Results of the sensory analysis of precision maize production

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SUMMARY

This research was carried out in 2018, at the Látókép Experimental Station of the University of Debrecen in a moderately warm and dry production area, on deep humus layered medium-hard calcareous chernozem soil. In the scope of the research, the chlorophyll content of maize (Zea mays L.) was examined under field circumstances by means of local sensory measurements and we were looking for correlation between the obtained values and the amount of yield. Our measurements were carried out with Minolta SPAD-502 and GreenSeeker devices at 3 measurement times (4 leaf stage, 10 leaf stage and silking). It was found that phenological phases had an effect on the obtained SPAD and NDVI values and were in a slightly significant correlation with the yield. The most significant correlation was found between the results obtained during silking and the amount of yield. This may be because the least time has passed between the measurement time and harvest. Results obtained during the 10-leaf stage show excessive values in each case, which can be due to a measurement error. It was found that the phenological phase had an effect on the correlation of SPAD and NDVI values and the amount of yield. As the phenological phase progressed, the correlation between the measured results and yield has increased.

Keywords: SPAD, NDVI, maize, chlorophyll

INTRODUCTION

At present, agriculture has to face numerous challenges. Quantity and quality of the produced goods must meet the ever-increasing demands (Elarab et al., 2015; Murray et al., 2018, Muhammad and Misbahullah, 2018). Direct effects of climate change are felt in our own lives, from the more and more frequent meteorological anomalies to the increased frequency of extreme dry periods. To reduce the adverse effects of climate change, technology provided by precision agriculture is an excellent opportunity, as optimization of agro-technical elements reduces disadvantageous climatic impacts, thus increasing the resistance of the agro-ecosystems of cereals (Pepó, 2010). The application of precision farming technologies is increasingly spreading in the cultivation of various agricultural crops, including maize production. The amount of data received from field measurements provides opportunity for farmers to gain new information constantly, to make responsible decisions, or to perform yield estimations even during a very early phenological phase. The efficiency of crop production and maize cultivation is also influenced by genotype, agro-technology and the environment. Plant sensory measurements can be used to determine how plants react to certain environmental effects allowing farmers to intervene in time. The chlorophyll content of plants is in close correlation with the amount of yield (Ványiné et al., 2012; Montemurro et al., 2006).

Barasel et al. (2017) found that both SPAD and NDVI values are suitable for the determination of chlorophyll content. Multiple authors have found positive correlation between the SPAD values measured during the vegetation period and the amount of yield (Markwell, 1995; Zhang, 2016; Reyes, 2017). The NDVI value is in close correlation with plant health (Tucker, 1979; Elarab et al., 2016) and its chlorophyll content; therefore, it is suitable for physiological measurements. Sid'ko et al. (2016) found that there is a close correlation between the chlorophyll content of the plant and yield (r = 0.8).

In the course of this research, the objective was to measure chlorophyll by means of plant sensors and to examine the correlation between the measured data and yield.

MATERIAL AND METHODS

Description of the experimental site

The examinations were carried out in 2018, at the Látókép Experimental Site of the University of Debrecen, Faculty of Agricultural and Food Sciences and Environmental Management (47° 33'N, 21° 26'S, 111 m), in a moderately warm and dry production area, on deep humus layered medium-hard calcareous chernozem soil. SPAD and NDVI measurements were performed in the field trial of the Institute of Land Use, Technology and Regional Development of the University of Debrecen. The complex long-term trial has a split-split plot design. The main plots have tillage and irrigation variants without replications. On the subplots, there are different artificial fertilizer doses and hybrids, while on the sub-subplots, 60 and 80 thousand plant ha^{-1} density treatments are present.

Equipment used in the scope of the research
Minolta Spad-502

In the course of the study, the amount of relative chlorophyll content of leaves was examined in a maize population. The SPAD-502 manufactured by Minolta measures the "greenness" of the leaf, or namely its relative chlorophyll content expressed in SPAD (Soil Plant Analysis Development) values. The SPAD value is calculated from the intensity of the red and infrared light transmitted through the leaf. Its operating

principle was developed by Inada (1963); the device determines the transmission of light through the leaf at 650 and 940 nm wavelengths. It calculates chlorophyll content, namely SPAD, ranging from 1 to 100 (Minolta Camera Co. Ltd., 1990). The device includes two light sources (LED) that emit a red light beam (650 nm) and an infrared light beam (940 nm) during the measurement. Chlorophyll molecules absorb a portion of the red light, but they let infrared light pass through, allowing the device to calculate an index (SPAD value) based on the proportion of the intensity of light beams entering the sensor, which varies between 1 and 100. It can be concluded based on previous studies that SPAD value is closely related to the chlorophyll and nitrogen content of leaves. Based on the regression equations determining the correlation between SPAD value and the measured biological parameters (chlorophyll content, nitrogen content, yield), it is possible to estimate nitrogen supply, chlorophyll content and yield. The tests were carried out at 3 measurement occasions at the 4-leaf and 10-leaf stage of maize and silking. The measurements were performed in 10 replications on the top leaf in the case of the 4-leaf and 10-leaf stages, and the leaf located opposite the ear in the case of silking.

Trimble GreenSeeker

The handheld Greenseeker is a device with an active light source. Method of determination: $NDVI=(NIR-R)/(NIR+R)$, where NIR is the near infrared (730-1100 nm) and R is the red (580-680 nm) wavelength range. The device illuminates the plants every 0.9 seconds and measures the reflected red and near infrared signal intensities. Based on the obtained values, normalized differentiated vegetation index (NDVI) is calculated. With the help of the NDVI, useful information can be collected about the condition of the plants which supports decisions related to the application of the given agro-technical intervention. NDVI is closely related to plant health (Tucker, 1979; Elarab et al., 2016) and its chlorophyll content,

therefore, it is suitable for plant physiology measurements.

The statistical analysis was performed in R statistical environment (RCore Team, 2018), by means of RStudio (RStudio Team, 2016) graphical interface using the "*agricolae*" (de Mendiburu, 2016) software package. In the study, the 80,000 plants ha^{-1} treatment was selected from the experimental data. Linear regression analysis was performed to analyse the correlation between SPAD and yield, NDVI and yield, and manually measured SPAD and NDVI values. The example code for this analysis in the R statistical environment is the following:

model <- with(database, lm(measured_variable1 ~ measured_variable1))
summary(model)
anova(model)

RESULTS AND DISCUSSION

Correlation of measured SPAD values and yield

Based on the regression analysis, it can be concluded that phenological phases have an effect on the chlorophyll content of the maize leaf. Joint analysis of the amount of yield and the results obtained in various phenological phases indicates that there is a low ($r = 0.21$) significant ($p <0.05$) correlation between the obtained values (*Table 1*). It was our intention to investigate the cause of the weak interaction; therefore, the correlations between the SPAD values measured in different phenological phases and yield were analysed one by one. Yield was influenced by the measured SPAD values at 4%. A significant weak correlation was found in 4 leaf stage ($r = 0.36$). A similar tendency was observed to the one recorded by Ragán (2017), namely with the progressing of the growing season, correlation of SPAD values and yield increased. There was a weak correlation between SPAD values obtained at 10 leaf stage and yield. During silking, the correlation between SPAD values and yield became closer; the SPAD value was 25% dependent on the amount of yield.

Table 1

Correlation of SPAD and yield in different phenological phases

SPAD – Yield	r^2	r^{2}%	r	Significance
All stages combined	0.04336	4.336	0.208231	0.00452 **
4 leaf stage	0.1307	13.07	0.361525	0.00419 **
10 leaf stage	0.054	5.4	0.232379	0.050 ns
silking	0.2517	25.17	0.501697	6.62 x 10-05 ***

Correlation of measured NDVI values and the amount of yield

In addition to the SPAD values, correlation between NDVI values and yield was also examined; it was found that there is a correlation between the measured NDVI values and the amount of yield. As the *Table 2* show in 4-leaf stage, the phenological phase significantly influenced the measured NDVI values. The highest

correlation ($r = 0.34$) was obtained in the case of the 4-leaf stage. We encountered a reverse correlation in 10 leaf phenological phase. Results of the 10-leaf stage opposed those included in technical literature, which may be due to a measurement error as the results obtained in the other measurements follow the previously established trend. During silking, a weak correlation was found between the obtained results.

Table 2

Correlation of NDVI values and yield in different phenological phases

NDVI – Yield	r^2	$r^2\%$	r	Significance
All measurements	0.002181	0.2181	0.046701	0.247 ns
4-leaf stage	0.1124	11.24	0.34	0.00762 **
10-leaf stage	-0.01052	-1.052	1.025671	0.5062 ns
silking	0.08641	8.641	0.29	0.0176 *

Combined effect of SPAD and NDVI on the amount of yield

Furthermore, correlation between the combined effect of SPAD and NDVI values with yield was also examined as the *Table 3* shows. All measurement results show a moderate correlation with yield. During silking, the measured SPAD and NDVI values were also moderately correlated with yield. The reason for the moderate correlation during silking may be that the least time between measuring and harvesting has passed in this case.

Table 3

Correlation of SPAD and NDVI values with the amount of yield

	r^2	$r^2\%$	r	Significance
Total	0.2809	28.09	0.53	2.452
4-leaf stage	0.2242	22.42	0.473498	0.000579
10-leaf stage	0.0402	4.02	0.200499	0.1317
silking	0.2428	24.28	0.492747	0.000312

Correlation of the measured SPAD and NDVI values

Correlation between the SPAD and NDVI values was also studied during the evaluation of the experiment. Examining the data, it can be stated that the most significant correlation occurred in the case of results measured during silking (r = 0.48). Measurement time, namely the phenological phase, had an impact on the correlation of SPAD and NDVI values (*Table 4*). Correlation improved with the progression of the phenological phase.

Table 4

SPAD and NDVI values compared to each other

SPAD and NDVI correlation	r^2	$r\%$	r	Significance
Total	0.2809	28.09	0.53	2.452
4-leaf stage	0.01097	1.097	0.104738	0.5175
10-leaf stage	0.01023	1.023	0.101143	0.4991
silking	0.2351	23.51	0.484871	0.0001202

CONCLUSIONS

It was found that phenological phases had an effect on the obtained SPAD and NDVI values and were in a weak significant correlation with the amount of yield. Both the SPAD and NDVI data show that the highest correlation was found between the results obtained during silking and the amount of yield. This may be caused by the fact that the least time has passed between measurement time and harvesting in this case. Results obtained during the 10-leaf stage show excessive data in each case, which can be due to a measurement error. There was a significant correlation between the relationship of SPAD and NDVI measurements and the phenological phases.

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