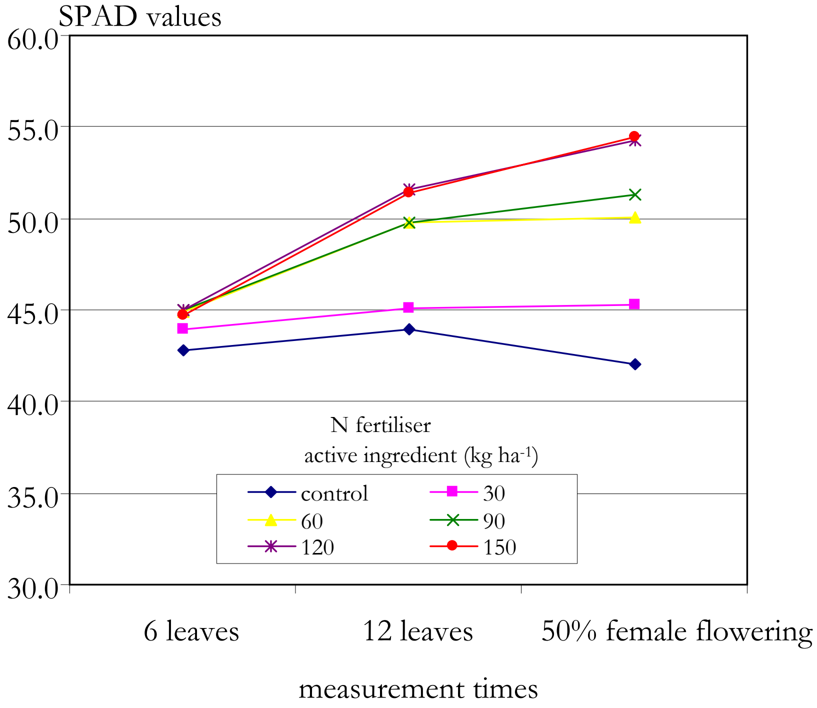


Figure 13: *SPAD values of maize during the growing season in the average of crop years with average precipitation supply*
(irrigated version)
(Debrecen, 2004, 2006)



In the average of fertiliser active ingredient treatments, irrigation significantly decreased SPAD values in the dry year of 2007 at 6 leaf stage, whereas we measured an increase at the time of flowering (*Figure 14*). In the crop year of average precipitation supply, irrigation decreased SPAD values at both measurement occasions, the biggest decrease could be observed at 12 leaf stage (*Figure 15*).

Figure 14: *The impact of irrigation on the SPAD values of maize during the growing period* (dry crop year) (Debrecen, 2007)

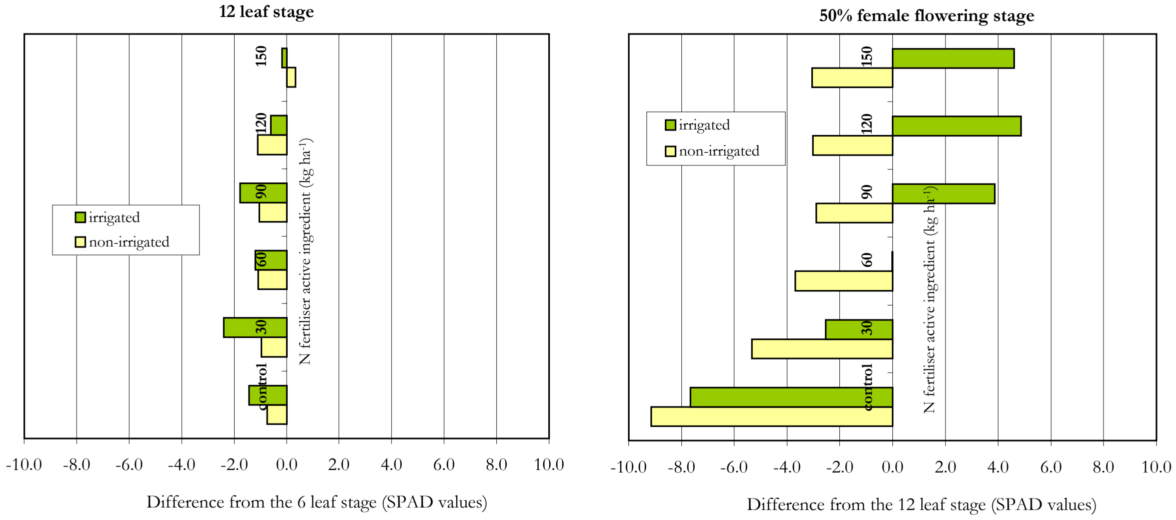
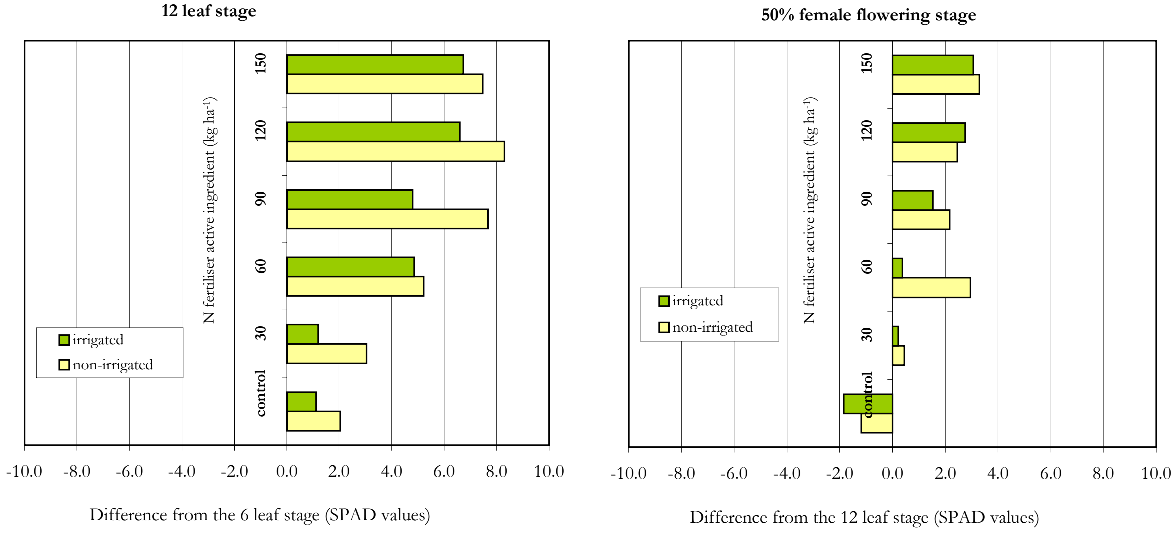


Figure 15: *The impact of irrigation on the SPAD values of maize during the growing period* (crop year with average precipitation supply) Debrecen, 2004, 2006)



To summarise our findings, we stated that – both in non-irrigated and irrigated treatments – SPAD values decreased in dry years, as the growing period progressed, whereas they increased in years with average precipitation supply. Nutrient uptake is rather intensive until 12 leaf stage in years with average precipitation supply. The decrease of SPAD values is the biggest at 50% female flowering in dry years.

As a result of irrigation – in the average of fertiliser active ingredient treatments – chlorophyll concentration decreases to a higher extent at 6 leaf stage than 50% female flowering both in dry years and both in years with average precipitation supply. By the time of 50% female flowering, chlorophyll concentration will be similar at 50% female flowering to that of 12 leaf stage, whereas we measured an increase in years with average precipitation supply.

We stated that besides the nitrogen demand of maize, the right technology of nitrogen fertilisation is also greatly influenced by the nutrient uptake curve of crops, as well as the dynamics of uptake. The nitrogen uptake of maize during vegetation is greatly modified by irrigation and crop year.

4.4. Evaluating the yield results of maize

In the non-irrigated version, the biggest **effect of fertilisation** on maize **yield** was observed in 2004 (3.979 t ha^{-1}), whereas we observed the smallest effect in 2007 (1.454 t ha^{-1}). The lowest yield within the non-fertilised treatment was obtained in 2007 (3.476 t ha^{-1}), whereas the highest was reached in 2004 (5.844 t ha^{-1}). Fertilisation effect ($P<0.001$) can be considered to be similar in years with average precipitation supply (2004, 2006) and dry years (2003, 2007) (3.089 t ha^{-1} and 3.167 t ha^{-1}, respectively), that is also justified by the SS value of variance analysis.

Based on the results of the Duncan test, we can state that – both in dry years and years with average precipitation supply – there was a reliable difference only among three nutrient treatments (non-fertilised, 30 and 60 kg N ha^{-1}). Both in the average of the four examined years and in each year, 60 kg N ha^{-1} fertiliser active ingredient was needed to achieve the maximum yield (*Table 3*).

Table 3. *Yield of maize (t ha^{-1})*
(non-irrigated version)
(Debrecen, 2003, 2004, 2006 and 2007)

Fertilised version	Yield, t ha^{-1}						
	2003	2004	2006	2007	Dry	Average	Joint
	Years				Crop years		
non-fertilised	4,137a	5,844a	4,808a	3,476a	3,854a	5,252a	4,553a
N_{30}	6,722b	8,157b	6,911b	3,986a	5,550b	7,445b	6,497b
N_{60}	7,918c	9,780c	7,397b,c	5,643c,d	6,943c	8,419c	7,681c
N_{90}	8,350c,d	10,060c	7,837c	5,835d	7,272c	8,790c	8,031c
N_{120}	8,927d	10,457c	8,030c	4,862b,c	7,185c	9,070c	8,128c
N_{150}	8,546c,d	10,663c	7,504b,c	4,322a,b	6,736c	8,858c	7,797c

Data in one column indicated by the same letter do not significantly differ from each other on the basis of Duncan test

Due to a descriptive logarithmic function and the cumulated statistics analysis, the impact of fertilisation on yield in non-irrigated treatments is suitable for describing the relationship, but the correlation between variables is average (r=0.547). In the examined years – with the exception of 2007 – we found a close correlation between fertilisation and yield. The fitting error was around 1 t ha^{-1} every year.

Our research results reliably showed that the effect of fertilisation in the *irrigated treatments* was higher (5.021 t ha^{-1}, $P<0.001$) in the average of four years than it was in the *non-irrigated version* (3.128 t ha^{-1}). In the average of treatments, the correlation between fertilisation and irrigation had the biggest impact in the dry year of 2007 (4.705 t ha^{-1}). In the dry year, the impact of fertilisation x irrigation was significantly higher (4.459 t ha^{-1}) than it was in the crop year with average precipitation supply (3.299 t ha^{-1}). As for the correlation between fertilisation and yield, the difference among the five nutritive levels in the dry year (non-fertilised, 30, 60, 90 and 120 kg N ha^{-1}) and the four levels in years with average precipitation supply (non-fertilised, 30, 60 and 90 kg N ha^{-1}) was also significant (*Table 4*). The yearly fertiliser reaction of maize differed to a smaller extent in the irrigated version than it did in the non-irrigated one, and yield fluctuation decreased. Based on the value of the correlation coefficient (r=0.764), there is a close correlation between fertilisation and grain yield. The accuracy of estimation is better in the irrigated treatments than it is in the non-irrigated ones.

Table 4. *Yield of maize (t ha^{-1})*
(irrigated version)
(Debrecen, 2003, 2004, 2006 and 2007)

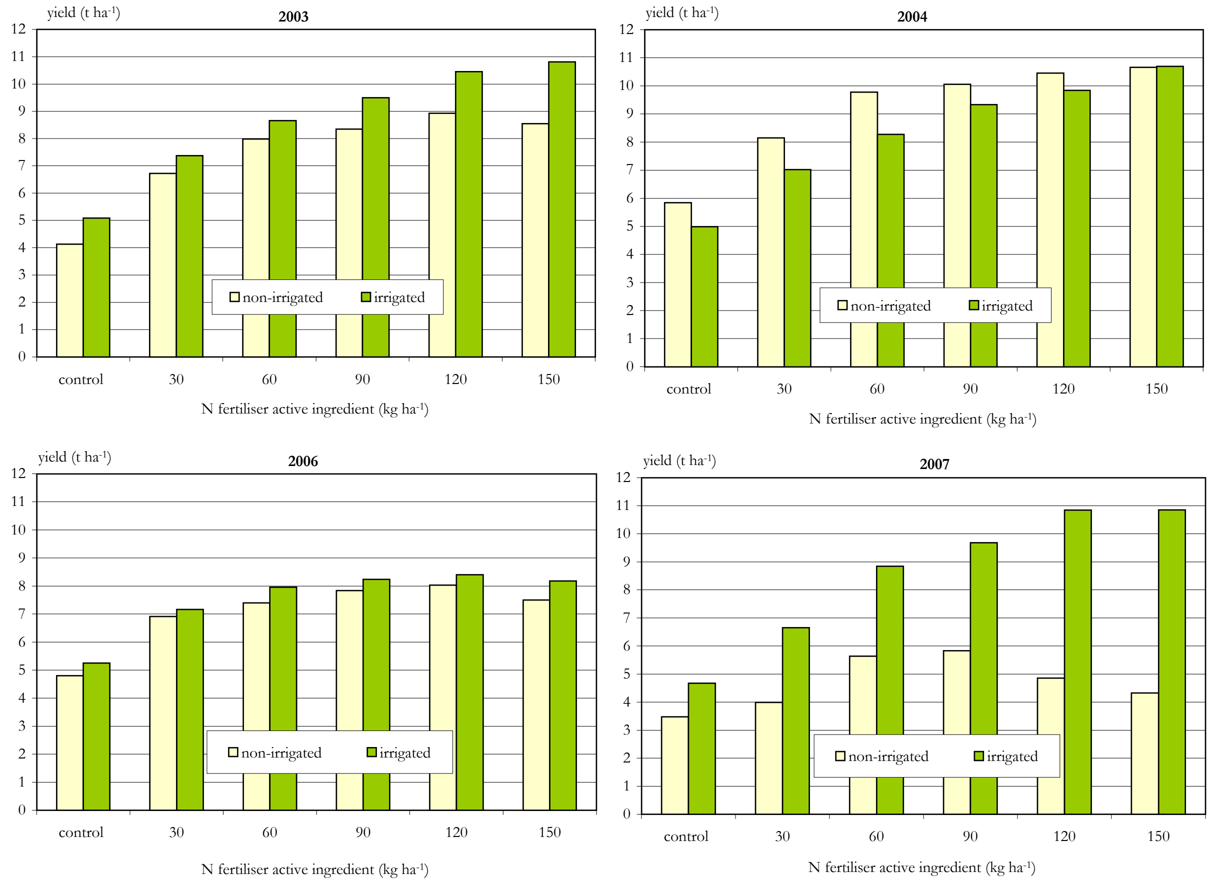
Fertilised version	Yield, t ha^{-1}						
	2003	2004	2006	2007	Dry	Average	Joint
	Years				Crop years		
non-fertilised	5,087a	4,988a	5,250a	4,672a	4,909a	5,138a	5,024a
N_{30}	7,379b	7,022b	7,165b	6,655b	7,069b	7,104b	7,086b
N_{60}	8,657c	8,275b,c	7,960c	8,845c	8,737c	8,095c	8,416c
N_{90}	9,502d	9,330c,d	8,236c	9,686c	9,581d	8,705c,d	9,143d
N_{120}	10,455e	9,845d,e	8,401c	10,846d	10,623e	9,020d	10,045e
N_{150}	10,812e	10,699e	8,181c	10,853d	10,830e	9,260d	9,821e

Data in one column indicated by the same letter do not significantly differ from each other on the basis of Duncan test

Irrigation reliably ($P<0.001$) increased yield in the average of four years and the treatments by 1.141 t ha^{-1}. Irrigation – similarly to the SPAD values measured at the 50% female flowering stage – increased grain yield results significantly ($P<0.001$) in dry years, whereas its yield increasing effect was not significant in years with average precipitation supply. The biggest irrigation-induced yield surplus in the average of fertiliser active ingredient treatments was obtained in 2007 (3.906

t ha^{-1}) (*Figure 16*). With the help of the t-test – jointly examining dry years and years with average precipitation supply – , we analysed the correlation between irrigation and different nutritive levels, which proved that irrigation significantly (P<0.001) increased maize yield at all six nutritive levels in dry years, whereas we did not get reliable irrigation effect in years with average precipitation supply (*Table 5*).

Figure 16: *The impact of fertilisation and irrigation on the yield of maize, (t ha^{-1})* (Debrecen, 2003, 2004, 2006 and 2007)



Finally, we examined the effect of fertilisation, irrigation and crop year on yield by variance analysis, using the same amount of fertiliser both in irrigated and non-irrigated treatments, considering all four years' data, by means of a variance analysis (cumulated evaluation) Based on SS values, we concluded that fertilisation had the most significant effect (1486,4), followed by crop year (375.4) and irrigation (234.2). All interactions indicated a significant difference (P<0.001). Among them, the most important interaction was year x irrigation (SS=433.9). These results indicate that the impact of fertilisation and irrigation is very important in yield fluctuation, that can be significantly modified by crop year.

Table 5. *The impact of irrigation on maize yield (t ha^{-1}), results of t-test*
(Debrecen, 2003, 2004 and 2006, 2007)

Fertilised version	Dry year			Average year			Joint		
	Sig	95% confidence interval of difference		Sig	95% confidence interval of difference		Sig	95% confidence interval of difference	
		lower level	upper level		lower level	upper level		lower level	upper level
non-fertilised	0,000	0,539	1,571	0,651	-0,617	0,388	0,022	0,070	0,871
N_{30}	0,000	0,703	2,334	0,297	-0,991	0,308	0,043	0,018	1,159
N_{60}	0,000	0,988	2,599	0,416	-1,114	0,467	0,016	0,141	1,328
N_{90}	0,000	1,574	3,0439	0,835	-0,896	0,727	0,000	0,526	1,697
N_{120}	0,000	2,490	4,3850	0,903	-0,874	0,774	0,000	0,997	2,389
N_{150}	0,000	3,104	5,0830	0,414	-0,576	1,381	0,000	1,483	3,012

In dry crop years (2003, 2007), the two years significantly (P<0.001) differed from each other. Irrigation and fertilisation reliably affected SPAD values at a significance level of 0.1%. The interactions of year x irrigation and irrigation x NPK (P<0.001) are also significant. The impact of fertilisation on yield was different in each year (P<0.01).

In average crop years (2003, 2007), irrigation did not have effect among the main impacts (year, irrigation, NPK). The interaction of year x irrigation is significant at a significance level of 5%, as irrigation reduced yield in one year and increased it in the other (P<0.001). The efficiency of fertilisation was greatly modified by crop year (P<0.001). The interaction of irrigation x NPK could not be statistically proven in average crop years.

4.5. Analysis of the correlation between SPAD values and maize yield

During the analysis of SPAD values and the yield data of maize, we observed that there is no correlation between the SPAD values measured at the 6 leaf stage and yield in the non-irrigated version, whereas the correlation between the two in the irrigated one is a weak stochastic one (r=0.260). As the vegetation period progressed, we found a closer correlation between the two variables both in the non-irrigated and the irrigated versions. The value of the correlation coefficient is positive in both cases, meaning that yield increased with the increase of SPAD value. Based on the statistical evaluation, the correlation between the two variables can be described by a linear function, also proven by the F-test at a significance level of 0.1%. Taking the value of coefficient of determination into consideration – as an average of four years – we concluded that there was an average (r=0.490) correlation between yield and SPAD values measured at the 50% female flowering stage in the non-irrigated version, whereas this correlation was stronger than average (r=0.623) in the irrigated one.

We conducted the analyses annually. We could not indicate any correlation between variables (SPAD values and yield) was average (r=0.735) in the non-irrigated treatments during 2003 – a dry and unfavourable year – at the 6 leaf stage. The correlation between the SPAD values measured at the 12 leaf stage and the 50% female flowering stage and yield was an average one. There was a closer correlation in the irrigated version than in the non-irrigated one. Linear function (P<0.001) is the most suitable for the description of the correlation between the variables. SPAD value proved to be a determination coefficient of 22.9% at the 12 leaf stage and 31.6% at flowering in the non-irrigated stage, whereas it was 45.7% in the irrigated one (*Figures 17–18*).

In 2004 – an average, moist year – , the correlation between the variables at the 6 leaf stage was weak in both non-irrigated and irrigated versions. The value of determination coefficient increased a lot in non-irrigated version at the 12 leaf stage and the 50% female flowering stage. The scatter diagram of the correlation between the two variables at the time of 50% female flowering and the regression line fit to the points is shown in *Figures 19–20*.

Figure 17: *Correlation between the SPAD value of maize at 50% female flowering stage and its yield (t ha^{-1})*
(non-irrigated version)
(Debrecen, 2003)

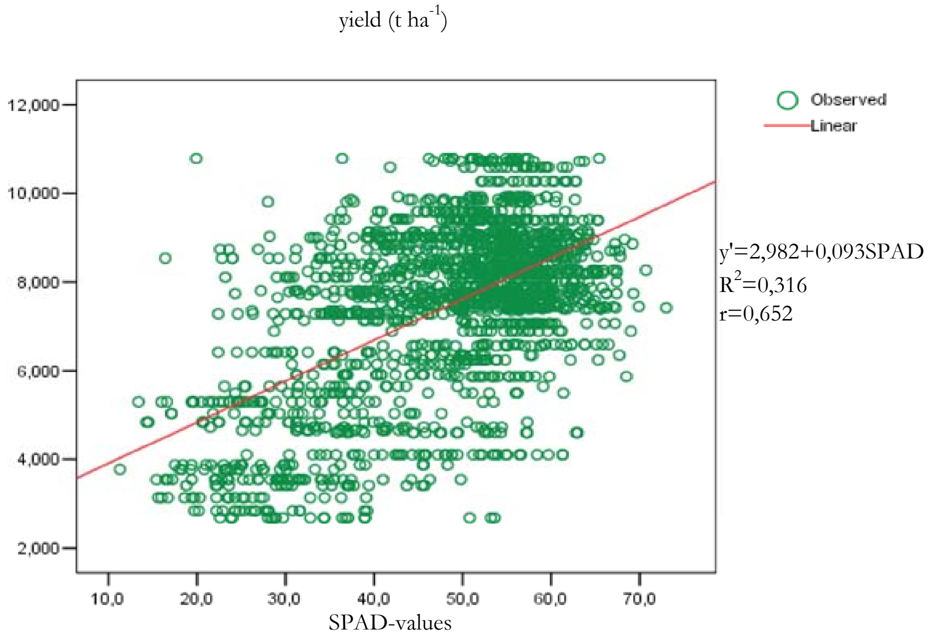
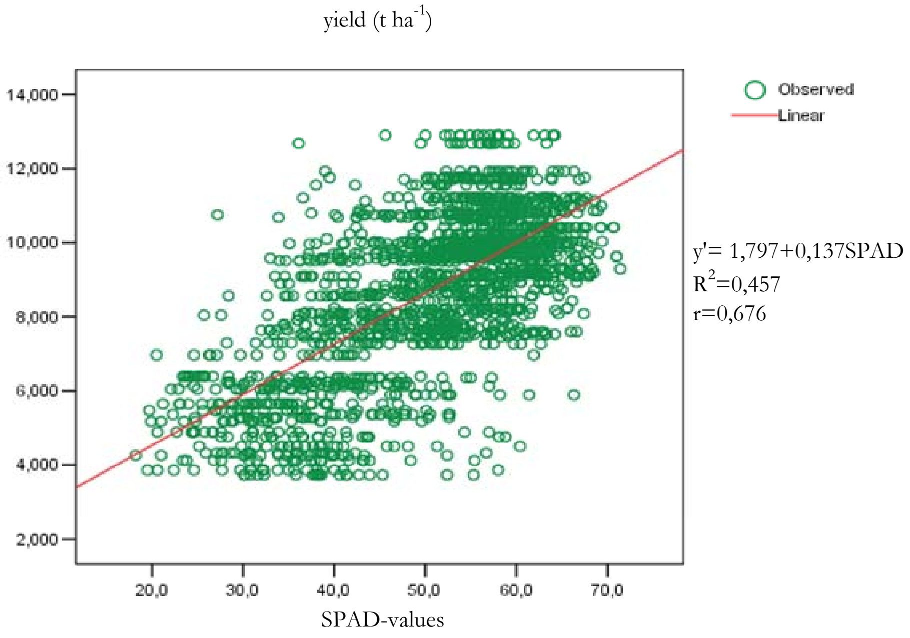
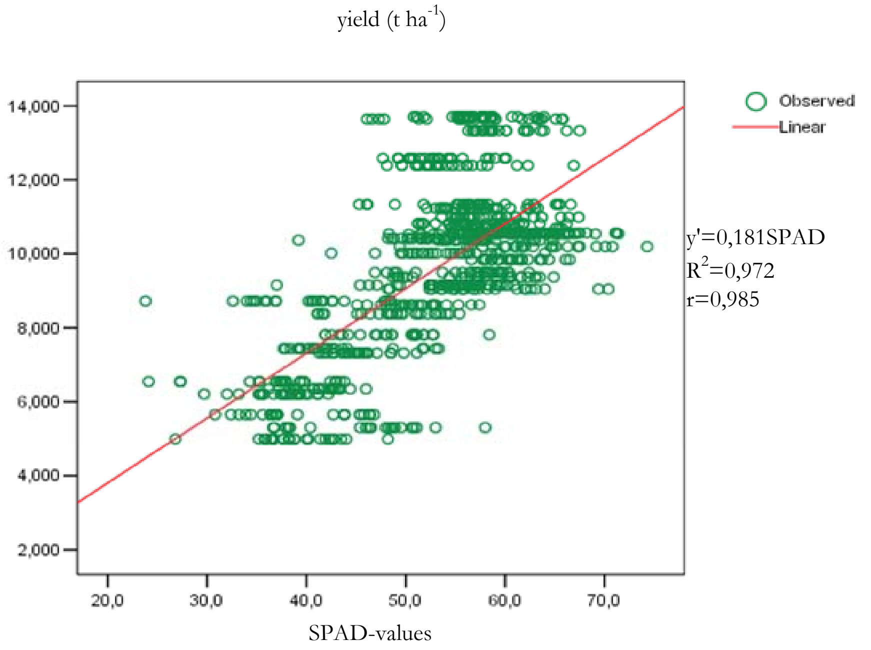


Figure 18: *Correlation between the SPAD value of maize at 50% female flowering stage and its yield (t ha^{-1})*
(irrigated version)
(Debrecen, 2003)



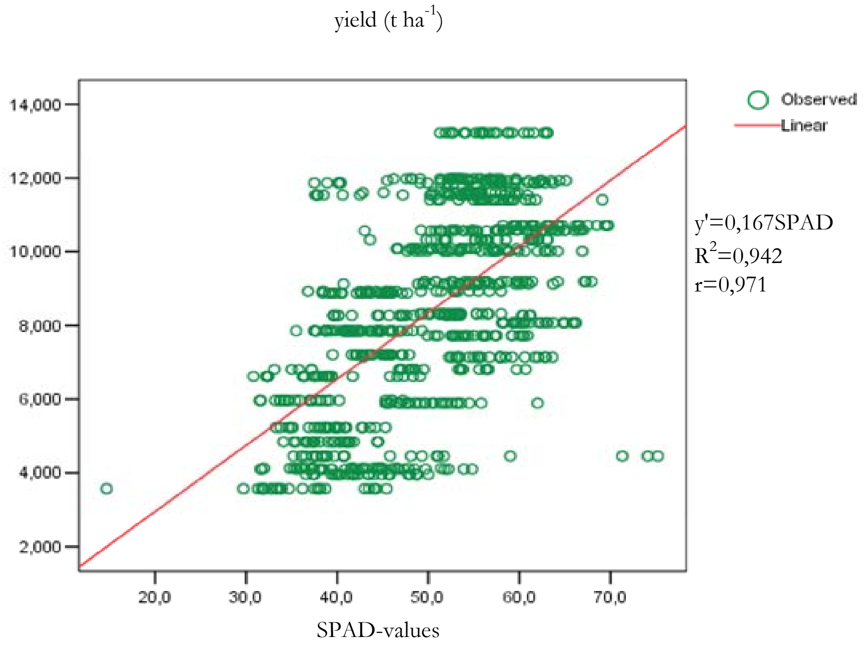
y'= 1,797+0,137SPAD
R^2=0,457
r=0,676

Figure 19: *Correlation between the SPAD value of maize at 50% female flowering stage and its yield (t ha^{-1})*
(non-irrigated version)
(Debrecen, 2004)



y'=0,181SPAD
R^2=0,972
r=0,985

Figure 20: *Correlation between the SPAD value of maize at 50% female flowering stage and its yield (t ha^{-1})*
(irrigated version)
(Debrecen, 2004)



The correlation between SPAD values and yield was weak in 2006 in non-irrigated treatments at the 6 leaf stage, whereas there was no correlation between the two variables. In the non-irrigated version – at the other two measurement occasions – the correlation between SPAD values and yield increased, but it was weaker than average. As the vegetation period progressed in the irrigated version, the stochastic correlation improved, whereas – similarly to 2004 – it was weaker than the one observed in the non-irrigated version. There was a significant correlation ($P<0.001$) between the variables.

There was a significant correlation between maize yield and SPAD values at 6 and 12 leaf stages ($P<0.01$) and at the 50% female flowering stage ($P<0.001$) in non-irrigated treatments in the droughty year of 2007. It was weak in all three cases, but – similarly to the previous years – the correlation was becoming stronger as the 50% female flowering stage got closer. In the irrigated version, the stochastic correlation between SPAD values measured at 6 and 12 leaf stages and yield was weak, whereas it was a close stochastic correlation between the two at the 50% female flowering stage. In 2007 – similarly to 2003 –, we found a closer correlation in the irrigated version at every measurement occasion, than we did in the non-irrigated one, that was also proven by F-test ($P<0.001$).

We concluded that that the correlation coefficient is positive both in the irrigated and non-irrigated versions, meaning that maize yield increased with the increase of SPAD value. The independent variable was in a stronger correlation with yield in the irrigated version in dry years (2003, 2007) at all three measurement occasions, than it was in the non-irrigated one. As a result of irrigation, the closeness of the correlation between SPAD values and yield decreased in years with average precipitation supply (2004, 2006).

4.6. N fertilisation consultancy based on SPAD values

The final aim of the research is examine whether the results gained serve practical crop production in the form of a fertilisation consultancy method.

Our experimental results proved that there is correlation between SPAD values and yield at the 12 leaf stage in non-irrigated version and at the 6 leaf stage in the irrigated version, therefore the values measured by the chlorophyll meter can serve as indicators for the N-status of maize and in calculating the additional amount of N fertiliser needed for the optimal yield.

Besides the N-status, the results of the chlorophyll meter can also be affected by other factors. In order to eliminate the impact of these factors, *we advise to establish a reference area adequately treated with N fertiliser*. This way, the chlorophyll measurements of the examined field can be compared to those of the reference area.

The reference area can either be two smaller (4.5m x 5 m), manually fertilised plot, or a long stripe with 6 rows that is fertilised mechanically. The reference area should be representative.

As for reference values, we used the SPAD values of the treatments for which 150 kg ha^{-1} nitrogen fertiliser was used. This was the basis, which the SPAD values of the experiment's other fertiliser active ingredient treatments were compared to. We determined the amount of fertiliser doses needed for the maximum yield for every year, per hybrids and in two versions (non-irrigated, irrigated). Generally, these values were not smaller than 98% of the reference SPAD values, therefore, in the case of 98% or bigger relative SPAD values, the actually applied fertiliser dose proved to be enough. In the case of values significantly lower than 98%, additional fertiliser has to be applied in order to reach the economically high yield. Based on our research results, we concluded that the amount of fertiliser to be applied additionally differs between the non-irrigated and irrigated versions. Our data also prove that the amount of nitrogen to be applied as basic fertiliser without any risk is 60 kg N ha^{-1} on chernozem soil (classified into the 1st production site category) within non-irrigated conditions, whereas this value is 90 kg N ha^{-1} within irrigated conditions. We advise the application of this amount of fertiliser independently of crop years. Following this, we compared the SPAD values measured in all treatments to those measured in the reference area, then used regression analysis to determine how much fertiliser active ingredient is equivalent to one percentage of shortage SPAD unit. This resulted in 6 kg N ha^{-1} fertiliser active ingredient within non-irrigated conditions and 9 kg N ha^{-1} within irrigated conditions.

Chlorophyll measurements have to be started at 6 leaf stage. At this stage, it is still possible to apply additional fertiliser doses. After the conduction of the average measurements of the reference area and the surrounding areas, the advised, additional amount of N can be determined on the basis of the following method.

In the non-irrigated version: If the relative SPAD value is 98% or bigger, the basic fertiliser active ingredient applied (60 kg N ha^{-1}) is enough for the plot. If it is significantly lower than this, then we advise to apply an extra 6 kg N ha^{-1} for each percentage of shortage. If the amount of additional fertiliser active ingredient exceeds 60 kg N ha^{-1}, we still do not advise to apply more than 60 kg N ha^{-1}. The calculation was done by the following formula.

$$100\frac{SPAD_{ref}-SPADt}{SPAD_{ref}}*6\ kg\ N/ha$$

Where:

$SPAD_{ref}$: SPAD value of the reference area

$SPAD_t$: SPAD value measured on the plot to be fertilised

In the irrigated version: Its calculation is similar to that of the non-irrigated version. As a matter of course, the basic fertiliser active ingredient is 90 kg N ha^{-1}. We advise to apply an extra 9 kg N ha^{-1} for each percentage of shortage. If the amount of additional fertiliser active ingredient exceeds 60 kg N ha^{-1}, we still do not advise to apply more than 60 kg N ha^{-1}. The formula above is modified the following way:

$$100\frac{SPAD_{ref}-SPADt}{SPAD_{ref}}*9\ kg\ N/ha$$

Where:

$SPAD_{ref}$: SPAD value of the reference area

$SPAD_t$: SPAD value measured on the plot to be fertilised

5. CONCLUSIONS

Successful maize production without the use of fertilisers is unfeasible. It is a permanent research and development task to determine the nutritive dose that is the most efficient, provides the biggest profit also conforms to the requirements of environmental protection.

The extent to which maize hybrids can utilise the nutritive stock of soil is an important standard of value. The control plots of long-term experiments – that has not been fertilised for more than 23 years – guarantee the reliability of results.

From the practical point of view, we have to consider that it is not only one year that the results of long-term experiments represent, but they indicate the last four years of the 23, during which the examined conditions has been continuously developing. Based on the data, we can provide a view on the easily measurable consequences of an approach focusing on harmonic plant nourishment and another one focusing on the exploitation of soil. The model-focused evaluation of the experiments makes it clear that the regular, harmonic fertilisation can become a rather important damage-reducing factor in critical periods.

The SPAD value and yield increasing effect of fertilisation was proved during the examined years, but its extent changed from year to year.

As for the change in the SPAD values of crop parts, our research data made us to conclude that the increase of fertiliser doses in leaf also makes SPAD values increase within identical degrees of water supply and the increasing water supply – in the case of identical degree of nutritive supply – decreases nitrogen concentration.

We concluded that the right technology of nitrogen fertilisation is greatly affected by the nutritive uptake curve and dynamics of the crop, besides the nitrogen demand of maize. The nitrogen uptake of maize is greatly modified by irrigation and crop year during vegetation.

When examining the impact of fertilisation, irrigation and crop year on maize yield, considering four years, we concluded that fertilisation had the most significant impact, followed by crop year and irrigation. All correlations showed significant ($P<0.001$) differences, the most significant of them was the correlation year x irrigation. These results show that fertilisation and irrigation have a rather significant role in yield fluctuation, that can also by greatly modified by crop year.

When evaluating the SPAD values and maize production, we concluded that the r value between the two increased, as the vegetation period was progressing – both in non-irrigated and irrigated versions. The value of correlation coefficient is positive in both versions, which means that the amount of yield increased in parallel with the increase of SPAD value. Based on the statistical evaluation, the correlation between the two variables can be described by a linear function, that is also justified by the F-test at a significance level of 0.1%.

Our research results provide help for producers who do not know the conditions of production well enough and for highly skilled experts in the determination of the amount of N, thereby decreasing the risk of under-, or overfertilising maize. This technology supplements and not substitutes the practice of the already proven N management and the other guiding principles of competent farming.

6. NEW AND NOVEL SCIENTIFIC RESULTS

- Fertilisation significantly ($P<0.001$) increased SPAD values. The correlation between fertilisation and SPAD values was still weak at the 6 leaf stage, that became stronger as the vegetation period progressed. The highest statistically justified SPAD value – both in dry years and those with average precipitation supply – was measured by applying 60 kg N fertiliser active ingredients per hectares at the 6 leaf stage within non-irrigated conditions, whereas this value was 30 kg N ha^{-1} within irrigated conditions and 120–120 kg N ha^{-1} at the 12 leaf stage and 50% female flowering stage, respectively.
- The correlation between fertilisation and SPAD values was greatly affected by crop year. The correlation was close in 2004 (a year with average precipitation supply) within non-irrigated conditions and it was the weakest in 2007 (the driest year). Irrigation increased maize yield by 1.14 t ha^{-1} in dry years, whereas there was no reliable effect of irrigation in years with average precipitation supply. In order to reach the statistically proven maximum of yield, lower (60 kg N ha^{-1}) fertiliser active ingredient treatments needed to be applied in the non-irrigated version, whereas this value was higher (120 kg N ha^{-1}) in the irrigated one. It was only dry years and the 50% female flowering stage, when irrigation reliably increased SPAD values. As a result of irrigation, chlorophyll concentration decreased at a higher rate at the 6 leaf stage than it did at the 50% female flowering stage. Irrigation made the correlation between SPAD values and yield stronger in the droughty year of 2007.
- As the growing period was progressing, SPAD value decreased in the dry crop year, whereas it increased in the year with average precipitation supply. The SPAD value strongly decreased by the time of 50% female flowering stage in the dry year.
- The correlation between SPAD values and maize yield proved to be positive in every case which, as the growing period was progressing became stronger and stronger.
- Our results make it possible further develop fertilisation consultancy.
    - If the relative SPAD value shows a significant N shortage at the 6 leaf stage, N active ingredient is advised to be applied in the growing period.
    - The results of the measurements taken at the 12 leaf stage and the 50% female flowering stage serve as a basis for the N active ingredient doses of the upcoming year in the form of a correlation coefficient.

If the relative SPAD value is 98%, or higher in the non-irrigated version, the 60 kg N ha^{-1} basic fertiliser treatment is enough. If it is significantly lower than that, we advise to apply an extra 6 kg N ha^{-1} for each percentage of shortage. As for the irrigated version, the basic fertiliser active ingredient is 90 kg N ha^{-1}, and we advise to apply and extra 9 kg N ha^{-1} for each percentage of shortage.

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