Acta fytotechn zootechn, 23, 2020(1): 7–14
http://www.acta.fapz.uniag.sk

Original Paper

Assimilation capacity by non-destructive *in situ* measurements in longterm experiment of maize (*Zea mays* L.) under different plant density and nitrigen supply in Chernozem

Péter Pepó, András Szabó, Lajos Dóka, Éva Szabó, Éva Babett Ábrahám*
University of Debrecen, Faculty of Agricultural and Food Sciences and Environmental Management,
Department of Crop Production and Applied Ecology, Hungary

Article Details: Received: 2019-10-15 | Accepted: 2019-12-31 | Available online: 2020-03-31

https://doi.org/10.15414/afz.2020.23.01.7-14

We conducted a long term experiment (set up in 1983) to examine the effects of fertilization and plant density on SPAD and LAI values as well as yield in 2017 and 2018, in two maize hybrids (Sushi, Fornad) in chernozem soil. Hybrid yields varied between 10.2–16.7 t ha^{-1} in 2017 and between 9.3–15.9 t ha^{-1} in 2018, depending on fertilization doses and plant density. The hybrids had SPAD$_{max}$ values in early July (55.5–60.4 in 2017 and 54.9–63.9 in 2018), whereas they got LAI$_{max}$ values in early July (3.0–5.3 m^2 m^{-2} in 2017) and early August (3.5–4.4 m^2 m^{-2} in 2018). Research data evaluated by Pearson correlation calculations proved that fertilization was the main factor that had a significant effect on SPAD and LAI values in the different maize phenophases (r = 0.6**–0.8** for SPAD, r = 0.5**–0.8** for LAI). Correlation among plant density, hybrid and SPAD and LAI values showed very weak correlations in both years (r = 0.1–0.3). The yield of the maize hybrids was most significantly affected by fertilizer in 2017 (r = 0.672**) and plant density in 2018 (r = 0.517**).

Keywords: long term experiment, LAI, SPAD, yield, Pearson correlation

1 Introduction

Maize has a significant role in both world (2nd largest production area) and Hungarian (largest production area of arable land) field crop production. It has very high genetic potential (it is a C4 photosynthetic type plant), but only 25–35% of which is currently utilised in Hungary (country average yield have been between 6.5–8.5 t ha^{-1} in last decade). In addition to its high yield potential, maize is largely affected by changes in ecological and agrotechnical conditions. From a crop formation perspective, changes in the dynamics of the assimilation capacity (leaf area, relative chlorophyll content) of the crop stand has a significant role in the vegetation period (Carter, 1994; Martinez and Guiamei, 2004; Hawkins et al., 2009). It is crucial to measure LAI and SPAD values in maize populations, as it makes it possible to gather data on photosynthetic activity via *in situ* non-destructive methods. LAI and SPAD values are affected by the year, the hybrid, fertilization and plant density as well. Fertilization makes huge changes in the SPAD (Yu et al., 2010; Széles et al., 2011) and LAI values of hybrids (Novoa and Loomis, 1981; Oikeh et al., 1998, Micskei et al., 2012). Some other references show that increasing plant density decreased the SPAD values (Su et al., 2012; Tajul et al., 2013) and increased the LAI values (Ahmad et al., 2010; Valadabadi and Farahani, 2010). Many researchers examined the relationship between maize SPAD and LAI values and yield. The relative chlorophyll concentration of maize (SPAD) had a positive correlation with nitrogen supply and maize yield (Széles, 2008; Bencze and Futó, 2017). Research results showed a strong positive correlation between LAI values at maize flowering and yield (Oikeh et al., 1998; Bavec and Bavec, 2002; Ma et al., 2005). However, research data by Esechie (1982), Remison and Lucas (1992) showed no correlation between leaf area index (LAI) and maize yield.

Several research shows that maize yield can be increased significantly by fertilization (Berzsenyi, 2010; Széll et

---

***Corresponding Author:** Éva Babett Ábrahám. University of Debrecen, Faculty of Agricultural and Food Sciences and Environmental Management, Department of *Crop Production* and Applied Ecology, Böszörményi út 138, 4032 Debrecen, Hungary. E-mail: abraham.eva@agr.unideb.hu

al., 2010; Vári and Pepó, 2011). However, the effects of fertilizers were largely affected by the water supply of the year (Azeez, 2009; Ványiné et al., 2012) as well as the hybrid (Körshens, 2006; D'Haene et al., 2007). At the same time, there is a strong correlation between optimum plant density and yield in maize production. Optimal plant density was affected by the water supply of the vegetation period (Sárvári and Pepó, 2014; Nagy, 2010; Berzsenyi et al., 2011) as well the water reservoirs of soil (Fulton, 1970; Dóka, 2015). In addition to water supply and year, the plant density response of the hybrids also plays a significant role in yield formation. Up-to-date hybrids can utilise more yield potential at higher crop density (Carlone and Russel, 1987; Russel, 1991; Haegele et al., 2014). The experimental results of Pepó and Murányi (2014, 2015) show that the yield of crop hybrids is also affected by cropping area (row spacing).

In our long-term chernozem soil experiment we studied the responses of different maize hybrids to fertilization and plant density, as well as measure photosynthesis capacity values (LAI, SPAD) in the vegetation season of maize. We examined the relations between LAI and SPAD values and maize yield.

2 Material and methods

In 1983, a long-term trial on calcareous chernozem soils (code CH accordind to WRB classification) was set up in the Hajdúság (Eastern Hungary), 15 km from Debrecen (latitude 47° 33′ N., and longitude 21° 27′ E.). The chernozem soil of the long-term experiment contains 2.7–2.8% humus, and total depth of the humus enriched horizon was about 0.8 m (Table 1). When the trial was set up, the soil contained 130 mg kg^{-1} AL-soluble P_2O_5 and 240 mg kg^{-1} AL-soluble K_2O. The calcareous chernozem soil is characterized by a specific plasticity index (KA) of 40 and nearly neutral pH (pH_{KCl} = 6.46). The soil has favourable water management characteristics.

During the long-term trial we applied treatment with 6 nutrient doses. In addition to the control treatment, a basic dose of N =30 kg ha^{-1} + P_2O_5 = 22.5 kg ha^{-1} + K_2O = 26.5 kg ha^{-1} was applied in double, triple, quadruple and quintuple quantities. In the trial, among these doses, the following treatments were examined:

	N	P_2O_5	K_2O
kg ha^{-1}			
control	0	0	0
N_{90} + PK	90	67.5	79.5
N_{150} + PK	150	112.5	132.5

Nitrogen fertilizer was applied to the plots 50% in the autumn and 50% in the spring, before sowing. The full amount (100%) of the phosphorous and the potassium was applied in the autumn before ploughing.

Two plant densities (65 thousand ha^{-1} and 85 thousand ha^{-1}) were set up in our long-term experiment with two different genotype (Sushi (FAO 340), Fornad (FAO 420). The trial was arranged in a split-split-plot design. The gross and net plot areas were 9.12 m^2 and 7.60 m^2, respectively. The trial involved four repetitions. The forecrop was winter wheat. The optimal agricultural elements (tilling, sowing, crop protection, harvesting) were used, which matched to modern maize production.

Important weather information for trial years are shown in Tables 2 and 3.

The meteorical data of experimental years proved that the rainfall of pre-vegetation periods (from October to Mach) was slightly (+20.9 mm) and highly (+131.7 mm) higher, compared with the 30-years mean in 2017 and 2018, respectively. The amount and the distribution of rainfall in the vegetation period (April–September) were much favourable in 2017 year, compared with 2018 year. The monthly average temperatures of vegetation periods were over the mean average in both years which modified the absolute values and dynamics of SPAD and LAI readings.

Table 1 Most important traits of calcareous chernozem soil in the long-term experiment (Debrecen)

Soil layer (m)	pH (KCl)	Elasticity number	$CaCO_3$ (%)	Humus (%)	Total N (%)	$NO_3 + NO_2$ (mg kg^{-1})	P_2O_5 (mg kg^{-1})	K_2O (mg kg^{-1})	Mg (mg kg^{-1})	Na (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})	Mn (mg kg^{-1})	SO_4 (mg kg^{-1})
							AL soluble							
0–0.25	6.46	43.0	0	2.76	0.150	6.20	133.4	239.8	332.4	38.0	2.80	5.86	438	9.25
0.25–0.50	6.36	44.6	0	2.16	0.120	1.74	48.0	173.6	405.4	66.2	0.80	4.54	406	9.13
0.50–0.75	6.58	47.6	0	1.52	0.086	0.60	40.4	123.0	366.6	55.4	0.58	3.64	339	10.80
0.75–1.00	7.27	46.6	10.25	0.90	0.083	1.92	39.8	93.6	249.0	67.8	0.48	2.24	74	7.95
1.00–1.30	7.36	45.4	12.75	0.59	0.078	1.78	31.6	78.0	286.6	62.6	0.84	1.64	4	22.98

Table 2 Rainfall in pre-vegetation and vegetation period of maize (Debrecen)

Vegetation period	Pre-vegetation period (Oct–March) (mm)	Rainfall (mm)						
		Apr.	May.	June	July	Aug.	Sept.	Total
2017	235.0	50.4	31.9	62.3	71.6	47.5	91.7	355.4
2018	345.8	36.6	60.0	66.8	41.9	97.5	20.6	323.4
30-years mean	214.1	52.8	64.0	66.5	66.1	49.0	47.5	346.0

Table 3 Monthly average temperature in the vegetation period of maize (Debrecen)

Vegetation period	Monthly average temperature (°C)						Mean
	Apr.	May.	June	July	Aug.	Sept.	
2017	10.1	16.3	20.9	21.0	22.1	15.5	17.65
2018	15.5	19.0	20.1	21.7	23.2	17.1	19.43
30-years mean	11.1	16.6	19.4	21.3	20.7	15.8	17.48

In our long-term experiment the leaf area index (LAI) and relative chlorophyll content (SPAD) were measured 5 times in the vegetation period of maize. The LAI values were determined using a SunScan Canopy Analysis System (SSI) portable leaf area measuring instruments in four repetitions with five measurements per repetition. SPAD and LAI values were measured during the morning period between 9–11 a.m.

For the measurement of the SPAD values a portable Soil Plant Analysis Development (SPAD-502 Plus, Konica Minolta) instrument was used. The instrument measures the light absorption of leaves in the blue and red (*R* = 600–700 nm) spectrum range, which corresponds to the maximum light absorption of chlorophyll. The values are based on near infra-red band in addition to the visible light spectra. The SPAD values can be regarded equal to the leaf chlorophyll content, as there is a very close correlation between the SPAD value and the chlorophyll content in the different crops. The SPAD values were measured in four repetitions with fifteen measurements per repetitions.

The statistical evaluation of experimental data was performed using the programmes Microsoft Excel 2013 and SPSS for Windows 13.0. For the evaluation of the results analysis of variance and Pearson's correlation analysis were used. The average values were copmpared with post hoc statistical test.

3 Results and discussion

We measured the SPAD and LAI values of maize plants 5 times during the vegetation seasons in 2017 and 2018. (Tables 4 and 5). All assessments were carried out between late May/early June and early September. Despite the significant differences between the years, there were no significant differences in the SPAD dynamics and maximum values of the two vegetation seasons. The late May / early June SPAD values (49.7–54.1 in 2017, 43.7–52.0 in 2018) were continuously increasing and reached their SPAD_{max} values in early July (04/07) in both years (55.5–60.4 in 2017 and 54.9–63.9 in 2018). After SPAD_{max} the readings of SPAD had a moderate decreasement in 2017 (28.3–54.9 at the time of the 01/09 measurement) and a significant drop in 2018 (9.3–14.5 as measured on 07/09), which was due to the temperature differences of July and August between the two years. Fertilization had significant increasements in both hybrids at most measurement times, plant density made no differences on them. There was no significant difference in the relative chlorophyll content of the two genotypes either. The temporal changes in leaf area index (LAI) showed similar dynamics comparing with relative chlorophyll values (SPAD) (Table 4, 5). The hybrids gave their LAI_{max} values in early July in 2017 (3.0–5.3 m^2 m^{-2} on 04/07) and early August in 2018 (3.5–4.4 m^2 m^{-2} on 06/08). As opposed to SPAD values, the decreasement of LAI values followed a similar trend in both years (1.5–3.0 m^2 m^{-2}, on 01/09/2017 and 1.1–2.3 m^2 m^{-2} on 07/09/2018). The LAI_{max} values were higher in 2018 than in 2018. Increasing fertilization doses and plant density resulted the higher LAI values of hybrids at all times of measurements. As a result of fertilization, there were significant differences in the N_{150} + PK treatment in 2017, whereas differences were not significant in most cases in 2018 and LAI_{max} values were reached in the N_{90} + PK treatment.

The effects of excellent chernozem soil, favourable water supply and near-optimal agrotechnology could moderate the negative temperature conditions of both years, so we obtained high yields in our long-term

Table 4 Effect of crop year and agrotechnical elements on the SPAD and LAI of maize in the vegetation period (Debrecen, chernozem soil, 2017)

Hybrid	Fertilization	65,000 ha^{-1}					85,000 ha^{-1}				
		09. 06.	22. 06.	04. 07.	17. 08.	01. 09.	09. 06.	22. 06.	04. 07.	17. 08.	01. 09.
		SPAD									
Sushi	Ø	51.6^{ab}	54.5^{a}	55.5^{a}	48.0^{a}	31.8^{a}	50.7^{a}	53.9^{a}	54.0^{a}	45.3^{a}	28.3^{a}
	N_{90} + PK	54.1^{b}	57.8^{b}	59.2^{b}	56.9^{b}	47.8^{b}	53.6^{b}	55.0^{ab}	58.5^{b}	56.7^{c}	46.7^{c}
	N_{150} + PK	52.2^{ab}	56.5^{ab}	60.4^{b}	58.9^{bc}	46.5^{b}	51.7^{ab}	56.4^{b}	59.4^{b}	58.0^{c}	46.6^{c}
Fornad	Ø	49.7^{a}	56.8^{ab}	57.6^{ab}	52.2^{ab}	34.2^{a}	52.1^{ab}	54.8^{ab}	56.5^{ab}	50.9^{b}	35.7^{b}
	N_{90} + PK	52.4^{ab}	57.7^{b}	59.1^{b}	59.2^{c}	53.5^{c}	51.6^{ab}	56.4^{b}	58.8^{b}	58.3^{c}	51.3^{cd}
	N_{150} + PK	49.8^{a}	56.6^{ab}	60.3^{b}	58.8^{bc}	53.1^{c}	51.6^{ab}	57.7^{b}	60.6^{b}	59.1^{c}	54.9^{d}
		LAI (m^{2} m^{-2})									
Sushi	Ø	1.0^{a}	2.0^{a}	3.8^{a}	2.1^{ab}	1.5^{a}	1.2^{a}	2.3^{ab}	3.9^{ab}	1.8^{a}	1.7^{a}
	N_{90} + PK	1.2^{a}	2.6^{b}	3.8^{a}	2.6^{b}	2.2^{c}	1.7^{ab}	2.9^{b}	4.9^{b}	2.6^{b}	2.2^{b}
	N_{150} + PK	1.8^{b}	2.4^{ab}	4.1^{a}	2.1^{ab}	2.2^{c}	2.0^{b}	3.0^{b}	5.3^{b}	2.2^{db}	2.2^{b}
Fornad	Ø	1.0^{a}	1.8^{a}	3.8^{a}	1.6^{a}	1.8^{b}	1.0^{a}	2.0^{a}	3.0^{a}	1.9^{a}	1.8^{a}
	N_{90} + PK	1.4^{ab}	2.2^{ab}	3.7^{a}	2.1^{ab}	2.0^{bc}	1.4^{ab}	2.9^{b}	4.1^{ab}	2.6^{b}	3.0^{c}
	N_{150} + PK	1.4^{ab}	2.5^{b}	3.8^{a}	1.9^{ab}	2.1^{c}	2.0^{b}	2.9^{b}	4.9^{b}	2.5^{b}	2.9^{c}

a, b, c, d letters are significantly different at $P \leq 0,05$ level

Table 5 Effect of crop year and agrotechnical elements on the SPAD and LAI of maize in the vegetation period (Debrecen, chernozem soil, 2018)

Hybrid	Fertilization	65,000 ha^{-1}					85,000 ha^{-1}				
		25. 05.	14. 06.	04. 07.	06. 08.	07. 09.	25. 05.	14. 06.	04. 07.	06. 08.	07. 09.
		SPAD									
Sushi	Ø	43.7^{a}	45.7^{a}	45.9^{a}	45.8^{a}	11.3^{a}	47.1^{a}	45.5^{a}	53.3^{a}	47.4^{a}	10.6^{ab}
	N_{90} + PK	51.0^{b}	55.9^{c}	62.5^{c}	54.7^{ab}	10.9^{a}	49.9^{b}	55.7^{b}	61.4^{b}	55.5^{b}	10.9^{ab}
	N_{150} + PK	50.7^{b}	59.7^{d}	62.4^{c}	54.2^{ab}	13.1^{b}	50.2^{b}	54.7^{b}	59.1^{b}	55.5^{b}	11.3^{ab}
Fornad	Ø	46.8^{ab}	49.1^{b}	58.4^{b}	49.8^{a}	11.3^{a}	49.7^{ab}	47.3^{ab}	58.3^{ab}	50.0^{ab}	9.3^{a}
	N_{90} + PK	49.8^{b}	59.6^{d}	63.9^{c}	59.9^{b}	10.7^{a}	52.0^{b}	57.5^{b}	60.5^{b}	54.7^{b}	12.1^{b}
	N_{150} + PK	50.0^{b}	58.7^{d}	61.8^{c}	56.4^{ab}	14.5^{b}	51.4^{b}	56.3^{b}	62.0^{b}	55.1^{b}	11.7^{b}
		LAI (m^{2} m^{-2})									
Sushi	Ø	0.8^{a}	1.8^{a}	2.4^{ab}	3.5^{a}	1.1^{a}	0.8^{a}	2.0^{a}	2.5^{a}	4.1^{ab}	1.3^{a}
	N_{90} + PK	0.9^{ab}	2.3^{b}	2.6^{ab}	3.8^{b}	1.6^{ab}	0.8^{a}	2.3^{ab}	2.9^{ab}	4.4^{b}	2.0^{b}
	N_{150} + PK	1.0^{a}	2.4^{b}	2.1^{a}	3.6^{ab}	1.9^{b}	1.0^{b}	2.6^{b}	2.5^{a}	3.7^{a}	2.1^{b}
Fornad	Ø	0.8^{a}	1.9^{a}	2.1^{a}	3.9^{b}	1.5^{ab}	0.9^{ab}	2.2^{ab}	3.0^{ab}	3.6^{a}	1.3^{a}
	N_{90} + PK	0.9^{ab}	2.5^{b}	2.9^{b}	3.9^{b}	2.3^{b}	1.0^{b}	2.5^{b}	3.2^{b}	4.0^{ab}	2.2^{b}
	N_{150} + PK	1.1^{a}	2.6^{b}	2.3^{ab}	3.6^{ab}	2.0^{b}	1.2^{b}	2.7^{b}	3.0^{ab}	3.9^{ab}	2.1^{b}

a, b, c letters are significantly different at $P \leq 0,05$ level experiments. The yields of hybrids varied between 10.2–16.7 t ha^{-1} in 2017 and between 9.3–15.9 t ha^{-1} in 2018, depending on fertilization and plant density (Table 6). In both years the fertilization had significant effects on the yield of maize hybrids. The yield surpluses of hybrids due to fertilization were 1.8–3.7 t ha^{-1} at 65 thousand ha^{-1} plant density, 2.1–5.9 t ha^{-1} at 85 thousand plant density, and 0.2–2.6 t ha^{-1} vs 1.1–2.3 t ha^{-1} in 2018, respectively. Increasing plant density lead to an increase in yield in both years, which was triggered by the significant amount of soil water supplies in spite of unfavourable temperature conditions in the vegetation season. The plant density of hybrids were different, i.e. in the Sushi hybrid increased plant density gave no significant yield increasement in the two years of our experiment (-0.2–+0.6 t ha^{-1} in 2017, vs 1.1–1.6 t ha^{-1} in 2018). In the Fornad hybrid, increased plant density realized a significant increase in yield (0.6–4.6 t ha^{-1} in 2017, 2.9–3.9 t ha^{-1} in 2018, respectively). The excellent nutrient and water supplies of the soil in the long-term experiment were proven by the high yield in the control treatment (10.2–11.1 t ha^{-1} in 2017, 9.3–13.6 t ha^{-1} in 2018, respectively). Sushi hybrid showed maximum yield in the N_{150} + PK (2017) and the N_{90} + PK (2018) treatment, whereas Fornad showed maximum yield in the $N_{90–150}$ + PK (2017) and N_{90} + PK (2018) treatment.

We applied the Pearson's correlation analysis to assess the correlations between the SPAD (Table 7) and LAI (Table 8) values with the hybrids, agrotechnological factors (fertilization, plant density) and yield at different measurement times. SPAD values showed relatively high correlations with nutrient supply in both years. In 2017, SPAD 3, SPAD 4 and SPAD 5 showed correlation coefficients of *r* = 0.630**, 0.773** and 0.795** with fertilization, respectively. In 2018, SPAD 2, SPAD 3 and SPAD 4 showed correlation coefficients of *r* = 0.799**, 0.530** and 0.593**, respectively. We found no correlations between the hybrids, plant density and SPAD values during the years of our experiments. According to our research data there were a very weak correlation between SPAD and yield (*r* = -0.018–0.424**), except at the time of the SPAD 4 (*r* = 0.619**) and SPAD 5 (*r* = 0.590**) measurements in 2017. Similarly, the Pearson's correlation analyses proved no significant correlations between LAI values measured at different times, hybrids and plant density. Fertilization

Table 6 Effect of genotype and agrotechnical elements on the yield of maize (Debrecen, chernozem soil, 2017–2018)

Hybrid	Fertilization	Yield (kg ha^{-1})			
		65,000 ha^{-1}		85,000 ha^{-1}	
		2017	2018	2017	2018
Sushi	Ø	11,123^{ab}	9,298^{a}	10,958^{a}	10,875^{a}
	N_{90} + PK	13,427^{b}	11,868^{b}	13,106^{b}	12,989^{b}
	N_{150} + PK	14,856^{b}	11,038^{ab}	15,439^{c}	12,322^{ab}
Fornad	Ø	10,246^{a}	10,534^{ab}	10,823^{a}	13,574^{b}
	N_{90} + PK	12,312^{ab}	12,990^{b}	15,433^{c}	15,915^{c}
	N_{150} + PK	12,072^{ab}	10,745^{ab}	16,682^{c}	14,647^{bc}

a, b, c letters are significantly different at $P \leq 0{,}05$ level

Table 7 Pearson correlation analysis among the agrotechnical elements (hybrid, plant density, fertilization) and yield and SPAD readings of maize (Debrecen, chernozem soil, 2017–2018)

Year		SPAD 1	SPAD 2	SPAD 3	SPAD 4	SPAD 5
2017	Hybrid	-0.254^{ns}	0.291*	0.174^{ns}	0.228^{ns}	0.303*
	Plant density	-0.062^{ns}	-0.231^{ns}	-0.129^{ns}	-0.089^{ns}	-0.025^{ns}
	Fertilization	0.074^{ns}	0.423**	0.630**	0.773**	0.795**
	Yield	0.018^{ns}	0.424**	0.275^{ns}	0.619**	0.590**
2018	Hybrid	0.190^{ns}	0.167^{ns}	0.222^{ns}	0.207^{ns}	0.065^{ns}
	Plant density	0.220^{ns}	-0.173^{ns}	-0.187^{ns}	-0.041^{ns}	-0.265^{ns}
	Fertilization	0.466**	0.799**	0.530**	0.593**	0.433**
	Yield	0.371**	0.297*	0.400**	0.339*	-0.224^{ns}

** – correlation at $LSD_{0.01}$ level, * – correlation at $LSD_{0.05}$ level, *ns* – non-significant

Table 8 Pearson correlation analysis among the agrotechnical elements (hybrid, plant density, fertilization) and yield and LAI (m^2 m^{-2}) readings of maize (Debrecen, chernozem soil, 2017–2018)

Year		LAI 1	LAI 2	LAI 3	LAI 4	LAI 5
2017	Hybrid	-0.111^{ns}	-0.137^{ns}	-0.164^{ns}	-0.089^{ns}	0.223^{ns}
	Plant density	0.239^{ns}	0.373**	0.230^{ns}	0.151^{ns}	0.361*
	Fertilization	0.593**	0.548**	0.315*	0.233^{ns}	0.752**
	Yield	0.486**	0.578**	0.496**	0.442**	0.659**
2018	Hybrid	0.188^{ns}	0.224^{ns}	0.200^{ns}	-0.036^{ns}	0.224^{ns}
	Plant density	0.093^{ns}	0.166^{ns}	0.391**	0.155^{ns}	0.106^{ns}
	Fertilization	0.470**	0.650**	0.012^{ns}	-0.023^{ns}	0.554**
	Yield	0.230^{ns}	0.349*	0.634**	0.306*	0.370**

** – correlation at $LSD_{0.01}$ level, * – correlation at $LSD_{0.05}$ level, *ns* – non-significant

Table 9 Pearson correlation analysis between the agrotechnical elements and the yield of maize (Debrecen, chernozem soil, 2017–2018)

	Hybrid	Plant density	Fertilization
2017	-0.450^{ns}	0.284^{ns}	0.672**
2018	0.374**	0.517**	0.247^{ns}

** – correlation at $LSD_{0.01}$ level, * – correlation at $LSD_{0.05}$ level, *ns* – non-significant

and LAI values showed moderate correlations at the vegetation periods of maize. In 2017 LAI 1, LAI 2, LAI 5 and fertilization treatments correlation values were *r* = 0.593**, 0.548** and 0.52**, whereas in 2018, LAI 1, LAI 2 and LAI 5 and fertilization showed correlations of *r* = 0.470**, 0.650** és 0.554**, respectively. Our results proved a moderate correlation between LAI values and yield in 2017 (*r* = 0.486**, 0.578**, 0.496**, 0.442, 0.659**), whereas in 2018 the correlation of the same factor was lower (*r* = 0.230, 0.349*, 0.634**, 0.306*, 0.370**), respectively.

Pearson's correlation analysis proved very weak correlations (*r* = -0.450–374**) between yields and hybrids in 2017 and 2018 (Table 9), but we had a relatively high correlation (*r* = 0.672**) between yields and fertilization in 2017. Similar correlation value (*r* = 0.517**) was between the plant density and the maize yield in 2018.

4 Conclusions

According to our 2017 and 2018 research results, the SPAD and LAI values of maize hybrids showed special dynamics in the vegetation season. SPAD and LAI values were growing from late May until early July (2017), and until early August (2018). Fertilization had a positive effect on SPAD values (Bencze és Futó, 2017, Yu et al., 2010) and the leaf area index (LAI) (Novoa and Loomis, 1981, Oikeh et al.; 1998; Micskey et al., 2012). As opposed to other researchers (Ahmad et al., 2010, Valadabadi and Farahani, 2010), in our experiments maize LAI values were not significantly increased by higher plant density.

Soil with excellent nutrient and water husbandry could significantly reduce the negative effects of the unfavourable weather conditions (high temperature values) of the vegetation season. The chernozem soil in our long-term experiment had excellent natural nutrient supplying capacity, which so we obtained high yields (10.2–11.1 t ha^{-1} in 2017, 9.3–13.6 t ha^{-1} in 2018, respectively) in the control plots. The maximum yield in 2017 was 15.4 t ha^{-1} in Sushi hybrid vs 16.7 t ha^{-1} in Fornad hybrid, whereas the maximum yield values in 2018 were 13.0 t ha^{-1} and 15.9 t ha^{-1}, respectively. Thus, our research results show that maize yield was affected by water supply (Azeez, 2009; Dóka, 2015; Ványiné et al., 2012), hybrid (2009; Körshens, 2006) and plant density (Sárvári and Pepó, 2014). Similarly to other research findings (Berzsenyi, 2010; Berzsenyi et al., 2011, Széll et al., 2010, Vári and Pepó, 2011), fertilization had the most significant effect on maize yield in our long-term experiment. As a result of fertilization, the yield surpluses compared to the control treatment were was 1.8–5.9 t ha^{-1} in 2017, and 0.2–2.6 t ha^{-1} in 2018, depending on hybrids and plant density. We have got a special interactive effect between fertilization and plant density in 2017. In case of no nutrient supply (control treatment), higher plant densities had minimal yield increasement (-0.2–+06 t ha^{-1}) as compared to the yield surpluses in the N_{150} + PK treatment (+0.6–+4.6 t ha^{-1}).

Using Pearson's correlation analysis we could state that fertilization was the main factor which significantly effects on SPAD and LAI values in the different maize phenophases. Correlations between fertilization and SPAD (*r* = 0.6**-0.8**) as well as LAI were relatively high (*r* = 0.5**-0.8**). According to our results we stated weak correlation (*r* = 0.1–0.3) among plant density, hybrid and SPAD and LAI values in both years. As opposed to research findings of Széles (2008), we found relatively weak correlations between SPAD and yield (*r* = -0.018–424**). We could prove moderate correlations (*r* = 0.4**–0.8**) between LAI values and yield at certain measurement times, as opposed to the research findings of Oikeh et al. (1998), Bavec and Bavec (2002) and Ma et al. (2005). The Pearson correlation analysis showed that hybrid (-0.450–0.374**) and plant density (0.284–0.517**) had very weak correlations with yield, whereas we could prove a moderate correlation between fertilization and yield (0.247–0.672**).

Acknowledgments

Supported by the GINOP-2.2.1-15-2016-00001 project

5 References

AHMAD, M. et al. (2010). Agro-physiological traits of three maize hybrids as influenced by varying plant density. *The Journal of Animal and Plant Sciences*, 20(1), 34–39

AZEEZ, J.O. (2009). Effect of nitrogen application and weed interference on performance of some tropical maize genotypes in Nigeria. *Pedosphere*,19(5), 654–662. https://doi.org/10.1016/S1002-0160(09)60160-0

BAVEC, F. and BAVEC, M. (2002). Effects of plant population on leaf area index, cob characteristics and grain yield of early maturing maize cultivars (FAO 100–400). *European Journal of Agronomy*, 16(2), 151–159. https://doi.org/10.1016/S1161-0301(01)00126-5

BENCZE, G. and FUTÓ, Z. (2017). Examination of the relationship between the relative chlorophyll content, leaf area index and yield of maize in a monoculture long term experiment. *Recent social and economic processes*, 12(3), 21–28.

BERZSENYI, Z. et al. (2011). Long-term effect of crop production factors on the yield and yield stability of maize (*Zea mays* L.) in different years. *Acta Agronomica Hungarica*, 59(3), 191–200 (2011). https://doi.org/10.1556/AAgr.59.2011.3.1

BERZSENYI, Z. (2010). Use of growth analysis to describe the N fertiliser responses of maize (*Zea mays* L.) hybrids. *Acta agronomica hungarica: a quarterly of the hungarian academy of sciences: an international multidisciplinary journal in agricultural science*, 58(1), 95–101.

CARLONE, M.R. and RUSSEL, W.A. (1987). Response to plant densities and N levels for four maize cultivars from different ears of breeding. *Crop Science*, 27(3), 465–470. https://doi.org/10.2135/cropsci1987.0011183X002700030008x

CARTER, G.A. (1994). Ratios of leaf reflectances in narrow wavebands as indicators of plant stress. *International Journal of Remote Sensing*, 15(3), 697–703. https://doi.org/10.1080/01431169408954109

DÓKA, L. F. (2015). The impact of different crop years on the water balance of the soil in mono- and biculture maize in different crop densities. *Crop production*, 64(2), 5–28.

D'HAENE, K. et al. (2007). Nitrogen and phosphorus balances of Hungarian farms. *European Journal of Agronomy*, 26(3), 224–234. https://doi.org/10.1016/j.eja.2006.10.005

ESECHIE, H. A. (1992). Effect of planting density on growth and yield of irrigated maize (*Zea mays*) in the Batinah Coast region of Oman. *The Journal of Agricultural Science*, 119(2), 165–169. https://doi.org/10.1017/S0021859600014076

FULTON, J.M. (1970) Relationship among soil moisture stress, plant populations, row spacing and yield of maize. *Canadian Journal of Plant Science*, 50(1), 31–38. https://doi.org/10.4141/cjps70-005

HAEGELE, J.W. et al. (2014). Row arrangement, phosphorous fertility, and hybrid contributions to managing increased plant density of maize. *Agronomy Journal*, 106(5), 1838–1846. https://doi.org/10.2134/cs2014-47-6-11

HAWKINS, T.S. et al. (2009). Modeling the Relationship between Extractable Chlorophyll and SPAD-502 Readings for Endangered Plant Species Research. *Journal for Nature Conservation*, 17(2), 123–127. https://doi.org/10.1016/j.jnc.2008.12.007

KÖRSCHENS, M. (2006). The importance of long-term experiments for soil science and environmental research – a review. *Plant Soil Environ*., 52(special issue), 1–8.

MA, B.L. et al. (2005). Comparison of Crop-Based Indicators with Soil Nitrate Test for Maize Nitrogen Requirement. *Agron. Journal*, 97(2), 462–471. https://doi.org/10.2134/agronj2005.0462

MARTINEZ, D.E. and GUIAMET, J.J. (2004) Distortion of the SPAD 502 chlorophyll meter readings by changes in irradiance and leaf water status. *Agronomie*, 24(1), 41–46. https://doi.org/10.1051/agro:2003060

MICSKEI, GY. et al. (2012). Relationships between maize yield and growth parameters in a long-term fertilization experiment. *Acta Agronomica Hungarica*, 60(3), 209–219. https://doi.org/10.1556/AAgr.60.2012.3.4

NAGY, J. (2010). The present and the future of cultivation of maize. *Crop Production*, 59(3), 85–111. https://doi.org/10.1556/Novenyterm.59.2010.3.6

NOVOA, R. and LOOMIS, R.S. (1981). Nitrogen and Plant Production. *Plant and Soil*, 58(1–3), 177–204. https://doi.org/10.1007/BF02180053

OIKEH, S.O. et al. (1998). Nitrogen Fertilizer Management Effects on Maize Grain Quality in the West African Moist Savanna. *Crop Science*, 38(4), 1056–1061. https://doi.org/10.2135/cropsci1998.0011183X003800040029x

PEPÓ, P. and MURÁNYI, E. (2014) Plant density impact on grain yield of maize (*Zea mays* L.) hybrids on chernozem soil of the Eastern Hungary. *Columella-Journal of Agricultural and Environmental Sciences*, 1(2), 95–100. https://doi.org/10.18380/SZIE.COLUM.2014.1.2.95

PEPÓ, P. and MURÁNYI, E. (2015). Examinations of cultivated area of different maize (*Zea mays* L.) hybrids. *Crop production*, 64(2), 1–17.

REMISON, S.U. and LUCAS, E.O. (1982). Effects of planting density on Leaf Area and Productivity of Two Maize Cultivars in Nigeria. *Experimental Agriculture*, 18(1) 93–100. https://doi.org/10.1017/S0014479700013478

RUSSEL, W.A. (1991). Genetic improvement of maize yields. *Adv. Agron*., 46(1), 245–298. https://doi.org/10.1016/S0065-2113(08)60582-9

SÁRVÁRI, M. and PEPÓ, P. (2014). Effect of Production Factors on Maize Yield and Yield Stability. *Cereal Research Communications*, 42(4), pp. 710–720. https://doi.org/10.1556/CRC.2014.0009

SU, Y.J. et al. (2012). Effects of planting density on growth and yield of summer maize Xundan 28. *Acta Agriculturae Jiangxi*, 24(6), 49–50, 53.

SZÉLES, A. (2008). The effect of crop year and fertilization on the interaction between the spad value and yield of maize (*Zea mays* l.) within non-irrigated conditions. *Cereal Research Communications*, 36(Supll. 5), 1367–1370.

SZÉLES, A. et al. (2011) Effect of N fertilisation on the chlorophyll content and grain yield of maize in different crop years. *Crop Production*, 60(Suppl.), 161–164.

SZÉLL, E. et al. (2010). Results of maize fertilization experiments on 4 different soil type. *Crop Production*, 59(4), 41–61.

TAJUL, M.I. et al. (2013). Influence of plant population and nitrogen-fertilizer at various levels on growth and growth efficiency of maize. *The Scientific World Journal*, 2013(1), 1–9. https://doi.org/10.1155/2013/193018

VALADABADI, S.A. and FARAHANI, H.A. (2010). Effects of planting density and pattern on physiological growth indices in maize (*Zea mays* L.) under nitrogenous fertilizer application. *Journal of Agricultural Extension and Rural Development*, 2(3), 40–47.

VÁNYINÉ, Sz. A. et al. (2012). Irrigation and nitrogen effects on the leaf chlorophyll content and grain yield of maize in different crop years. *Agricultural water management*, 107(1), 133–144.

VÁRI, E. and PEPÓ, P. (2011). Effect of agro-technical factors on the agronomy properties in long term experiment. *Crop Production*, 60(4), 115–130. https://doi.org/10.1556/Novenyterm.60.2011.4.6

YU, H. et al. (2010). Evaluation of SPAD and Dualex for In-Season Maize Nitrogen Status Estimation. *Acta Agronomica Sinica*, 36(5), 840–847. https://doi.org/10.3724/SP.J.1006.2010.00840T