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Correlation between photosynthetic traits and yield in sunflower

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ABSTRACT

The impact of sowing dates (early, normal and late) on the crop physiological parameters (leaf area index (LAI), chlorophyll content (SPAD)) and yield of sunflower cultivars (NK Neoma, NK Ferti, PR64H42) was observed in 2012, 2013, and 2014 on chernozem soil in Eastern Hungary. The obtained LAI_{max} values were 5.1–5.3 m^2/m^2 (early sowing date), 4.5–5.2 m^2/m^2 (normal sowing date) and 4.4–5.2 m^2/m^2 (late sowing date). Pearson's correlation analysis revealed a close negative correlation between LAI_{max} and sowing date in 2013 and 2014 ($r = -0.920^{**}$, $r = -0.813^{**}$) and an average, non-significant correlation between LAI_{max} and sunflower yield ($r = 0.575^{ns}$, $r = 0.509^{ns}$). The relative chlorophyll content was not significantly affected by either growing year, sowing date or genotype in the period between May and July (~40). In the case of high infection index (Ii) values (2012), sunflower cultivars had the highest yield in the late sowing date (4.3–5.3 t/ha). However, average Ii values (2013) were associated with the highest yields in normal sowing date (5.1–5.3 t/ha) and moderate Ii values (2014) showed the highest yields in early sowing dates (4.6–5.1 t/ha).

Keywords: *Helianthus annuus* L.; oil crop; pathogens; weather conditions; agrotechnical elements

Sunflower is the fourth most important oil crop in the world and the most important oil crop in Hungary. The sowing area of sunflower is between 600–650 thousand hectares in Hungary and its average yield is between 2.3–2.7 t/ha. Sunflower has a favourable climatic adaptability and provides satisfactory yield also in dry and warm weather condition. At the same time, extreme weather conditions (dry or rainy weather) decrease sunflower yield (Erdem et al. 2001, Szabó and Pepó 2005, Mijic et al. 2012). Unfavourable climatic impacts can be mitigated partially by selecting proper cultivars (Simic et al. 2008, Pepó and Vad 2011) and by applying optimised agrotechnical elements (sowing date, crop density, fungicide application, etc.). Despite the fact that sunflower is able to tolerate different sowing dates (Sin et al. 1996, Balalic et al. 2007), early and delayed sowing dates reduce its yield (Miller et al. 1984, Lawal et al. 2011, Baghdadi et al. 2014).

The photosynthetic capacity of sunflower is defined by its leaf area index (LAI) and chlorophyll content (SPAD), as well as the dynamics of their change during the vegetation period. The maximum LAI (LAI_{max})values (2.0–5.0 m^2/m^2) were obtained in the flowering phenophase in various experiments (Thavaprakash et al. 2003, Pepó and Novák 2014). According to certain researchers (Rawson and Turner 1983, Hall et al. 1985, Thavaprakash et al. 2003), there was a close positive correlation between LAI and yield. The relative chlorophyll content of sunflower is also important from the aspect of photosynthetic capacity. SPAD readings decreased towards the end of the growing season (Nezamia et al. 2008).

Sunflower yield is significantly affected by various stem, leaf and head diseases. Strong infections may lead to even up to 20–50% yield reduction. The most severe yield loss is usually observed if pathogens infect the crop before flowering (Pepó and Novák 2014), and moderate infection was in late sowing date (Mogle et al. 2006).

The aim of this research was to identify the LAI values and SPAD readings of different sunflower cultivars, as well as their dynamics in different growing years. The correlations between crop physiological parameters (LAI, SPAD) were studied and the infection of diseases and sunflower yield in the case of different sowing dates.

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MATERIAL AND METHODS

The experiment was established on calcareous chernozem soil at the Látókép Experiment Site of the University of Debrecen, Faculty of Agricultural and Food Sciences and Environmental Management, Institute of Crop Sciences. The experiment site is located 15 km from Debrecen (47°5'N, 21°4'E). The experimental soil was calcareous chernozem loam (organic carbon 1.5–1.6%, pH_{KCl} = 6.5, AL-soluble P and K = 57–62 mg/kg and 199–208 mg/kg, respectively; heaviness index according to Arany: A_K = 42–44). The soil has favourable water management characteristics (the water holding capacity of the 0–200 cm soil layer is 680 mm out of which 50% is available water). The soil traits were measured in the Central Lab of Debrecen University according to international standards.

The experiments were established in 2012, 2013 and 2014 with split-plot design and four replications. The total (gross) plot size was 19.76 m^2 and the harvested area (net plot size) was 12.5 m^2. The inter row distance was 0.76 m.

The following three sowing dates were examined in all three years of the experiment:

– early sowing date: 23/03/2012, 17/04/2013, 26/03/2014;
– normal sowing date: 10/04/2012, 25/04/2013, 07/04/2014;
– late sowing date: 05/05/2012, 08/05/2013, 06/05/2014.

The following sunflower cultivars were examined in the experiment: NK Neoma (LO); NK Ferti (HO); PR64H42 (HO).

The crop density of sunflower cultivars in the experiment was 55 thousand plants/ha. Fungicide treatments were used on two phenophases (at the 8-10-true leaf stage and the beginning of flowering). In both cases, fungicide dimoxistrobin + boscalid was used. The agrotechnical elements were uniformed in the studied years and these elements fitted to the intensive crop technology used in the studied region. The previous crop was winter wheat and the conventional tillage was used (in summer and autumn: disking + ploughing, in spring: seedbed preparation by combinator). The fertilizer doses were uniform in all three years: N = 68 kg/ha (in spring, before planting), P = 17.44 kg/ha and K = 74.70 kg/ha (in autumn before ploughing). Preemergent herbicide application (S-metolachlor + oxyfluorfen) was used. Sampo plot harvestor was used for the harvest in early, middle and late September depending on sowing dates.

The LAI values were determined with the portable SunScan canopy analysis systems (SSI) leaf area index meter. The relative chlorophyll content of the sunflower leaf was determined using a portable soil plant analysis development (SPAD-502 Plus, Konica Minolta, Japan) chlorophyll measurement device. The measurements were carried out on the top leaves of sunflower plants in different dates in vegetation period (the exact dates can be found in Figure 1). LAI and SPAD values were obtained in four replications.

Sunflower has many leaf, stem and head diseases. The most important diseases of sunflower are the following: *Diaporthe helianthi*, *Phoma macdonaldii*, *Alternaria helianthi* and head diseases caused by *Sclerotinia*, *Bothritys* etc. The infected area to total area ratio (%) was measured. Different diseases cause interactive effects on the yield of sunflower so a complex infection index was worked out to commonly evaluate the four most important diseases of sunflower. A special coordinate system (each axis represents one disease) was used. The formula of infection index is:

$$I_i = \left(\frac{D \times H}{2} + \frac{D \times Ph}{2} + \frac{A \times H}{2} + \frac{A \times Ph}{2}\right) \div 100$$

Where: Ii – infection index; D – *Diaporthe* infection (%); H – head diseases (%); A – *Alternaria* infection (%); Ph – *Phoma* infection (%).

The area of the rectangle (which represents the infection index) was calculated by dividing it into four triangles.

The processing and statistical evaluation of the experimental data were performed with Microsoft Excel 2013 (USA) and SPSS for Windows 13.0 (USA). The obtained results were evaluated with ANOVA and Pearson's correlation analysis. In correlation analysis the *r* values mean weak (r = 0.3–0.5), average (r = 0.5–0.7) and strong (r = 0.7–1.0) interactions.

RESULTS AND DISCUSSION

In 2012 there was normal sum of rainfall in the spring and in June and July, while the weather was extremely dry and hot in August. Significant huge rainfall (136.3 mm) in March of 2013 filled up the field water capacity (FWC) of chernozem soil and

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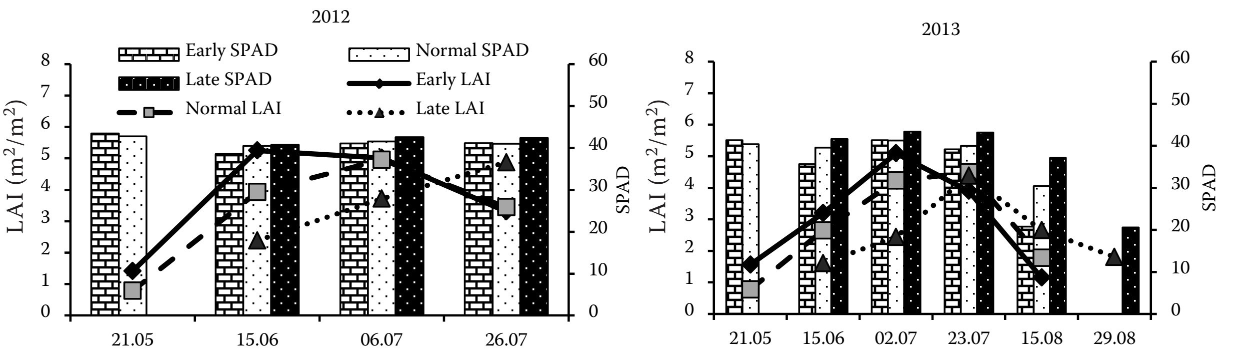

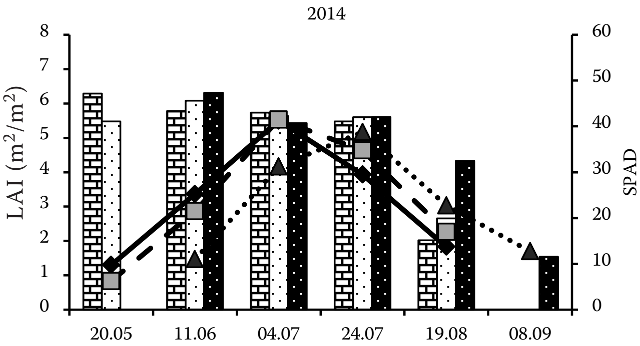

		LSD$_{5\%}$					
		21.05.	15.06.	06.07.	26.07.		
2012	SPAD	1.5	0.9	1.2	0.8	–	–
	LAI	0.3	0.7	0.5	0.5		
		21.05.	15.06.	02.07.	23.07.	15.08.	29.08.
2013	SPAD	1.8	0.6	1.1	1.6	6.4	–
	LAI	0.3	0.3	0.6	0.5	0.5	
		20.05.	11.06.	04.07.	24.07.	19.08.	08.09.
2014	SPAD	1.6	1.5	1.5	1.6	1.7	–
	LAI	0.2	0.4	0.5	1.1	0.3	

Figure 1. Effect of sowing date and experimental year on the dynamics of leaf area index (LAI) and chlorophyll content (SPAD) in sunflower (Debrecen, chernozem soil, average of cultivars, 2012–2014)

the disponible water (DW) of FWC compensated the dry period (June–August) in the vegetation season of 2013. In 2014, the normal spring weather was followed by extremely dry weather in June and extremely rainy weather in July. The monthly mean temperatures of the sunflower growing season exceeded the multiple-year-averages in all three years.

The meteorological data of the experimental years are shown in Table 1.

Experimental year, sowing date and genotype affected the maximum LAI and maximum relative chlorophyll content (LAI_{max}, $SPAD_{max}$) of sunflower, as well as their dynamics during the growing season. These factors (LAI, SPAD) determined the photosynthetic capacity of sunflower populations, which, in addition to diseases, significantly affected the yield of sunflower cultivars. Sowing date primarily affected the LAI values of sunflower cultivars and had a non-significant impact on the SPAD values. The maximum LAI values were obtained in early and normal sowing dates in the beginning of July. However, in late

Table 1. Some important meteorological data in the growing period of sunflower (Debrecen, 2012–2014)

Month	Sum of rainfall (mm)				Mean temperature (°C)			
	2012	2013	2014	30 year average	2012	2013	2014	30 year average
March	1.4	136.3	11.3	33.5	6.3	2.9	8.9	5.0
April	20.7	48.0	39.6	42.4	11.7	12.0	12.3	10.7
May	71.9	68.7	69.4	58.8	16.4	16.6	15.4	15.8
June	91.7	30.8	7.9	79.5	20.9	19.6	19.0	18.7
July	65.3	15.6	128.0	65.7	23.3	21.2	21.2	20.3
August	4.1	32.2	44.8	60.7	22.5	21.5	19.8	19.6
Total	255.1	331.6	301.0	340.0	–	–	–	–
Average	–	–	–	–	16.85	15.63	16.10	15.02

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Table 2. Pearson correlation analysis between the sowing date and yield and maximum leaf area index of sunflower cultivars (Debrecen, 2012–2014)

	2012	2013	2014
Sowing date	-0.394^{ns}	-0.920^{**}	-0.813^{**}
Yield	-0.338^{ns}	0.575^{ns}	0.509^{ns}

**Correlation on $LSD_{0.01}$ level; ^{ns}non-significant

Table 3. Pearson correlation analysis between the sowing date and yield and maximum chlorophyll content of sunflower cultivars (Debrecen, 2012–2014)

	2012	2013	2014
Sowing date	0.584^{*}	0.708^{*}	-0.305^{ns}
Yield	0.689^{*}	-0.656^{*}	0.239^{ns}

*Correlation on $LSD_{0.05}$ level; ^{ns}non-significant

sowing dates, the maximum LAI was obtained in the end of July, when the development of the canopy was delayed by 3–4 weeks (Figures 1). The LAI_{max} values of the examined cultivars did not significantly differ from each other. The size of the leaf area of sunflower showed specific dynamics during these years. In the first two months of the growing season (May and June), extremely intensive LAI increase was observed in all three examined years. In July, moderate leaf area reduction was observed both in the early and normal sowing dates, while a significant reduction of LAI was measured in August. In the early and normal sowing date, there was no active assimilatory leaf area from the end of August to the beginning of September. There was little assimilatory leaf area even from the end of August to the beginning of September in late sowing of sunflower (Figure 1). Sunflower cultivars gave their LAI_{max} values in the flowering phenophases, which can be characterised by around 5.0 m^2/m^2 as in the studies of Thavaprakash et al. (2003) and Debaeke et al. (2014). Cui et al. (2000) proved that the rational increase of leaf area is a key crop physiological factor to increase the yields of sunflower.

The assimilation capacity of sunflower cultivars is affected not only by leaf area and its dynamics, but also by the leaf chlorophyll content and its changes during the growing season. The SPAD values were not significantly affected either by experimental year, sowing date or genotype in the period from May to July of the growing season. The SPAD values of the experimental years were between 40 and 47 in May, 36 and 47 in June, 41 and 43 in the beginning of July and 39 and 43 in the end of July. A strong reduction in SPAD values was measured only in August. Similar SPAD dynamics were observed by Nezamia et al. (2008) in their sunflower experiments.

The results of the correlation analysis (Table 2) showed that there was an average positive non-significant correlation between LAI_{max} and sunflower yield in 2013 and 2014 ($r = 0.575^{ns}$, and $r = 0.509^{ns}$). Contrary to this experiment, Rawson and Turner (1983), Hall et al. (1985) and Thavaprakash et al. (2003) concluded that there was a close positive correlation between the LAI values and the yield of sunflower. The experimental data of this study proved a close negative correlation between LAI_{max} and sowing date in 2013 and 2014 ($r = -0.920^{**}$, $r = 0.813^{**}$). There was an average correlation between $SPAD_{max}$ and sowing date (Table 3) in 2012 ($r = 0.584^{*}$) and 2013 ($r = 0.708^{*}$).

In addition to photosynthetic capacity (LAI and SPAD), the yield of sunflower cultivars is significantly affected by the length of vegetation period and the level of disease infection. The level and dynamics of leaf, stem and head diseases are determined by growing year. A complex indicator (infection index) was worked out, which represents the infection level of the four major diseases of sunflower. The Ii values are shown in Table 4. The Ii values were modified by growing year, sowing date and genotype. In 2012 (more rainfall from May to July) and early sowing date, the infection index was higher. In 2012 in early sowing date Ii were 57.3–72.5, in 2013 16.5–27.7 and in 2014 15.6–22.8, respectively. The Ii were much lower in late sowing date (in 2012 6.2–9.2, in 2013 3.1–7.8, in 2014 2.9–3.9).

The results of Pearson's correlation analysis showed that there was a close negative correla-

Table 3. Pearson correlation analysis between the sowing date and yield and maximum chlorophyll content of sunflower cultivars (Debrecen, 2012–2014)

	2012	2013	2014
Sowing date	0.584^{*}	0.708^{*}	-0.305^{ns}
Yield	0.689^{*}	-0.656^{*}	0.239^{ns}

*Correlation on $LSD_{0.05}$ level; ^{ns}non-significant

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Table 4. Effect of experimental year and sowing date on the infection index (Ii) and yield (kg/ha) of sunflower cultivars (Debrecen, 2012–2014)

Year	Sowing date	Cv. NK Neoma		Cv. NK Ferti		Cv. PR 64 H 42	
		Ii	yield	Ii	yield	Ii	yield
2012	early	72.5[bc]	4107[bc]	57.3[bc]	3619[c]	65.0[bc]	3742[c]
	average	56.9[ac]	4550[ac]	43.5[ac]	3910[ac]	55.9[ac]	3968[ac]
	late	6.2[ab]	5326[ab]	9.6[ab]	4970[ab]	7.2[ab]	4326[ab]
2013	early	27.7[bc]	4380[bc]	20.4[bc]	4984[c]	16.5[bc]	4838[c]
	average	15.1[ac]	5103[ac]	17.2[ac]	5282[ac]	10.9[ac]	5090[ac]
	late	6.4[ab]	4125[b]	7.8[ab]	4337[ab]	3.1[ab]	4381[ab]
2014	early	15.6[bc]	5010[c]	16.3[bc]	5072[c]	22.8[bc]	4590[c]
	average	9.7[ac]	4812[c]	11.5[ac]	4960[c]	15.5[ac]	4562[c]
	late	3.3[ab]	4428[a]	2.9[ab]	4290[ab]	3.9[ab]	3940[ab]

[a,b,c]Letters are significantly different at $P \leq 0.05$ level

tion between sowing date and infection index in all three examined years (Table 5). The correlation coefficients between sowing date and Ii were $r = -0.904^{**}$ in 2012, $r = -0.850^{**}$ in 2013 and $r = -0.883^{**}$ in 2014, respectively. The highest infection was present in 2012, especially in early and normal sowing dates. Despite the favourable LAI and SPAD values in 2012 (due to strong infection), the highest yields were obtained in late sowing date (4.3–5.3 t/ha), compared to early (3.6–4.1 t/ha) and normal (3.9–4.6 t/ha) sowing dates (Table 4). Due to favourable crop physiological parameters (LAI, SPAD) and the more moderate level of infection (average infection indexes), the maximum yield of sunflower cultivars in 2013 (5.1–5.3 t/ha) were observed in the normal sowing date. The lowest level of infection was observed in 2014 (moderate infection indexes). LAI and SPAD values were almost identical in 2014 in early and normal sowing dates. In the late sowing dates sunflower canopy, both the LAI_{max} value and LAI dynamics lagged behind the respective values of early and normal sowing dates, while the vegetation period was also 10–15 days shorter. The yields of early sowing date and normal sowing date in 2014 (4.6–5.1 t/ha) were significantly higher compared to late sowing date (3.9–4.4 t/ha).

Table 5. Pearson correlation analysis between the sowing date and yield and the infection index of sunflower cultivars (Debrecen, 2012–2014)

	2012	2013	2014
Sowing date	–0.904**	–0.850**	–0.883**
Yield	–0.634**	0.265[ns]	0.375*

**Correlation at $LSD_{0.01}$ level; *Correlation at $LSD_{0.05}$ level; [ns]non-significant

The obtained results proved that the extreme weather conditions (dry or rainy) decrease the yield of sunflower. According to the findings of Erdem et al. (2001), Szabó and Pepó (2005) and Mijic et al. (2012) the growing year could reduce the yield of sunflower by 1.0–3.0 t/ha depending on weather situation. These unfavourable climatic impacts can be mitigated by cultivar selection (Simic et al. 2008, Pepó and Vad 2011). The maximum yield of cv. NK Neoma was significantly higher than yields of other cultivars in 2012. In 2013 and 2014 growing seasons cvs. NK Ferti and NK Neoma gave similar maximum yields (5.0–5.3 t/ha) but there were no significant differences among the yields of cultivars. Among the agrotechnical elements the sowing date is a key factor to reduce the harmful climatic effects on the yield of sunflower cultivars. Sunflower is able to tolerate the extreme sowing dates (Sin et al. 1996, Balalic et al. 2007). Early and late sowing dates reduced sunflower yields in this experiment. Miller et al. (1984), Lawal et al. (2011) and Baghdadi et al. (2014) obtained lower yields in early and late sowing dates of sunflower.

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