doi: 10.17221/676/2015-PSE

Connection between normalized difference vegetation index and yield in maize

T. Spitkó, Z. Nagy, Z.T. Zsubori, C. Szőke, T. Berzy, J. Pintér, C.L. Marton

Agricultural Institute, Centre for Agricultural Research, Hungarian Academy of Sciences, Martonvásár, Hungary

ABSTRACT

The preliminary estimation of expected yields and the accuracy of this evaluation provide information for decisions related to the harvest. The quantification of predictions makes it possible to estimate the accuracy of the prognosis. The yields that can be expected at the end of the vegetation season depend on the intensity of the photosynthetic activity. Numerous devices are now available to measure the quantity of photosynthetically active pigments in leaves, including the instrument GreenSeeker^{TM} used in the present experiments, which records the value of normalized difference vegetation index. The present work attempted to answer the question of whether the yield could be predicted by means of multiple measurements during the vegetation period. Other questions raised were which phenophase was the most suitable for predicting yield, how values recorded at different times correlated with the yield, whether the strength of this correlation increased or decreased as harvest approached, and whether yield could be estimated at flowering, or in even earlier phenophases.

Keywords: chlorophyll meter; yield components; yield prediction; *Zea mays* L.

The estimation of expected crop yields is an important field of agronomic research. The quantity of yield that can be harvested from a given growing area is determined mainly by the weather, the quality and nutrient supplies of the soil, and the genetic traits of the crops (Parry and Hawkesford 2010). Models now exist that consider the effect of weather, nutrient supply and plant physiological parameters on the yield obtained (Raun et al. 2001).

The first photometric studies on crop stands dated from the late 1970s and involved winter wheat (Tucker 1979). It was already clear from these first experiments that measurements on the light reflected from or absorbed by the plants could be used to draw conclusions on the total aboveground biomass and on its photosynthetic activity, as the properties of absorbed and reflected light were determined largely by the quantity of chlorophyll (Rouse et al. 1974). The index derived from the light absorption and reflection ability in the near infrared (λ = 700–1300 nm) and visible red (λ = 500–700 nm) ranges is known as the normalized difference vegetation index (NDVI) (Govaerts and Verhulst 2010):

$$NDVI = \frac{R_{NIR} - R_{RED}}{R_{NIR} + R_{RED}}$$

Where: NIR – near infrared radiation reflectance; RED – visible red radiation reflectance.

This index exhibits a strong correlation with the crop yield data in certain physiological phases, but the correlation is weaker if the measurements are not made in the right phenophase. Previous work has shown that the NDVI value is most closely correlated with the nitrogen content of the leaves (Raun et al. 2001). In cases where the water supplies are the main limiting factor for plant growth, however, it may provide information on drought tolerance (Govaerts and Verhulst 2010). Drought is also the environmental effect causing the greatest yield losses in maize production. Above-optimum temperatures and water deficit

Supported by the DROPS EU FP7 Collaborative Project and additional EU_ BONUS_12-1-2012-0017 action.

doi: 10.17221/676/2015-PSE

may result in substantial changes in the physiological status of the plants and these changes are in good correlation with the chlorophyll content of the plants (Bänziger and Araus 2007). The plant chlorophyll content can be easily measured using non-destructive methods, such as those based on NDVI measurements, which have also been applied to examine the resistance of maize genotypes to drought stress (Aparicio et al. 2000). In the present experiments a GreenSeeker^{TM} instrument was used, which is designed for automatic calculation of NDVI values (Raun et al. 2002). This index is used for yield estimation both in nitrogen fertilisation experiments and in drought stress studies. It was established by Teal et al. (2006) that in the early stages of development NDVI values are not always closely correlated with yields. However, while clearly defined, close correlations were found with the nitrogen supplies, it was found in tests on drought resistance that the rate of senescence and tolerance of water deficit did not always exhibit a strong correlation with the index. It was therefore considered important to test the NDVI values of 85 maize cultivars from the late vegetative phase until maturity and to compare these with the yield data. The aim of the study was to determine whether yield levels could be predicted using optical tools, whether there was any correlation between quantified photosynthetic activity data and the yield achieved, how strong this correlation was.

MATERIAL AND METHODS

The experiments were laid out in a random block design with two (irrigated: WW) or three (non-irrigated: WD) replications. The plot size was 5.6 m, row distance 0.73 m (calculated plant number was cca. 65 000 plants/ha). The cultivars were collected in the framework of the Drops project UMR INRA-SUPAGRO, with an European flint tester. A total of 85 genotypes were included in the experiment (Table 1).

Irrigation was only performed on the WW plot, 4–5 times. Linear irrigation equipment was used, which supplied a uniform quantity of water along the whole length of the plot. On each occasion 40–50 mm irrigation water was used. The watering was sufficient in the WW blocks (no drought symptomes occured) while the WD plots suffered from drought during the flowering and grain filling period (leaf rolling, seed abortion or asynchronous flowering were observed).

The weather condition was favourable for testing drought tolerance in all three years. In 2011 the total amount of precipitation was half (260 mm) of the 30-year's average (560 mm). During the season, the monthly average temperatures (19.96°C in June and 21.56°C in August) were higher than the usual ones (19.77°C and 20.73°C). The next year (2012) was dry again, the total amount of precipitation was 334 mm and this, with the water shortage of the previous year caused serious drought during the whole summer period. The average temperature was higher than usual, and the daily maximum temperature often went above 35°C in July and August. 2013 was also arid, the precipitation was less than usual (477 mm), the average monthly temperature was 22.17°C in Jule (30 year's average is 21.50°C) and 22.10°C in August. The drought was present in all three years during the vegetation period and mainly at flowering and grain filling time.

Table 1. Female components of the examined cultivars (male parent was an European flint tester in all cases)

A310	B113	EC169	EZ47	F912	LH38	NC290	PH207	W23
A347	B37	EC334	F1808	F918	LH74	NDB8	PHB09	W602S
A374	B73	EP10	F7001	F924	LH82	NQ508	PHG39	W64A
AS5707	B84	EP2008-18	F7025	F98902	Lp5	Oh02	PHG47	W9
B100	B89	EP51	F7028	FR19	ML606	Oh33	PHG83	W95115
B104	B97	EP52	F7081	HMV5325	Mo17	Oh43	PHG86	
B105	B98	EP55	F712	HMV5405	MS153	Os426	PHH93	
B106	CO109	EZ11A	F748	HMV5422	MS71	Pa405	UH_P089	
B107	DK78371A	EZ37	F838	LAN496	N25	PB116	UH_P128	
B108	DKFBHJ	EZ40	F894	LH145	N6	PB98TR	UH250	

doi: 10.17221/676/2015-PSE

The measurements were performed on a fine, sunny, wind-free day on dry plant surfaces, holding the sensor of the GreenSeeker^{TM} 50 cm above the stand (Govaerts and Verhulst 2010). The measurements were carried out during the vegetation season at V8 (8-leaf stage), 50% tasselling, and 15, 30, 45 days after anthesis stages.

Yield data were calculated after harvesting with a small-plot combine. The instrument used for the measurements recorded the yield per plot (g) and the grain moisture (%) at the same time. Statistical analysis was performed using the Agronomix Inc. Agrobase software (Winnipeg, Manitoba, Canada) and the Genstat programs (Hemel Hempstead, UK). Linear correlation analysis was used to reveal correlations between the parameters.

RESULTS AND DISCUSSION

The first instrumental measurements of NDVI were carried out when the plants were in the 8-leaf stage, prior to 50% tasselling. The values recorded for the 85 cultivars ranged from 0.73–0.86, with a grand mean over the whole experiment of 0.81. Both irrigation and the year had a significant effect on the development of the photosynthetically active leaf area. Plants raised under irrigated conditions had a mean value of 0.83, while those grown under rain-fed conditions had an NDVI of 0.78. Although statistical analysis showed significant differences between the years, these differences were not substantial from the physiological point of view (NDVI values of 0.81–0.82). When the measurements were repeated at 50% tasselling, the results showed a slight reduction in the photosynthetically active leaf area. On this occasion, the grand mean was 0.76, with a range of 0.68 to 0.83. The irrigated stand again exhibited higher photosynthetic activity (0.77), while the mean value was lower without irrigation (0.74). The mean NDVI values recorded at flowering were almost the same in the three years (0.75–0.76).

Measurements were made again 15 days after tasselling, when the grand mean was 0.60 (with

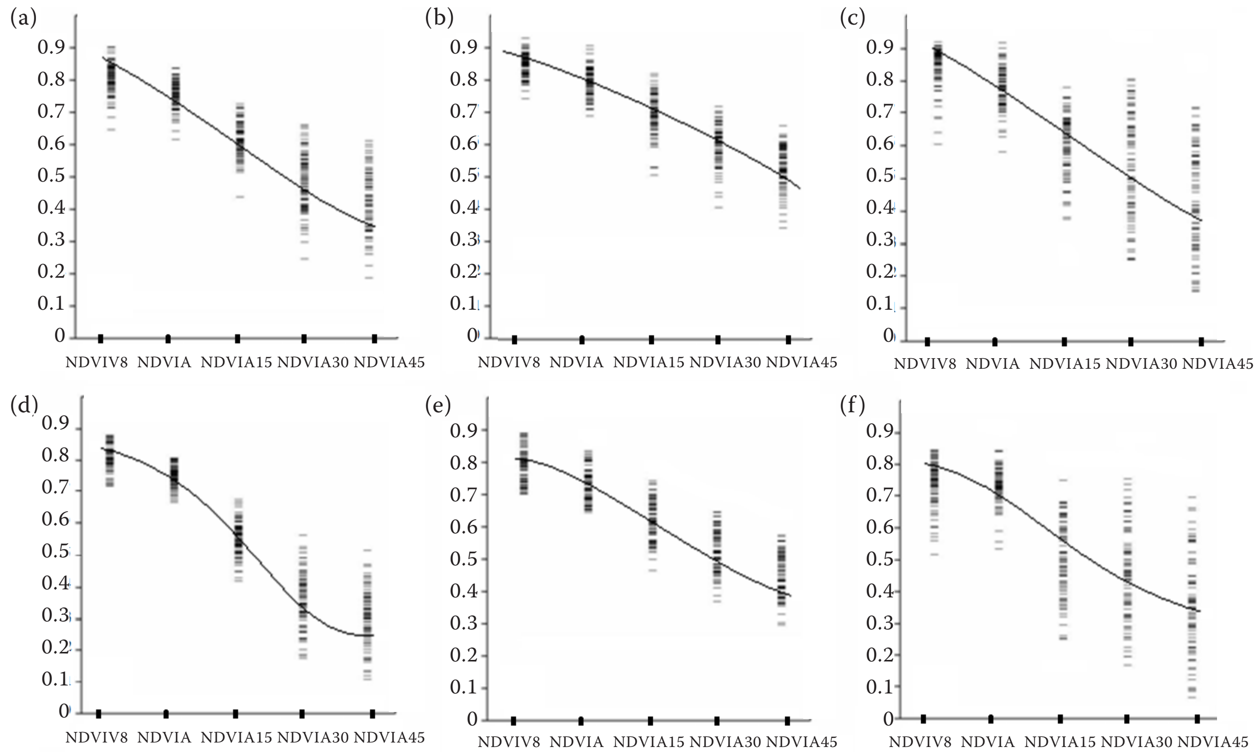

Figure 1. The normalized difference vegetation index (NDVI) values of the 85 genotypes visualized in frequency distribution diagram in three years (a, d – 2011; b, e – 2012; c, f – 2013), in irrigated (a, b, c) and rain fed (d, e, f) conditions. NDVI V8 – NDVI value at 8-leaf stage (V8 stage); NDVIA – NDVI value at 50% tasseling; NDVIA15 – NDVI value 15 days after 50% male flowering; NDVIA30 – NDVI value 30 days after 50% male flowering; NDVIA45 – NDVI value 45 days after 50% male flowering. The density of the lines presents the frequency of the data and the extension of the column shows the expansion of the data occurrence

doi: 10.17221/676/2015-PSE

extreme values of 0.42 and 0.71), indicating a further decline in photosynthetic activity. The effect of irrigation became more pronounced (0.56 on rain-fed and 0.64 on irrigated plots). At this stage the favourable effect of water supplies was clear, plants grown under optimum conditions having a larger photosynthetically active leaf area than their non-irrigated counterparts (Figure 1). This is important, because crop yield is generally correlated with canopy development. In this way this index can be used to develop a relationship to yield (Zhang et al. 1999).

The year effect was also greater, with NDVI values of 0.59 in 2011, 0.55 in 2013 and the highest value (0.66) in 2012. In all three years, irrigation significantly increased the photosynthetically active leaf area.

Thirty days after flowering, the grand mean of the experiment was 0.50, with a range of 0.33–0.66. The favourable effect of irrigation continued to be manifested, with values of 0.46 for the rain-fed and 0.54 for the irrigated treatment.

The last measurements of NDVI were made 45 days after tasselling, shortly before the kernels reached biological maturity. At this stage the grand mean was 0.42, with values ranging from 0.25 to 0.58. The favourable effect of irrigation could still be detected: on average the photosynthetic activity had a value around 0.08 higher on irrigated plots.

The year effect was even greater at this measuring date, with values of 0.49 in 2012, 0.41 in 2013 and 0.37 in 2011. Irrigation considerably enhanced the photosynthetically active area of the plants 45 days after tasselling in all three years. Raun et al. (2001) established a nondestructive estimation of yield potential using spectral measurements in winter wheat based on the concept developed by Tucker (1979). NDVI is highly correlated with total aboveground biomass yield potential could be predicted as a result of the strong relationship between NDVI and grain yield.

The NDVI values recorded at the various measurement times were compared with the yields obtained at harvest. The results of linear correlation analysis are illustrated in Figure 2.

The correlation was of medium strength, indicating a significant relationship between the measured parameters and the yield. The correlation was smallest before flowering (r = 0.30, representing a weak, almost negligible correlation). This strengthened at 50% tasselling (r = 0.36), reaching a maximum 15 days after flowering (r = 0.52). Two and four weeks later the values were around 0.47–0.48, indicating a correlation of medium strength. The linear correlation between the yield and the NDVI value was moderate (0.22) in the early developmental stages in June, the highest during the flowering time (0.66) and after this period the values decreased to 0.63 and 0.31 in the grain filling and maturity stage, respectively (Zhang et al. 1999).

The results suggest that the correlations are weaker under rain-fed conditions and are strengthened by irrigation. The year also had a significant effect, with weaker correlations (0.13–0.23) in 2012, which was unfavourable for maize production, and closer correlations in favourable years (0.14–0.52).

It can be stated on the basis of the yields recorded in the experiments that when maize was grown in dry years without irrigation the yield was considerably smaller (a yield depression of 27.1% compared with the irrigated plots, averaged over the genotypes). Several studies done under restricted management situations such as irrigation and limited soil variability have demonstrated the relationship of NDVI and other vegetative indices with final grain yield in maize. Mean NDVI values generally peak at tasselling, however, values during the mid-grain filling period were found to be the most correlated to final grain yield. This period displays the greatest potential for estimating yield (Shanahan et al. 2001).

The NDVI value reached a maximum prior to flowering, and a slight decreasing tendency could be observed by 50% tasselling. Further slight reductions were observed 15 and 30 days after flowering, though the extent of this decrease depended on the water supplies. In a favourable year or in the case of irrigated production all the genotypes exhibited a similar slow, uniform reduction in the quantity of photosynthetically active molecules. Greater differences were observed in a dry year without irrigation, when the drought tolerance of the individual genotypes became more important. The rate at which the photosynthetically active area declined accelerated and considerable differences could be observed between the hybrids in the later stages of the vegetation period. Irrigation or favourable rainfall supplies substantially increased the photosynthetically active leaf area recorded on

doi: 10.17221/676/2015-PSE

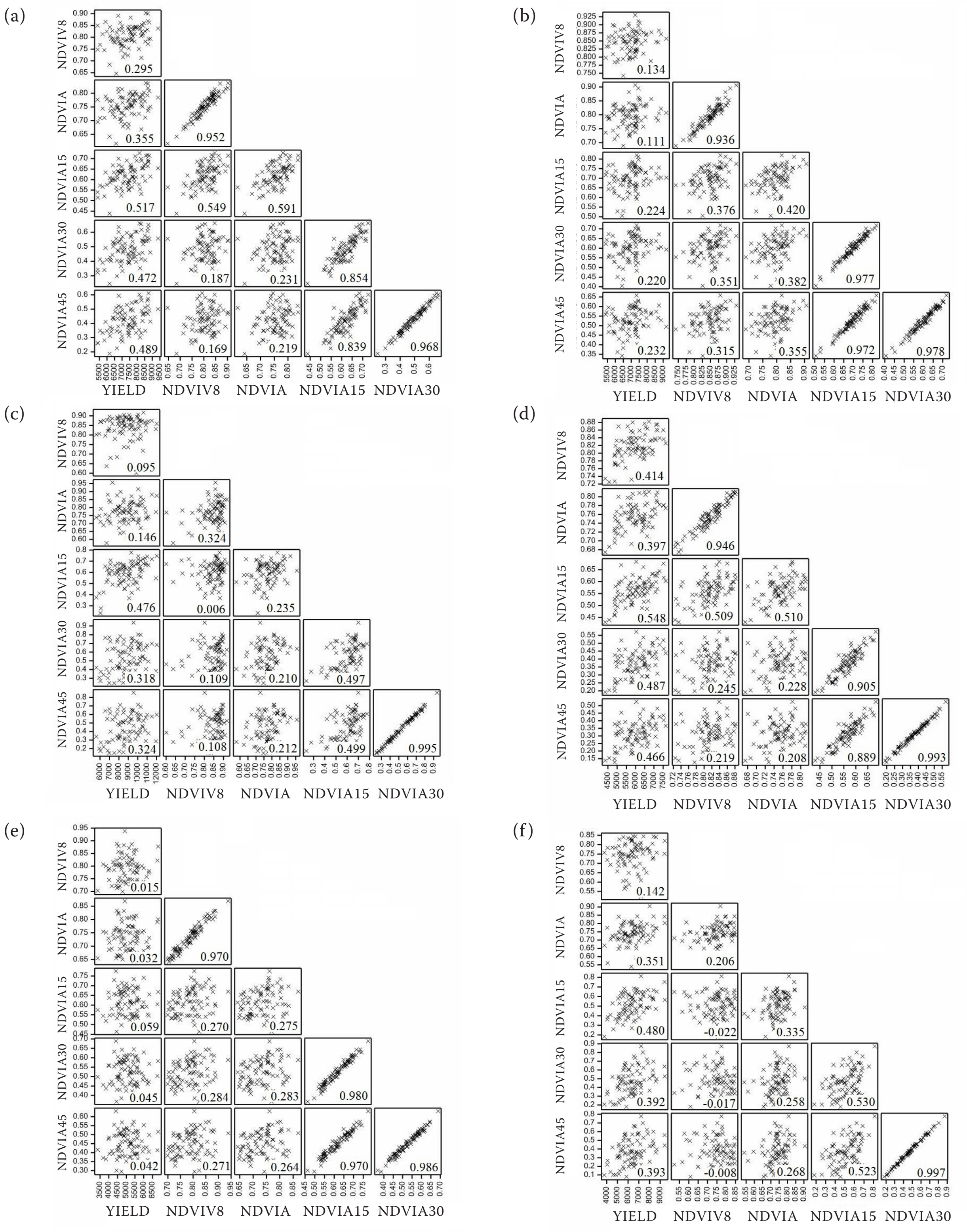

Figure 2. Linear correlation matrix of the normalized difference vegetation index (NDVI) values and yield in three years (a, d – 2011; b, e – 2012; c, f – 2013), in irrigated (a, b, c) and rain fed (d, e, f) conditions. NDVI V8 – NDVI value at 8-leaf stage (V8 stage); NDVIA – NDVI value at 50% tasseling; NDVIA15 – NDVI value 15 days after 50% male flowering; NDVIA30 – NDVI value 30 days after 50% male flowering; NDVIA45 – NDVI value 45 days after 50% male flowering, YIELD – harvested crop (kg). The values of the correlation coefficient (r) are indicated in the boxes, yield values are in kilogram, NDVI is dimensionless value

doi: 10.17221/676/2015-PSE

the 45th day after flowering, indicating that the production of assimilates was continuing, leading to higher yields in such years. Temporal water shortage is not always reflected by lower vegetation cover. However, water shortage at critical stages – before and during flowering and from flowering to ripening – has a greater effect on yield than on NDVI, even if it occurred during a short period of time, of which this may have been the case (Sawasawa 2003).

The phenological status of the plants is also important for yield estimation. Measurements performed using the GreenSeeker™ instrument indicated that the NDVI values obtained for plants in the 8-leaf stage differed greatly as a function of the year and the presence or absence of irrigation. Correlation analysis showed that the correlation between the yield and the NDVI values measured in this phenophase was weak or negligible.

The results obtained at 50% tasselling allowed clearer conclusions to be drawn on the likely yield, though these were still somewhat unreliable. Photosynthetic activity measurements made 15 days after flowering gave the best results, exhibiting the closest correlation with the final yield (r = 0.5–0.6, representing a moderately strong correlation). It also proved worthwhile to carry out measurements in later stages of the vegetation period, as the correlation was still significant, though weak (r = < 0.5). These conclusions are similar to those found by Zhang et al. (1999): weak correlation in the early stages, the highest during flowering and a slow decrease until the maturity stage.

It can be seen from the study that it is possible to predict expected yields at flowering or during the two weeks after flowering, when reliable results can be obtained respecting the yields to be expected at the end of the season.

The results thus suggest that NDVI values recorded after flowering are the most suitable for yield estimation, as there is a closer correlation between grain filling and the production of assimilates at this stage.

REFERENCES

Aparicio N., Villegas D., Casadesús J., Araus J.L., Royo C. (2000): Spectral vegetation indices as nondestructive tools for determining durum wheat yield. Agronomy Journal, 92: 83–91.

Bänziger M., Araus J. (2007): Recent advances in breeding maize for drought and salinity stress tolerance. In: Jenks M.A., Hasegawa P.M., Jain S.M. (eds): Advances in Molecular Breeding Toward Drought and Salt Tolerant Crops. Houten, Springer, 587–601.

Govaerts B., Verhulst N. (2010): The Normalized Difference Vegetation Index (NDVI) Greenseeker (TM) Handheld Sensor: Toward the Integrated Evaluation of Crop Management. Part A – Concepts and Case Studies. Mexico, CIMMYT, 1–16.

Parry M.A.J., Hawkesford M.J. (2010): Food security: Increasing yield and improving resource use efficiency. Proceedings of the Nutrition Society, 69: 592–600.

Raun W.R., Solie J.B., Johnson G.V., Stone M.L., Lukina E.V., Thomason W.E., Schepers J.S. (2001): In-season prediction of potential grain yield in winter wheat using canopy reflectance. Agronomy Journal, 93: 131–138.

Raun W.R., Solie J.B., Johnson G.V., Stone M.L., Mullen R.W., Freeman K.W., Thomason W.E., Lukina E.V. (2002): Improving nitrogen use efficiency in cereal grain production with optical sensing and variable rate application. Agronomy Journal, 94: 815–820.

Rouse J.W., Haas R.H., Schell J.A., Deering D.W. (1974): Monitoring vegetation systems in the Great Plains with ERTS. In: Proceedings Third ERTS-1 Symposium, NASA Goddard, NASA SP-35, 309–317.

Sawasawa H.L.A. (2003): Crop Yield Estimation: Integrating RS, GIS and Management Factors. [MSc thesis] Enschede, International Institute for Geo-Information Science and Earth Observation Enschede, 43–44.

Shanahan J.F., Schepers J.S., Francis D.D., Varvel G.E., Wilhelm W., Tringe J.M., Schlemmer M.R., Major D.J. (2001): Use of remote-sensing imagery to estimate corn grain yield. Agronomy and Horticulture – Faculty Publications, Paper 9.

Teal R.K., Tubana B., Girma K., Freeman K.W., Arnall D.B., Walsh O., Raun W.R. (2006): In-season prediction of corn grain yield potential using normalized difference vegetation index. Agronomy Journal, 98: 1488–1494.

Tucker C.J. (1979): Red and photographic infrared linear combinations for monitoring vegetation. Remote Sensing of Environment, 8: 127–150.

Zhang M., Hendley P., Drost D., O'Neill M., Ustin S. (1999): Corn and soybean yield indicators using remotely sensed vegetation index. In: Robert P.C., Rust R.H., Larson W.E., Robert P.C., Rust R.H., Larson W.E. (eds.): Precision Agriculture. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, 1475–1481.

Received on November 11, 2015
Accepted on May 24, 2016

Corresponding author:
Tamás Spitkó, Ph.D., Hungarian Academy of Sciences, Centre for Agricultural Research, Agricultural Institute, Brunszvik u. 2., H 2462 Martonvásár, Hungary; e-mail: spitko.tamas@agrar.mta.hu