Ph.D. Thesis

A COMPARATIVE STUDY ON THE IMPACTS OF ECOLOGICAL AND AGROTECHNICAL FACTORS IN CEREALS OF DIFFERENT PHYSIOLOGY

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1. Introduction

The productivity of field crops is determined primarily by the biological, genetic factors, secondly, by the ecological conditions and thirdly, by the agrotechnical factors. In the production technology of cereals, these factors should be harmonized. In line with sustainable crop production, such production biology studies and assimilation surface examinations need to be carried out with which the rate and degree of dry matter formation and its distribution in the different plant parts can be measured. These data could help in the exploration of the cause and effect relationships in yield formation. There have been earlier trials for yield forecast, which made estimations from the weather data of the given year. However, the yield forecasts for cereals were very controversial in numerous cases. The current scientific knowledge in crop production demands that not only the final produce should be analyzed, but also the influencing factors and technological elements should be considered. This can be achieved by making observations and measurements during the season, after the analysis of which a more precise yield forecast can be made. Growth analysis enables such measurements in the course of which the effects of the different treatments (e.g. fertilization, crop rotation, plant density, irrigation, crop protection etc.) could be monitored not only in the harvested yield but also during the whole season via the observation of changes in growth dynamics.

The effects of agrotechnical treatments can be measured in significant differences in yield, however, less is known about the agronomical, ecological and physiological factors behind the yield differences and the interactions between them. For these reasons, special emphasis was laid on the ecophysiological examinations, especially on the exploration of new correlations between the yield and the growth, relative chlorophyll content and leaf area of the studied cereals (winter wheat and maize). We aim to determine the relationship between the rate of dry matter accumulation and the yield of the studied crops. Our target is to determine how the environmental conditions (weather) determine the amount of plant biomass, the assimilation surface and the yield of crops. We also tried to determine the correlations between the studied growth parameters (CGR, RGR, LAD, HI) and the yield and whether these measurements could be used for yield forecasts.

The thirty-year long-term experiment enables the study of the effect of the different agrotechnical factors (fertilization, irrigation, crop rotation, crop protection) on the yield and the plant physiological and agronomical parameters.

The results can contribute to the clarification of the effect of the environmental and agrotechnical factors influencing the yields and to the exact determination of correlations between the plant produce, the phytomass and the growth parameters. It can be revealed which applied agrotechnical factor or factors have the greatest effect on the studied parameters. The correlation tests can prove the relationships between the leaf area, the leaf area duration, the relative chlorophyll content, the growth factors and the amount of yield. Using the obtained research results, we can decide which parameters and which agrotechnical factors contribute to the formation of the maximum grain yield. The importance and novelty of the research topic is also indicated by the fact that a comparative study of cereals with different photosynthetic basis (C3, C4 crops) was carried out.

Our research can help primarily the growers in the future, as they can obtain information on the yield-influencing factors, the effect and role of the technological elements via the use of instruments that can be applied simply and quickly in the practice. With the help of the system that can be monitored throughout the whole year, the growers can obtain such information which can contribute to more profitable and higher yields in the following years.

2. Materials and methods

The study was carried out in the period between September 2010 and October 2013 in the period between September 2010 and October 2013 at the experimental site of the University of Debrecen Centre for Agricultural and Applied Economic Sciences at Látókép in the polyfactorial long-term experiment set up by Prof. Dr. László Ruzsányi in 1983 and supervised by Prof. Dr. Péter Pepó. The meteorological data are presented in *Figure 1*. The studied species were winter wheat and maize. The experimental plots were set up in a randomized block design in four repetitions, the plot size was 9.2 m x 5 m (46 m^2).

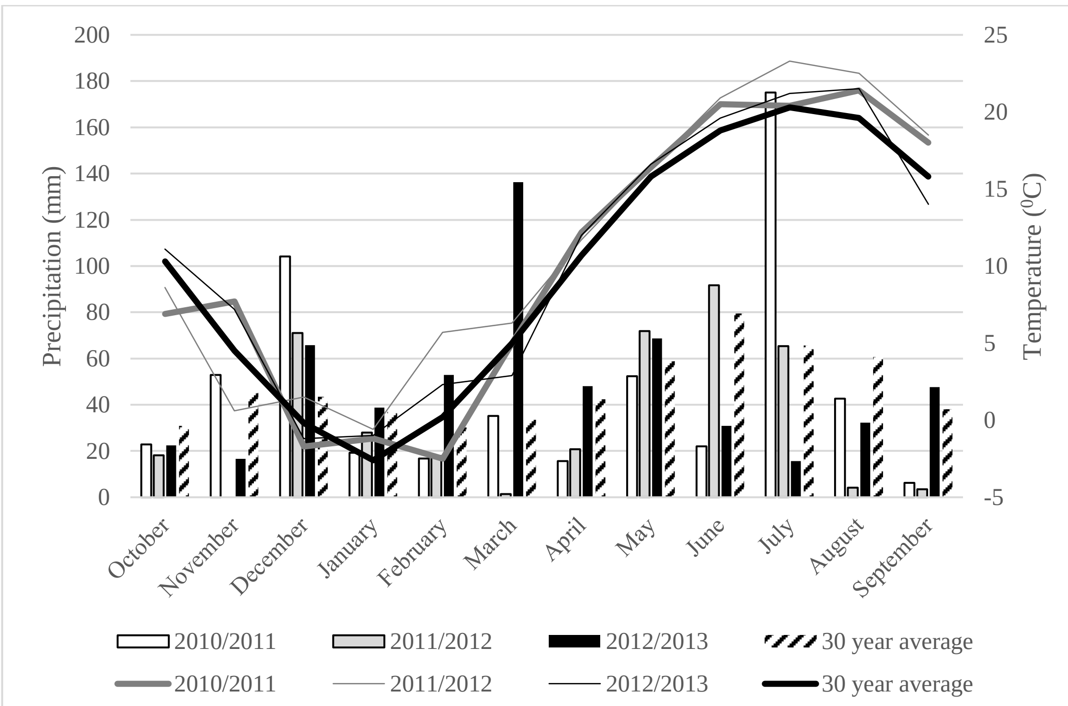


Figure 1.: **Meteorological parameters in the vegetation period of winter wheat and maize** (precipitation, mean monthly temperature, Debrecen, October 2010.- September 2013.)

The tested wheat variety was GK Csillag. The first production technology element tested was the crop rotation where triculture (pea-wheat-maize) and biculture (wheat-maize) were set up. The second agrotechnical element was the fertilization (control, $N_{50}P_{35}K_{40}$, $N_{100}P_{70}K_{80}$, $N_{150}P_{105}K_{120}$, $N_{200}P_{140}K_{160}$). The third variable was the crop protection, where three models were set up (extensive, average, intensive). From among winter wheat diseases, the disease severity was determined for powdery mildew, Helminthosporium leaf blotch and leaf rust. The severity of the different leaf diseases was observed on 20 randomly selected plants, which was expressed as a percentage of the active leaf tissue.

The maize hybrid used in the experiment was Reseda (PR37M81; FAO 360). The first tested production technology element was the crop rotation where triculture (pea-wheat-maize), biculture (wheat-maize) and monoculture treatments were set up. The second agrotechnical element was the fertilization (control, $N_{60}P_{45}K_{45}$, $N_{120}P_{90}K_{90}$, $N_{180}P_{135}K_{135}$, $N_{240}P_{180}K_{180}$). The third variable was the irrigation where the treatments applied were non-irrigated (I1), irrigated to 50 % of the optimum water supply (I2) and irrigated to the optimum water supply (I3).

The applied research methods in winter wheat and maize were: plant sampling, chlorophyll measurement, leaf area measurement and the calculation of growth analysis indices. The assessments were adjusted to the different phenophases of winter wheat and maize. The leaf area index (LAI) per m^2 was determined using a portable leaf area meter. For the measurement of the relative chlorophyll content of the two plant species, a SPAD-502 Plus instrument was used. Using the classical growth analysis method, the growth indicators (CGR, RGR, HI, LAD) were calculated for the interval between the two samplings from the total dry mass and LAI values.

$$\text{CGR} = \frac{1}{P} * \frac{(W2-W1)}{t2-t1} \qquad \text{RGR}= \frac{lnW2-lnW1}{t2-t1}$$

$$\text{HI}= \frac{yield}{\text{useful product}} * 100 \qquad \text{LAD}= \frac{LAI1+LAI2}{2} * (t2-t1)$$

Crop growth rate (CGR) is a measure of the increase in size, mass or number of crops over a period of time. The unit of the CGR is g m^{-2} d^{-1} or t ha^{-1} y^{-1}.
Relative Growth Rate (RGR) is a measure used to quantify the speed of plant growth. It is measured as the mass increase per aboveground biomass per day, for example as g d^{-1} or g w^{-1}.
The *Harvest Index* means the weight of a harvested product as a percentage of the total plant weight of a crop. The HI is a dimensionless quantity, the unit of the HI is %.
Leaf area duration (LAD) is the area under the LAI curve over time. The long term relationship of information found from the leaf Area Index, where the volume of ground covered in relation to upper leaf surface area is measured against time.

The statistical evaluation of the data was performed using the programs *Microsoft Excel 2013* and *SPPS for Windows 13.0*. The results were evaluated by using one-way and three-way analysis of variance. For determining the relationships between the studied factors, Pearson's correlations were calculated and regression analysis and stability analysis calculations were also carried out. The quantification of the agrotechnical elements' effects on the yield was done by variance component decomposition.

3. Results

3.1. The effect of ecological and agrotechnical elements on the phytopathological characteristics of winter wheat

The occurrence of leaf diseases in winter wheat and the degree of infection are determined by the year, but the applied agrotechnique is also a significant modifying factor. In the three experimental years, crop protection had a 9-13% share in the formation of the maximum yield. The application of fungicides once and twice during the season resulted in a moderate and significant reduction of leaf disease severity, respectively; a medium negative correlation was found between the diseases and the plant protection treatments. According to our results, the powdery mildew, Helminthosporium leaf blotch and leaf rust infections were less strongly, but still significantly influenced by the crop rotation, while fertilization had a significant effect on the occurrence of diseases in all three experimental years (2011-2013).

3.2. The effect of ecological and agrotechnical factors on the yields of winter wheat and maize

Winter wheat

The yield of winter wheat was significantly influenced by the fertilization and the crop rotation in the years of 2011, 2012 and 2013, while crop protection did not have a significant effect. By the decomposition of variance components, we determined the percentage share of agrotechnical factors (crop rotation, crop protection, fertilization) in the yield of winter wheat *(Figure 2.)*.

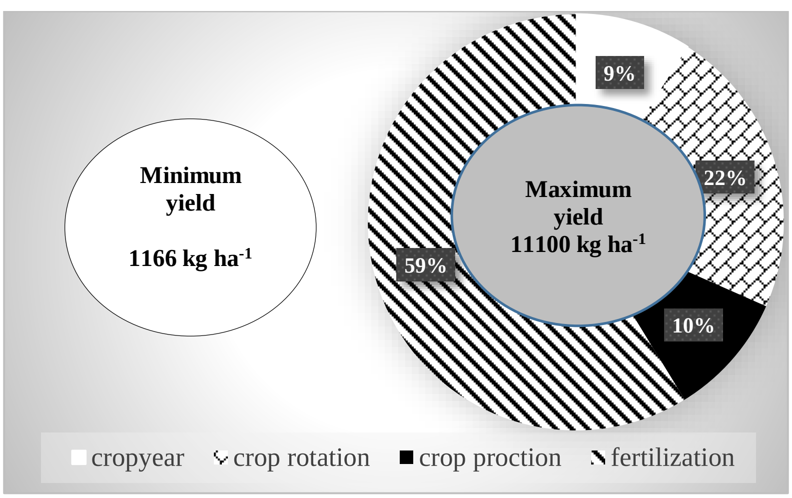


Figure 2. **The roles of fertilization, crop rotation, crop protection and the year in the yield of winter wheat** (Debrecen, 2011-2013)

As an average of the three years, the year, the crop rotation, the crop protection and the fertilization contributed to the yield by 9.04 %, 22.57 %, 9.62 % and 58.77 %, respectively.

In the different crop protection treatments, we found that higher yields were obtained in the stands treated once and twice than in the extensive model. In the biculture treatment, the maximum yields were obtained at the highest fertilization level (N_{200}+PK) in all three experimental years. In triculture, however, the maximum yield was obtained at lower fertilization levels, at the dosages of N_{100}+PK in 2011 and N_{150}+PK in 2012 and 2013. By applying the intensive crop protection model, the yield of winter wheat can be kept in the interval of 8.5-10.5 t ha^{-1}. In the extensive model, the yields varied between 1.5 and 2.5 t ha^{-1} (bi) and between 4.5 and 6.5 t ha^{-1} (tri), consequently, they were considerably lower than in the case of the intensive technology.

Maize

The yield of maize was significantly influenced by the fertilization and the crop rotation. As an average of the three years, the year, the crop rotation, the irrigation and the fertilization had a 3.5 %, 29.8 %, 21.5 % and 45.2 % share in the yield, respectively (*Figure 3*). Maize grown in monoculture gave 2003-2090 kg ha^{-1} lower yields as an average of three years than maize grown in crop rotation. According to our studies, the optimum N+PK amount is influenced by several factors, on the one hand, by the year, on the other hand, by the applied agrotechnique (crop rotation, irrigation).

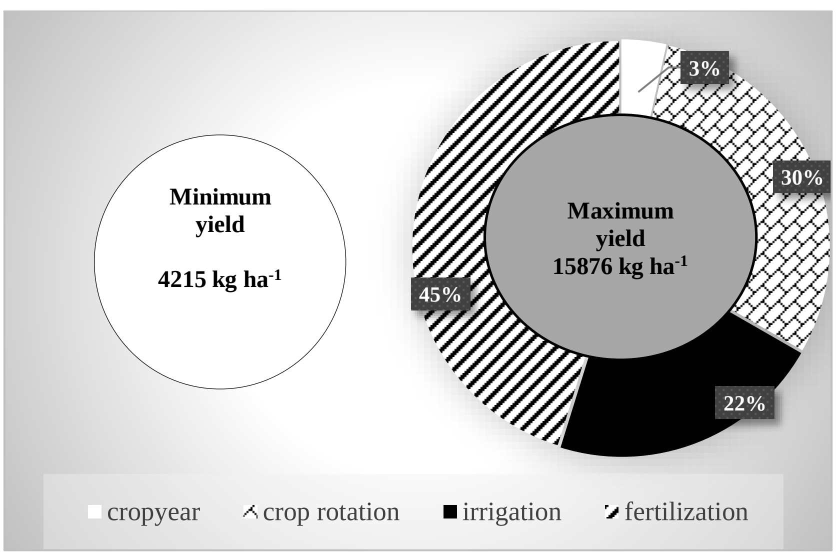


Figure 3. **The roles of fertilization, crop rotation, irrigation and the year in the yield of maize** (Debrecen, 2011-2013)

Based on the three-year results, the highest yields were obtained at the fertilization levels of $N_{180-240}$+PK in monoculture, $N_{120-180}$+PK in biculture and N_{60-120}+PK in triculture. The yield increment due to irrigation was determined by the nature of the year. In all three experimental years, maize was irrigated several times, therefore, we could quantify the impact of irrigation, which resulted in a yield increment of 434-994 kg ha^{-1} in 2011, 994-653 kg ha^{-1} in 2012 and 1874-2664 kg ha^{-1} in 2013. In the intensive model, the yield of maize was between 12.5-14.5 t ha^{-1}. In the extensive crop production model, the yield of maize varied between 4.5 and 7.0 t ha^{-1} (in monoculture), 9.0 and 11.5 t ha^{-1} (in biculture) and 9.0 and 11.0 t ha^{-1} (in triculture), it was considerably lower than that in the intensive technology.

3.3. The effect of ecological and agrotechnical factors on the physiological parameters of winter wheat and maize

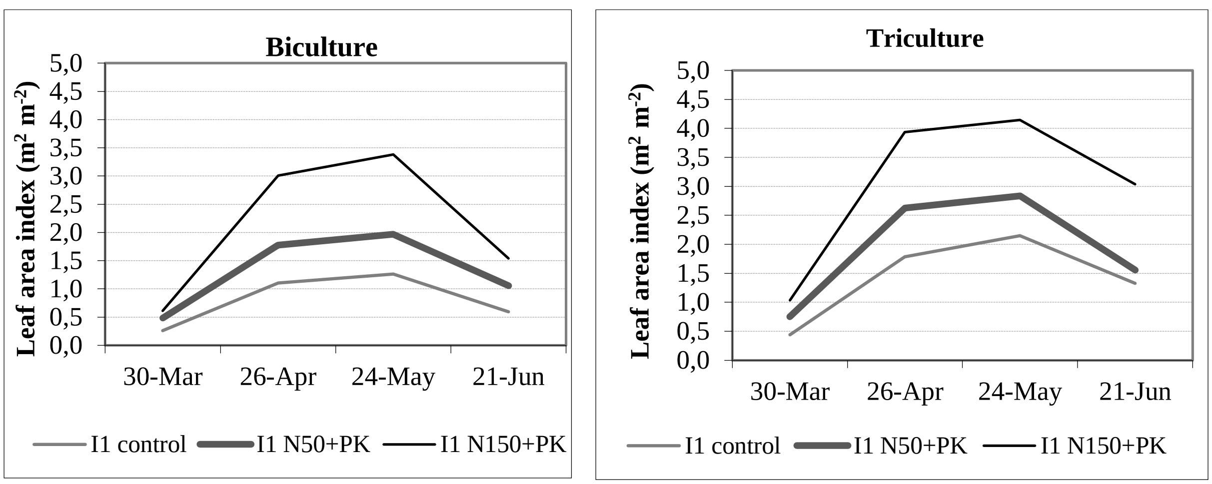
Relative chlorophyll content

When analyzing the SPAD values of winter wheat, we found that fertilization and crop rotation have a significant effect on this index. The relative chlorophyll content can be described by a bell-shaped curve, the maximum SPAD values were measured at 2-3 nodal stage and at flowering depending on the year. In all three experimental years, the maximum relative chlorophyll content was obtained at the fertilization level of N_{150}+PK. Pea increases the nitrogen stock of the soil, it has a beneficial effect on the water management and the physical and chemical characteristics of the soil, thereby, the nitrogen supply of winter wheat is more favourable than after maize as a forecrop.

The relative chlorophyll content of maize can also be described by a bell-shaped curve, the maximum SPAD values were measured at male and female flowering depending upon the year. In all three crop rotation models, significant differences were found between the control and the fertilization levels of $N_{120-180}$+PK. From among the three crop rotation systems, the lowest relative chlorophyll content was obtained in monoculture and depending upon the applied agrotechnique, considerably lower values were measured in the period of grain filling. As a result of irrigation, an increasing trend can be observed in the relative chlorophyll content, however, this could not be proven statistically.

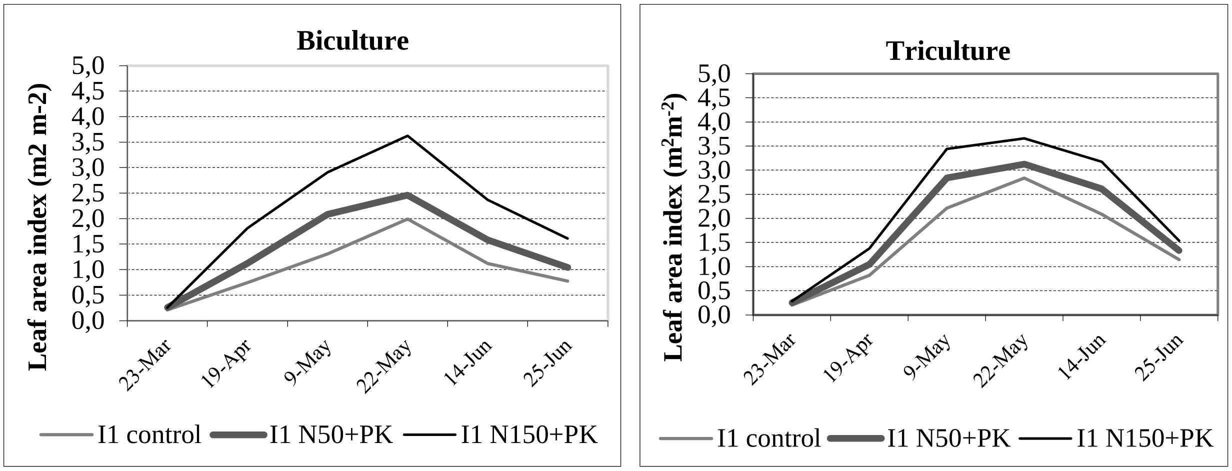
Leaf area

A strong increasing period was observed in the leaf area index until the stages of 2-3 nodes-flowering. The maximum leaf area was obtained at that time, then a slow or steep reduction was found. The leaf area was significantly modified by the year and the agrotechnical factors. After maize as a forecrop, fertilization had a significant effect on the dynamics and the maximum value of the leaf area index up to the N_{150}+PK treatment. A similar trend could be observed in triculture and significant differences were measured between the three fertilization treatments in all three years. When comparing the two crop rotation systems, we found that a moderate effect of the forecrop on the LAI values could be observed at the end of tillering, while at later phenophases the leaf area was significantly higher in triculture at all three fertilization levels. The LAI values were also higher at the last measurement after pea as a forecrop, the dying of leaves was quicker in biculture *(Figure 4-6)*.



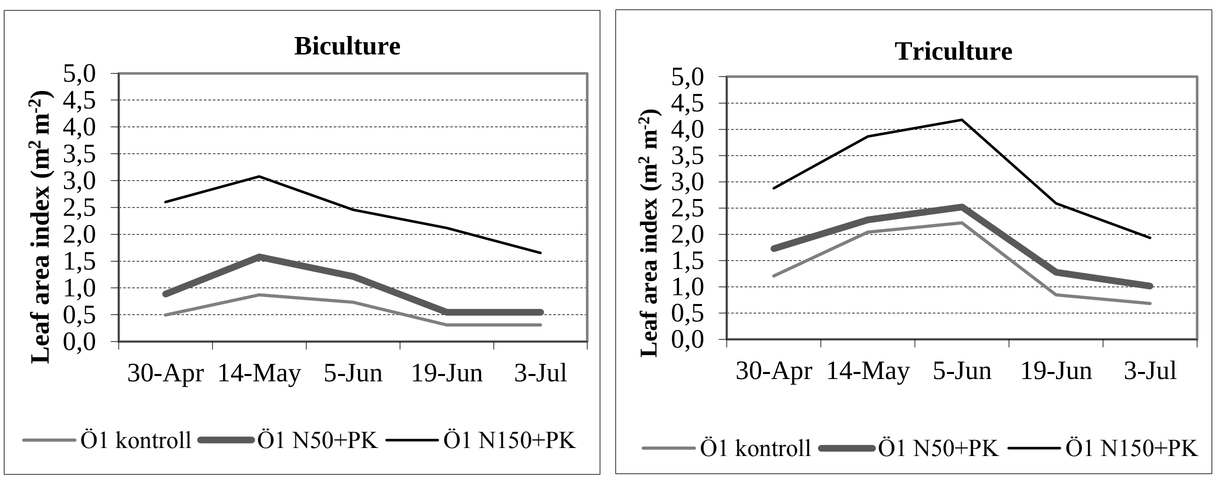
	30-Mar	*26-Apr*	*24- May*	*21-Jun*
LSD $_{5\%}$ fertilization	*0,2*	*0,8*	*0,8*	*0,6*
LSD $_{5\%}$ crop rotation	*0,2*	*0,5*	*0,6*	*0,6*

Figure 4.: **Development of LAI-values of winter wheat in a bi-and triculture crop rotation system** (Debrecen, 2011.)



	23-Mar	19-Apr	09-May	22-May	14-Jun	25-Jun
LSD $_{5\%}$ fertilization	*0,03*	*0,2*	*0,6*	*0,5*	*0,6*	*0,2*
LSD $_{5\%}$ crop rotation	*0,03*	*0,3*	*0,6*	*0,6*	*0,5*	*0,3*

Figure 5.: **Development of LAI-values of winter wheat in a bi-and triculture crop rotation system** (Debrecen, 2012.)



	30-Apr	14-May	05-Jun	19-Jun	03-Jul
LSD $_{5\%}$ fertilization	*0,3*	*0,4*	*1,1*	*0,4*	*0,3*
LSD $_{5\%}$ crop rotation	*0,8*	*0,8*	*0,9*	*0,7*	*0,5*

Figure 6.: **Development of LAI-values of winter wheat in a bi-and triculture crop rotation system** (Debrecen, 2013.)

The maximum LAI values in maize were measured at the 12-leaf or male flowering stages depending on the year. The dynamics and maximum value of the leaf area index were significantly determined by fertilization. Crop rotation had a strong effect, though it varied with the year. The lowest leaf area was measured in monoculture in 2011 and 2013. In biculture and triculture, even the dying of leaves was slower than in monoculture. However, monoculture proved to be significantly better in 2012 than biculture or triculture. There were no significant differences in leaf area between the irrigated and the non-irrigated plots.

Dry mass

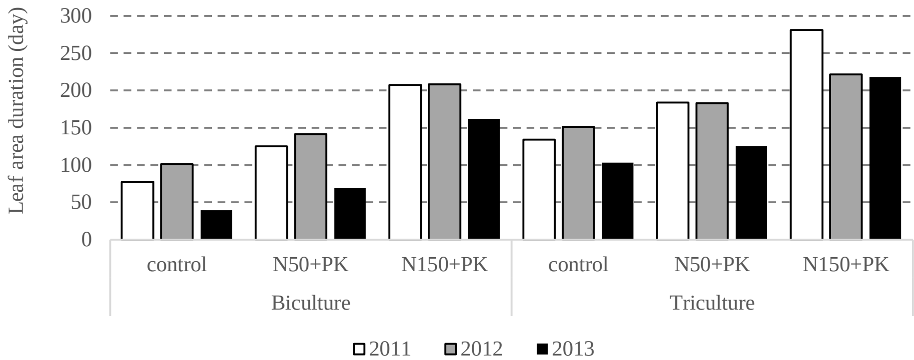
The dry mass of both species was significantly influenced by the applied agrotechnical treatments (crop rotation, fertilization) and was greatly modified by the weather factors of the season. The dynamics of dry matter accumulation proved that dry matter formation lasted until the end of the season in both maize and winter wheat. The total dry mass of winter wheat varied between 688.0 and 1528.4 g m^{-2} in the control, 814.0 and 2217.6 g m^{-2} in the N_{50}+PK treatment and between 1275.2 and 2570.4 g m^{-2} in the N_{150}+PK treatment depending upon the crop rotation. The total dry mass of maize varied between 1320.1 and 2751.6 g m^{-2} in the control, 1870.6 and 3071.9 g m^{-2} in the N_{120}+PK treatment and between 2090.2 and 3036.3 g m^{-2} in the N_{180}+PK treatment depending upon the crop rotation and the water supply.

3.4. The effect of the ecological and agrotechnical factors on the growth analysis values of winter wheat and maize

Leaf area duration

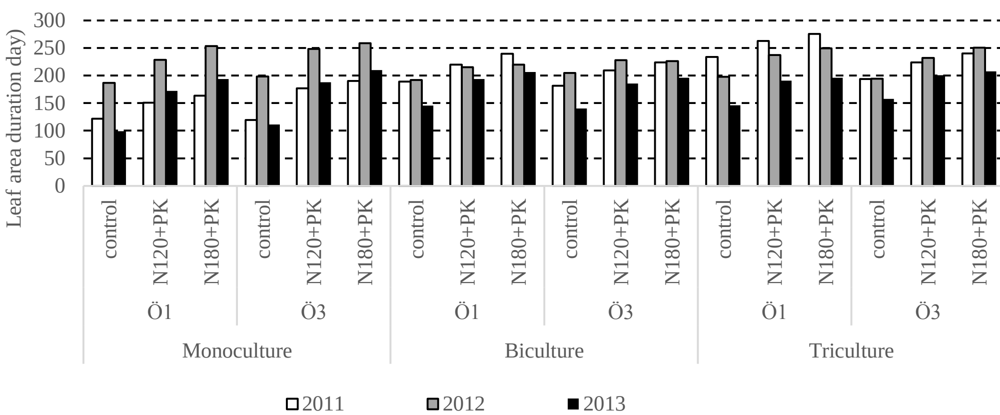
A very tight correlation was found between leaf area duration (LAD) and the yield of winter wheat in all three years. The correlation between the yield of maize and leaf area duration was considerably weaker than that of winter wheat. Fertilization had the greatest impact on the duration of leaves in all three experimental years, crop rotation had a weaker modifying effect on LAD values.

The highest LAD values were obtained at the fertilization level of N_{150}+PK in winter wheat, with 207-281 days in 2011, 208-221 days in 2012 and 162-218 days in 2013, the highest LAD values in maize were observed at the dosage of N_{180}+PK, 163-276 days in 2011, 226-254 days in 2012, 194-210 days in 2013 depending upon the crop rotation and the irrigation treatment.



	LAD 2011.	*LAD 2012.*	*LAD 2013.*
LSD 5% fertilization	*38*	*27*	*37*
LSD 5% crop rotation	*52*	*35*	*46*

Figure 7.: **Effect of the agrotechnical factors (crop rotation, fertilization) on the Leaf Area Duration (LAD) of winter wheat** (Debrecen, 2011-2013.)



	LAD 2011.	*LAD 2012.*	*LAD 2013.*
LSD 5% fertilization	*25*	*10*	*13*
LSD 5% crop rotation	*18*	*15*	*21*
LSD 5% irrigation	*22*	*13*	*17*

Figure 8.: **Effect of the agrotechnical factors (crop rotation, fertilization, irrigation) on the Leaf Area Duration (LAD) of maize** (Debrecen, 2011-2013.)

Crop growth rate

The growth and development of winter wheat and maize, thereby, the crop growth rate (CGR), the relative growth rate (RGR) and the harvest index (HI) are greatly determined on the one hand, by the agrotechnical factors and on the other hand, by the year. Both in maize and in winter wheat, fertilization had the primary role among the technological elements. As a result of fertilization, the crop growth rate of winter wheat was significantly increased. The highest CGR values were measured at the dosage of N_{150}+PK. When comparing the two crop rotation systems, we found that the CGR values were always lower in the stands sown after maize, that is the dry matter accumulation was less intensive than after pea, however, this could not be verified by statistics in all cases.

The CGR values of maize showed a trend similar to that of winter wheat. The CGR values were low in maize at the beginning of dry matter accumulation, then a steep increase was observed, followed by a slight reduction in the last measurement period. The CGR-increasing effect of increasing fertilization and crop rotation could be verified statistically, however, irrigation did not have a significant effect on this growth analysis index.

Relative growth rate

Relative growth rate showed a similar pattern both in winter wheat and in maize, the highest RGR values were measured in the first measurement period, however, there were great differences in the magnitude of the values. In winter wheat, fertilization had a significant effect on RGR values in several periods, however, the effect of crop rotation on this growth analysis index was not significant.

In maize, the fertilization had a significant effect on RGR values until tassel emergence. The forecrop had a considerable effect on the RGR values only until 12-leaf stage, at this point, biculture proved to be the best. Irrigation did not have a significant effect on the relative growth rate.

Harvest Index

The harvest index varied between 22 and 37% in 2011 and between 28 and 45% in 2012 depending upon the fertilization. A statistically verifiable difference as a result of fertilization was observed in 2013 with harvest index values ranging from 19 to 53 %. In 2011 and 2012, the crop rotation had a significant effect on the harvest index.

In 2011, the highest values (38.9-45.8%) were measured at the fertilization level of N_{120}+PK in maize. From among the three crop rotation systems, biculture was significantly better in 2012 than monoculture (41.6 % as an average of irrigation and fertilization treatments). In the same year, irrigation also had a significant effect on HI values. In 2012, the harvest index was considerably higher (35.6-48.1 %) than in 2011, primarily in the control plots. There were significant differences between the fertilization treatments. When studying the three crop rotation systems, it can be stated that the harvest index was the smallest in monoculture (42.5% as an average of the treatments), while triculture proved to be the best (46.9% as an average of the treatments), there was a significant difference between the two crop rotation systems. Irrigation did not have a significant effect. In 2013, the HI values were similar to those of 2011 and 2012, however, in addition to fertilization, irrigation had an important role from among the agrotechnical factors. There were no significant differences between the three crop rotation systems in this year.

The correlation between the harvest index and the amount of yield was not significant in winter wheat, however, there was a positive medium correlation (r=0.411-0.664) between these two figures in maize.

3.5. Comparison and evaluation of the photosynthetic capacity of maize and winter wheat

The photosynthetic activity of plants is greatly determined by the leaf area and the chlorophyll content. There were no significant differences between winter wheat and maize in their maximum leaf area (LAI_{max}) and maximum relative chlorophyll content values ($SPAD_{max}$), however, there were differences of several tons between the maximum yields of the two species. Therefore, it was necessary to introduce a new index which was named photosynthetic capacity (Ph.C.).

$$Ph.C. = \left(\frac{Yield\ max}{LAI\ max} * \frac{Yield\ max}{SPAD\ max} \right) / 1000$$

The magnitude of the two components of photosynthetic capacity (SPAD-value, LAI) could be influenced by several agrotechnical factors both in maize and in winter wheat. Under optimum fertilization in winter wheat, the LAI_{max} and the maximum relative chlorophyll content values varied between 3.1-4.2 $m^2\ m^{-2}$ and 53-59, respectively, depending upon the year, while the yields were between 6.2 and 9.8 t ha^{-1}. In maize, the LAI_{max} and $SPAD_{max}$ values and the yields varied between 2.3-4. $m^2\ m^{-2}$, 55-61 and 9.4-14.7 t ha^{-1}, respectively, in the three experimental years. There were considerable differences between the yields of the C3 and C4 species, which could also be detected in the photosynthetic capacity.

Fertilization had a strong effect on the photosynthetic capacity of winter wheat, the Ph.C. values ranged from 61 to 90 in the control plots in biculture, while in triculture the same values were 159 and 469 in the non-fertilized plots. In our experiment, the crop rotation also had a great impact on the photosynthetic capacity. Under optimum fertilization, the Ph.C. values were more balanced, they ranged from 240 to 446 at the fertilization level of N_{150}+PK depending upon the crop rotation and the year *(Table 1.)*.

Table 1.: **Effect of agrotechnical factors on the photosynthetic capacity of winter wheat**

(Debrecen, 2011-2013)

Year	Fertilization	Biculture I1				Triculture I1			
		Yield (kg ha^{-1})	LAI max (m^2 m^{-2})	SPAD max	**Ph.C.**	Termés (kg ha^{-1})	LAI max (m^2 m^{-2})	SPAD max	**Ph.C.**
2011	control	2046	1,3	56	**61**	6570	2,2	43	**469**
	N_{150}+PK	7742	3,4	59	**305**	9830	4,1	54	**446**
2012	kontroll	2429	2,0	38	**82**	5015	2,8	56	**159**
	N_{150}+PK	7283	3,6	59	**240**	8203	3,7	59	**309**
2013	control	1558	0,9	32	**90**	4811	2,2	45	**243**
	N_{150}+PK	6205	3,1	53	**243**	8660	4,2	54	**372**

Table 2.: **Effect of agrotechnical factors on the photosynthetic capacity of maize**

(Debrecen, 2011-2013)

Year	Monoculture									
	Fertilization	I1				Fertilization	I3			
		Yield (kg ha^{-1})	LAI $_{max}$ (m^2 m^{-2})	$SPAD_{max}$	**Ph.C.**		Yield (kg ha^{-1})	LAI $_{max}$ (m^2 m^{-2})	$SPAD_{max}$	**Ph.C.**
2011	control	6226	2,4	50	**325**	kontroll	6741	2,0	47	**501**
	N_{180}+PK	11362	2,8	56	**815**	N_{180}+PK	12903	3,1	58	**926**
2012	control	6715	2,7	52	**325**	kontroll	7028	2,6	55	**346**
	N_{180}+PK	10641	3,3	59	**584**	N_{180}+PK	11669	3,5	59	**656**
2013	control	4862	1,4	48	**341**	kontroll	5725	1,7	44	**439**
	N_{180}+PK	9386	2,6	57	**607**	N_{180}+PK	12821	2,5	57	**1176**
Year	Biculture									
	Műtrá-gyázás	I1				Fertilization	I3			
		Termés (kg ha^{-1})	LAI $_{max}$ (m^2 m^{-2})	$SPAD_{max}$	**Ph.C.**		Yield (kg ha^{-1})	LAI $_{max}$ (m^2 m^{-2})	$SPAD_{max}$	**Ph.C.**
2011	control	8769	2,9	54	**484**	kontroll	9075	3,2	55	**470**
	N_{180}+PK	12670	3,5	58	**788**	N_{120}+PK	14117	3,8	60	**888**
2012	control	9389	2,8	61	**508**	kontroll	10126	2,8	59	**614**
	N_{180}+PK	11886	3,2	61	**729**	N_{180}+PK	13083	3,0	61	**931**
2013	control	9208	2,0	53	**808**	kontroll	11614	2,1	51	**1266**
	N_{180}+PK	11947	3,0	58	**813**	N_{180}+PK	14689	2,3	57	**1631**
Year	Triculture									
	Fertilization	I1				Fertilization	I3			
		Yield (kg ha^{-1})	LAI $_{max}$ (m^2 m^{-2})	$SPAD_{max}$	**Ph.C.**		Yield (kg ha^{-1})	LAI_{max} (m^2 m^{-2})	$SPAD_{max}$	**Ph.C.**
2011	control	9602	3,9	59	**407**	control	10652	3,5	57	**570**
	N_{120}+PK	12388	4,2	60	**615**	N_{180}+PK	13148	4,2	59	**695**
2012	control	9656	2,8	58	**573**	control	10140	2,6	58	**671**
	N_{120}+PK	11955	3,1	60	**781**	N_{120}+PK	13170	3,1	60	**940**
2013	control	9029	2,1	51	**781**	control	10971	1,9	53	**1202**
	N_{120}+PK	10812	2,6	57	**800**	N_{120}+PK	14676	2,4	55	**1658**

The photosynthetic capacity of maize was primarily influenced by the fertilization and the crop rotation, the Ph.C. values were 325-501 in the control plots in monoculture, 470-931 in biculture and 407-1202 in triculture in the non-fertilized plots. Under optimum fertilization, the values ranged between 584 and 1658 depending upon the crop rotation and the year *(Table 2.)*.

3.6. Study of the correlations between the yield-influencing factors in winter wheat and maize

Using correlation analysis, the strength of the correlations between the studied parameters and the applied agrotechnical treatments was determined. We aimed to determine the correlations between the crop rotation, the fertilization, the crop protection and the yield of winter wheat and between the crop rotation, the fertilization, the irrigation and the yield of maize. With the correlation analyses, we could prove that the leaf area, the leaf area duration, the relative chlorophyll content, the dry mass and several growth factors are correlated with the amount of yield in a C3 and a C4 plant. Using correlation analysis, we found that the leaf area index (LAI), the relative chlorophyll content (SPAD) and the leaf area duration (LAD) have primary roles in the yield forecast in the early season. In winter wheat, the measurement of the dry mass also provides a possibility for yield estimation as it has a tight positive correlation with the amount of yield. Consequently, the grain yield of winter wheat is directly related to dry mass. In winter wheat, the amount of yield was determined on the one hand by the fertilization (r=0.651-0.832) and the crop rotation (r=0.195-0.638) from among the agrotechnical factors, while on the other hand, a medium negative correlation was found between the diseases and the crop protection treatments. Crop protection contributes to the formation of maximum yields via the reduction of diseases (powdery mildew, Helminthosporium leaf blotch, leaf rust). In maize, the fertilization had the strongest impact (r=0.533-0.723) on the amount of yield from among the agrotechnical elements. The correlation between the crop rotation and the amount of yield was significant but weak (r= 0.336-0.423), while irrigation had a loose, non-significant correlation with yield in 2011 and 2012. In 2013, irrigation had a greater influence on the yield than in 2011 and 2012 (r=0.497).

4. Novel scientific results

1. We determined the factors affecting the LAI and SPAD values in winter wheat and maize. Fertilization had a significant effect on the maximum leaf area index and on the relative chlorophyll content in all the three years in both species. There was a tight and medium correlation between the two indices (LAI, SPAD) and the fertilization in winter wheat and maize, respectively. Crop rotation had a medium positive correlation with both the leaf area index and the relative chlorophyll content values.
2. The growth and development of winter wheat and maize are determined by the agrotechnical factors and the year. In both crops, the calculated growth analysis indices (CGR, RGR) gave a precise description of the different rates of dry matter accumulation due to the different treatments in the different years. In both winter wheat and maize, fertilization had an outstanding role among the technological elements.
3. A very tight correlation (r=0.895-0.922) was found between leaf area duration (LAD) and the amount of yield in winter wheat in all three years. Fertilization had the strongest influence on the leaf area duration (r=0.791-0.845), while crop rotation had a lower modifying effect on LAD values (r=0.416-0.499). The correlation between the amount of maize yield and the duration of leaves was considerably weaker, than in winter wheat (r=0.531-0.696). Crop rotation had an influence on the leaf area duration of maize only in one year, while fertilization had a strong effect on the LAD values.
4. From among the plant physiological measurements, the leaf area index (LAI), the relative chlorophyll content (SPAD) and the leaf area duration (LAD) are of primary role in yield forecasting in the early season in winter wheat and in maize.
5. A tight positive correlation (r=0.578-0.854) was found between the dry mass and the yield of winter wheat. Therefore the dry mass is an appropriate device in yield forecasting. The formation of the proper vegetative mass is important for achieving a favourable level of yield in winter wheat.
6. A new calculation (formula) was introduced for the standardized determination of photosynthetic activity in winter wheat (C3) and maize. This new index was named photosynthetic capacity (Ph.C.). According to their Ph.C. values, there are marked differences between the C3 and C4 cereals. The year and other factors also had a

considerable effect on photosynthesis and its efficacy, still the calculated Ph.C. was 250-500 in winter wheat under optimum fertilization, while the same value was 600-1600 in maize.

7. In spite of the different years, the yields of maize and winter wheat were almost the same under the optimized agrotechnique. The maximum yields were 10.8 t ha^{-1} in 2011, 8.6 t ha^{-1} in 2012 and 9.1 t ha^{-1} in 2013 in winter wheat, while the maximum yields of maize ranged from 13.1 to 14.6 t ha^{-1} depending upon the year. The intensive crop production model results in better yield safety both in winter wheat and maize
8. From among the applied agrotechnical factors, fertilization had the strongest impact on the yield of winter wheat (59 %) and maize (45 %). However we found strong relationship between the crop rotation and the yield (winter wheat: 22 %, maize: 30 %). Crop protection did not increase the yield significantly, but it contributed to the formation of maximum yields via the reduction of diseases (powdery mildew, Helminthosporium leaf blotch, leaf rust), that is it had an indirect effect (10 %). The abiotic stress, the water deficiency could be moderated by irrigation, the role of the irrigation at the 3-year average was 22 %.

5. Results applicable in the practice

1. By using the proper plant physiological parameters (SPAD, LAI) and by performing phytomass measurements, the potential yield can be forecasted at a relatively early period of the season (winter wheat: stem elongation, maize: male flowering). This was proven by correlation analysis in all three years.
2. By plant physiological and phytomass examinations, the effects of the different treatments (fertilization, crop rotation, irrigation) could be studied not only in the harvested yield but also throughout the whole season. From among the applied agrotechnical factors, fertilization had the strongest influence on the plant physiological parameters and the dry mass.
3. In both plant species, fertilization and crop rotation were the primary yield-determining agrotechnical factors as an average of the years (2011-2013) .
4. The different agrotechnical factors (crop rotation, fertilization, crop rotation, irrigation) have a different efficacy in the production technology of winter wheat and maize which should be taken into consideration at their application in the practice. On an excellent chernozem soil (with high buffering capacity regarding both the ecological and agrotechnical factors), the agrotechnical inputs have favourable agronomical efficacy in both winter wheat and maize. Maize (C4 crop) produces a larger biomass than winter wheat (C3 crop), thereby creating the physiological basis for a higher grain yield.
5. We have determined the capacity of the extensive and intensive crop production models of winter wheat and maize on chernozem soil in the Hajdúság. By applying the intensive crop model, the yields of winter wheat and maize can be kept at 8.5-10.5 t ha^{-1} and 12.5-14.5 t ha^{-1}, respectively. In the extensive crop production model, the yields of winter wheat were 1.5-2.5 t ha^{-1} (bi), 4.5-6.5 t ha^{-1} (tri) and the yields of maize were 4.5-7.0 t ha^{-1} (mono), 9.0-11.5 t ha^{-1} (bi) and 9.0-11.0 t ha^{-1} (tri), that is they were considerably lower than those of the intensive technologies. Both winter wheat and maize give high returns for the application of the intensive crop production technology on chernozem soil. The intensive crop production model results not only in higher yields but also in better yield safety both

in winter wheat and maize as compared to the extensive model.

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