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Correlation between the Sowing Date and the Yield of Maize on Chernozem Soil, in Connection with the Leaf Area Index and the Photosynthesis

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***Abstract*—**Our sowing date experiment took place in the Demonstration Garden of Institution of Plant Sciences, Centre for Agricultural Sciences of University of Debrecen, in 2012-2014. The paper contains data of test year 2014. Our purpose, besides several other examinations, was to observe how sowing date influences the leaf area index and the activity of photosynthesis of maize hybrids, and how those factors affect fruiting. In the experiment we monitored the change of the leaf area index and the photosynthesis of hybrids with four different growing seasons. The results obtained confirm that not only the environmental and agricultural factors in the growing season have effect on the yield, but also other factors like the leaf area index and the photosynthesis are determinative parameters, and all those factors together, modifying the effects of each other, develop average yields.

***Keywords*—**Sowing date, hybrid, leaf area index, photosynthetic capacity.

I. Introduction

IN Hungary, in the last one and a half or two decades, fluctuations in the average yield of maize exceeded even 50-60%, which is caused together by the ecological, biological and agrotechnical factors. Sources of the problem are, on one hand, the climate change, the increasing extremes occurring in the weather, inadequate utilization of the biological funds, in many cases not using certified seed of the appropriate value, and on the other hand, the inefficient nutrient supply, errors in sowing technology and the defectiveness of plant protection.

In maize production, sowing technology has a featured role among agrotechnical factors, and choosing the appropriate one significantly affects effectiveness of the production. The sowing date has an outstanding importance in stress tolerance of maize, since with an earlier sowing date flowering occurs earlier, thus avoiding the drought period critical to the development of maize. Besides yield, yield stability will also increase. The development of the black layer happens earlier, after which the water release begins.

Growth analysis is a scientific method applicable in plant production, that allows the effect of experimental treatments and environmental factors to be measured not only in the final product (grains, biomass), but the changes in the dynamics of photosynthetic production are examined in the entire time period of the growth and development of the plant. Scientific multiparameter analysis of the results of plant production experiments can be conducted by using indicators of growth analysis as well as the additional agronomic, ecological and physiological measurements [1].

All kinds of accumulation of organic matter, the formation of biomass and within that, yield formation is based on photosynthesis. To reach maximum yields, appropriate amount of relative chlorophyll content is essential, since as the first step in the process of photosynthesis, carotenoids and chlorophylls absorb light. Due to this fact, the role of the adequate leaf area is also significant, as the photosynthetic pigments are in the photosynthetically active parts of the plant tissues. Yield of maize is strongly determined by the efficiency of photosynthesis [2]. The value of the photosynthesis is extremely variable in space and time, because it is affected by both the environment and the biological features of the plant. The intensity of photosynthesis of leaves on given levels on the plant considerably differs as a consequence of the age and exposure of leaves to light (due to the self-shading of lower leaves of a developed stand) [3]. With modifying the sowing date, the solar radiation and temperature conditions change in the growing season of maize. The useful amount of heat and the photosynthetically active radiation will also decrease with a late sowing date. This fact is fundamentally defined the development of the yield of maize in the experiments of [4], [5] in years 1995-1996. It was observed that the period of increase in the reproductive mass can be divided into two parts. In the first stage, reproductive mass of stands sown later date was higher. On the other hand, in the second stage the reproductive mass with the later sowing date was smaller. The sowing date has affected the rate and time period of growth in the stage of grain filling. Late sown hybrids had significantly less time for grain filling in both years.

Based on the results of [6] the photosynthetic activity and the chlorophyll content of new maize hybrids after flowering decreased much more slower than those of the old type of hybrids. Reference [7] examined the effect of growth temperature on the net photosynthetic rate with inbred maize lines with different cold tolerance. It was found that with plants grown in optimum temperature there was no significant difference between the lines in the net photosynthetic rate, while after cold treatment, the photosynthetic rate of the lines with a lower cold tolerance strongly decreased.

References [8], [9] examined the impact of the crop year and the region on the size of the assimilating leaf area above the cob, in a three years long experiment. Close correlation

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was found between the vegetable production and the leaf area above the cob (R^2 = 0.658). Hybrids with the largest leaf area above the cob had the maximum weight of cobs. With a larger leaf area, solar energy is used more successfully, however, above a certain level, photosynthesis of the lower leaves is obstructed due to self-shading. In addition, with a larger leaf area, the extent of evaporation also increases [10]. According to the results of [11], with ideal climate and soil characteristics, yield can increase up to 5.5-6 m^2 m^{-2} LAI, reaching the maximum production. In the case where the ecological conditions are unfavourable, the maximum crop is produced with a lower LAI value.

With an optimum nutrient and water supply, growth of the plant, yield formation and quantity of the grain crop are determined by the leaf area. [12], [13].

Reference [14] in a five-year experiment, it was observed that the scale of the organic matter production is affected primarily by the photosynthetically active radiation captured and utilized by the leaves, however, the amount of that radiation depends on the leaf area.

II. Material and Method

Sowing date experiments took place in the Demonstration Garden of the Institute of Plant Sciences of University of Debrecen, in years 2012-2014. Type of the soil in the experimental area is eluviated chernozem. The top layer of the soil does not contain lime; the subsoil is in 7-9 m depth. Due to lack of lime, top layer of the soil is dry, in dry crop years it tends to be parched. Thickness of the mould layer is 50-70 cm, organic matter content of the soil is 2.57%.

The previous cropping was maize, nutrient supply was uniformly N 120, P_2O_5 80, K_2O 110 kg ha^{-1} active agent, and the number of plants per hectare was 73000. The experiment is with a two-factor random block layout. The thesis contains the data of test year 2014.

Besides a number of other examinations, our goal was to detect how the sowing date affects the leaf area and the photosynthetic activity of maize hybrids, and what impacts these factors have on yield formation. In the experiment, changes of the photosynthesis and leaf area of hybrids with four different growing seasons were examined.

The leaf area index for 1 m^2 was measured with SunScan Canopy Analysis Systems portable leaf area meter, and 8 measurements were carried out with each sowing date. For determining the relative chlorophyll concentration of leaves SPAD 502 Plus appliance was used, with 30 measurements per sowing date, which results were recalculated based on the photosynthetic capacity (Ph.C.) index developed by Professor Peter Pepó Dr. The calculation is based on the leaf area index, the relative chlorophyll content and maximum values of yield. The measurements were connected to phenological stages, four-four times in 2014.

The data from the sowing date experiment were processed by [15] two-factor analysis of variance, linear and parabolic regression analysis and Microsoft Office Excel (2013) program.

In 2014, the experimental plots were sown at the following dates:

- 1st sowing date: 27 March.
- 2nd sowing date: 14 April.
- 3rd sowing date: 8 May.
- Crop was harvested uniformly on 7 October 2014.

Precipitation for maize production was favourable in 2014; however, its distribution was adverse, since in June only minimum amount of rain fell. Compared to the previous years, months with more favourable amount of rain facilitated consistent development and growth of maize. After lack of precipitation, the weather of the summer half-year, compared to the dry July, August of the previous years, was the opposite. Since this year, there was significant amount of precipitation in those months critical for the generative development. In July 2014, precipitation was 9 mm more in July, and 35 mm more in August compared to the 30-year average (Table I).

TABLE I
The Amount of Rainfall and Temperature during the Investigated Crop Year (Debrecen, 2014)

Precipitation (Mm)			
Months	30 Year's Average	2014	Difference
March	33.5	12.0	-21.5
April	42.4	16.9	-25.5
May	58.8	53.0	-5.8
June	79.5	8.4	-71.1
July	65.7	75.1	9.4
August	60.7	95.7	35.0
September	38.0	63.8	25.8
Totally	**378.6**	**324.9**	**-53.7**
Temperature (°C)			
Months	30 Year's Average	2014	Difference
March	5.0	8.9	3.9
April	10.7	12.3	1.6
May	15.8	15.4	-0.4
June	18.7	19.0	0.3
July	20.3	21.2	0.9
August	19.6	19.8	0.2
September	15.8	16.7	0.9
Average	**15.1**	**16.2**	**1.1**

III. Results

A. Leaf Area of Maize Hybrids Depending on Sowing Dates in 2014

During the measurement of the leaf area index a similar trend was shown by the four tested hybrids depending on the sowing dates, however, in leaf area values large differences occurred.

With hybrid P9578 the measured LAI values depending on the sowing date varied between 0.98-3.99 m^2 m^{-2}. The first measurement on 20 June showed that the first sowing date resulted in the maximum leaf area (2,10 m^2 m^{-2}), while compared to that, with the third sowing date significantly smaller values were detected, as the leaf area did not reach even 1 m^2 m^{-2}. With all the three sowing dates, plants produced the largest leaf area by the time of the third measurement on 25 July. On the other hand, for that time, leaf area values of the second and third sowing date (3.99 m^2 m^{-2};

3.94 m^2 m^{-2}) were significantly higher than that of the first sowing date (3.46 m^2 m^{-2}). After that with all the three sowing dates, the lower leaves gradually began to age, which is shown by the results of the measurement on 23 Aug, since with the first and second sowing dates, compared to the data gained a month before, significantly lower LAI values were detected. The greatest extent of shrivelling occurred with the second sowing date; where the leaf area index of the hybrid was 1.59 m^2 m^{-2} lower than at the end of July.

In the average of the measurements, there was no substantial difference between the three sowing dates. The close relationship between sowing date and leaf area is confirmed also by the R^2 values (0.9671-0.9999) of the regression analysis (Fig. 1).

Leaf area of hybrid DKC 4590 varied between 0.94-3.94 m^2 m^{-2} during the growing season. Based on the results of measurements in June, the value of LAI was significantly higher with the previous sowing dates than with the later sowing date on 8 May, which differences statistically could also be proved. The fastest leaf growth appeared with the third sowing date, as the second and third measurements detected 1.35 m^2 m^{-2} and 2.61 m^2 m^{-2} larger leaf areas, however, shrivelling was slow. The highest leaf area value (3.94 m^2 m^{-2}) could be observed with the second sowing date also with this hybrid, after the first measurement a 0.94 m^2 m^{-2} higher, and in July, a 1.49 m^2 m^{-2} higher value was detected. At the end of July, with the first sowing date 0.41 m^2 m^{-2} and with the third sowing date 0.39 m^2 m^{-2} smaller leaf area was measured than with the second sowing date. Also in this case, the most dynamic shrivelling can be observed with the second sowing date, which is well demonstrated by the 1.25 m^2 m^{-2} smaller leaf area measured on 23 August. Insertion of trend functions was also very close (R^2=0.8667-0.9994).

Leaf area of hybrid Kamaria changed differently from that of the other tested hybrids during the growing season. During analysis of the hybrid with the smaller maximum leaf area value (0.98-3.73 m^2 m^{-2}) it can be observed, that the hybrid had a 0.48 m^2 m^{-2} and 0.74 m^2 m^{-2} larger leaf area at the beginning of July with the first and second sowing date, than hybrid P9578 with a shorter growing season. The hybrid reached the maximum active assimilating leaf area also by this time with the second sowing date (0.98-3.73 m^2 m^{-2}), and with the first and the second sowing date the maximum values (3.56 m^2 m^{-2} and 3.58 m^2 m^{-2}) were observed at the end of July.

Hybrid DA Sonka with the longest growing season had the largest leaf area during its growing season, its LAI values changed between 0.89-4.10 m^2 m^{-2}. Compared to hybrids P9578 and DKC, it had a significantly larger leaf area even during the first measurement, a 0.50 and 0.45 m^2 m^{-2} higher value with the first sowing date. This trend had remained by the time of the second measurement, since compared to hybrid P9578 with the first and the second sowing date, with DA Sonka reliably higher values were gained. The hybrid reached the largest leaf area value of 4.10 m^2 m^{-2} at the end of July, with the first sowing date. DA Sonka, a hybrid with a longer growing season, with the third sowing date, had not yet started to shrivel after that, as during the measurement on 23 Aug, 3.91 m^2 m^{-2} LAI values were measured, which were significantly higher than the leaf area values with the first and second sowing dates. The insertion of the trend lines was extremely close also in this case, since the value of R^2 was above 0.9 (Fig. 2).

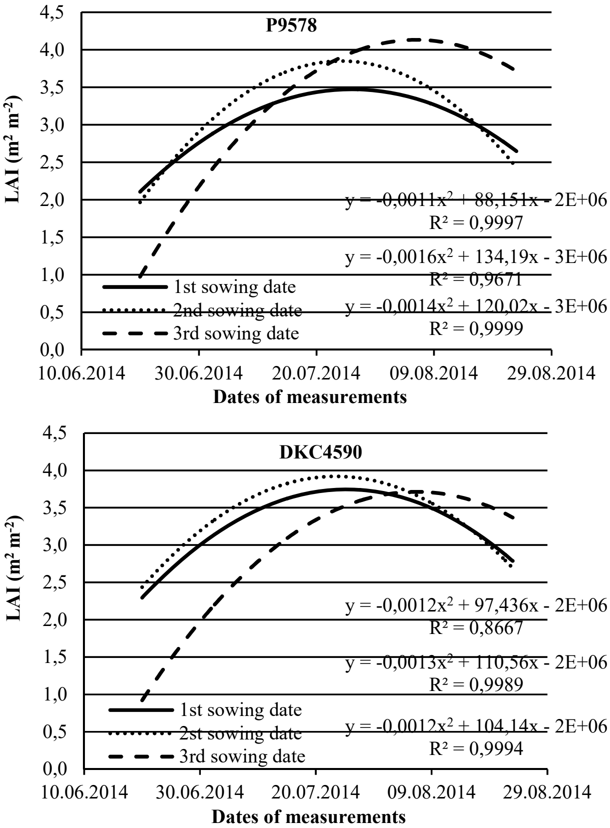

Fig. 1 The leaf area index (LAI) of corn hybrids sown at different sowing times, 2014

During the examination of the correlation between LAI and yield, it was found that most of the hybrids had the maximum LAI values with the lowest yields. Also, the maximum yields produced mainly with the third sowing date were detected with lower leaf area.

The correlation between LAI and yield showed up also with the different sowing dates, however, here it is just moderately close (R^2 = 0.3995), as production is just partly determined by the leaf area, and several factors together play a role in yield formation.

B. Change in the Photosynthetic Capacity (Ph.C.) of Maize Hybrids Depending on Sowing Dates in 2014

During the test, we were searching for answers to how the test factors such as the sowing date and the genotype affect the efficiency of photosynthesis. The photosynthetic capacity of maize is strongly influenced both by the sowing date and the hybrid. With the first sowing date 511-821; with the second 473-625; with the third 591-869 Ph.C values were gained.

Between the hybrids significant differences were found that can be verified statistically as well, and which can be explained by the different sowing dates.

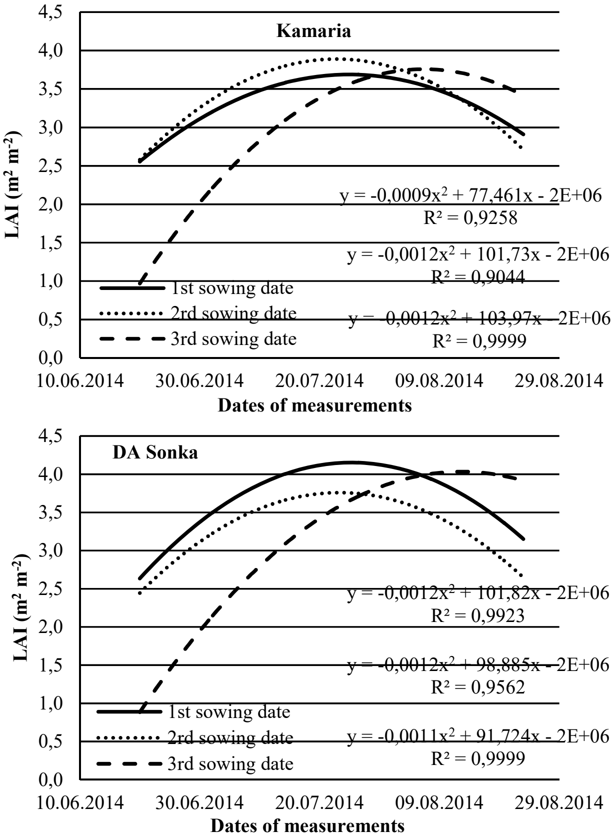

Fig. 2 The leaf area index (LAI) of maize hybrids sown at different sowing dates, 2014

Hybrid DKC 4590 had the most intense photosynthetic system. It is the hybrid which reacts to weather extremes the best, because with every sowing date, it had significantly higher photosynthetic values than the other three tested hybrids. With the first and third sowing dates, significantly higher values were gained than with the second sowing date, though that value was not reliable. Similar trend was shown by hybrid DA Sonka, but here photosynthetic capacity values already with the first sowing date was significantly lower than that with the third sowing date.

Also in case of the other two hybrids there were significant differences between the different sowing dates, but another tendency prevailed. Photosynthesis of hybrid P9578 was the highest with the first sowing date and compared to that, its value with the second and third sowing date was, however, significantly lower. Also with hybrid Kamaria, the maximum value of photosynthesis was measured with the first sowing date, and it showed similar activity also with the third sowing date (Fig. 3).

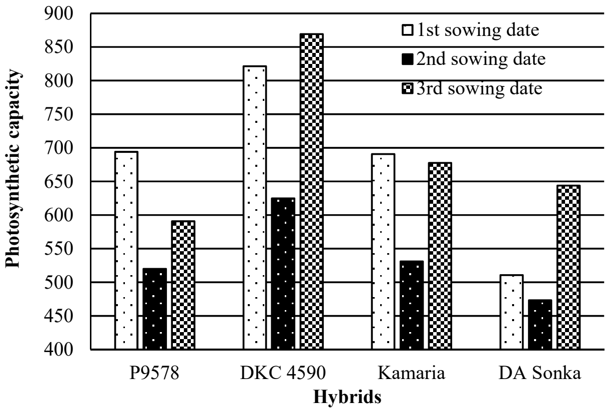

Fig. 3 The photosynthetic capacity (Ph.C.) of maize hybrids sown at different sowing dates, 2014

C. Relationship between the Photosynthetic Capacity (Ph.C.) and Yield of Corn Hybrids

Hybrid DKC 4590 is the most tolerant to sowing date, as from the four tested hybrids; it had the highest Ph.C values with all the sowing dates and with the highest yield results. The hybrid reached its maximum yield with the third sowing date, and compared to that, with the first and second sowing date it had reliably 0.74 t ha^{-1} and 1.38 t ha^{-1} lower results. Photosynthetic activity followed a similar trend to yield results, which proves also that photosynthesis plays an important role in yield formation by the accumulation of organic matter (Fig. 4).

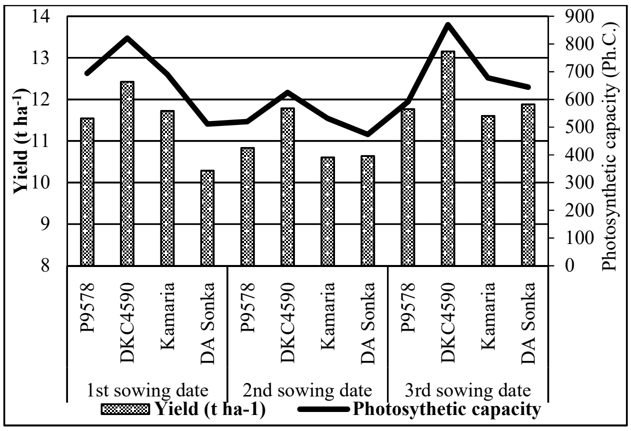

Fig. 4 Correlation between the yield and the photosynthesis, 2014

Photosynthetic capacity of hybrid P9578 was the highest already with the first sowing date, but it reached the highest yield (11.77 t ha^{-1}) with the third sowing date. Similarly to the Ph.C values of hybrid Kamaria, also its yield was nearly the same with the first (11.72 t ha^{-1}) and third (11.61 t ha^{-1}) sowing date. With the second sowing date, with the decrease in the photosynthetic activity its yield significantly decreased (10.61 t ha^{-1}), too.

The difference was significant also between the yields of hybrid DA Sonka with the three different sowing dates. It reached its maximum yield (11.88 t ha^{-1}), similarly to its photosynthetic capacity, with the third sowing date.

Correlation between the photosynthetic capacity and the yield was also examined by linear regression analysis. As a result of the analysis, it can be concluded that photosynthesis plays an important role in yield formation. Fig. 5 shows that the correlation between the two factors is very close (R^2 = 0.8593).

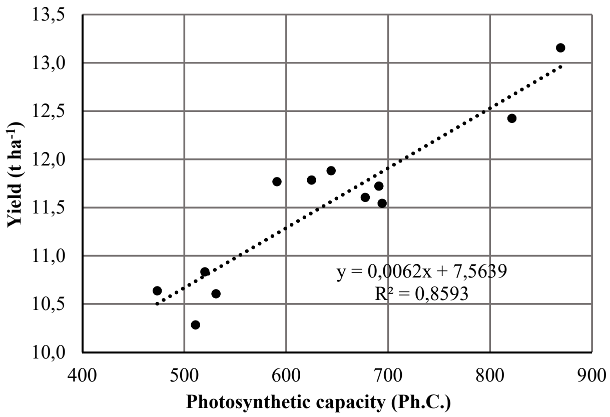

Fig. 5 Linear regression between of the yield and photosynthetic capacity, 2014

IV. Conclusions

Based on the test results it can be concluded that the leaf area has a determining role in yield formation of maize hybrids with the different sowing dates. The tested hybrids reached their lowest leaf area value mostly with the third sowing date and with the highest yield results. On the other hand, the maximum leaf area values were observed with significantly lower yields. Comparing also with literary data [10], the explanation for the above can be the fact that with increase in the leaf area, the organic matter production is also improving. At the same time, after achieving a certain value, self-shading and the more intense evaporation cause the organic matter accumulation to slow; thereby increase in yield production reduces.

In the examination of the photosynthetic capacity, it is very conspicuous that with the third sowing date the performance of the youngest plants is prominently high, which can be explained by the different ripening periods. With a delayed sowing date the period of ripening lasts longer, thereby the CO_2 absorption is also more active in the same period compared to the application of the earlier sowing dates. Thus the water release of late sown plants is slower; with the higher yield results they have higher grain moisture content at harvest.

In maize production, also sowing dates are best to be applied specifically to the given hybrids, since it influences, at a large extent, not just the yield, but also the efficiency of production. Results show that yield results are affected not only by environmental and agrotechnical factors occurring during the growing season, but other factors, such as the leaf area and the photosynthesis are also determining elements, and all these factors together, modifying the effect of each other, develop the average yields.

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