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Evaluation of the correlation between weather parameters and the normalized difference vegetation index (NDVI) determined with a field measurement method

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Abstact—The level of nitrogen supply of a plant population can be quickly measured with non-destructive optical measurement devices and the differentiated determination of nitrogen shortage, while the replenishment of nitrogen can also be carried out. The level of nitrogen supply is based on the fact that the chlorophyll content of crops is in close correlation with nitrogen content and that the amount of chlorophyll can be easily measured on the basis of the light absorption of chlorophyll molecules. The successfulness of optical measurements can be influenced by the change of weather parameters; therefore, it is important to know the correlations between the measurement results and weather parameters when it comes to practical use.

The GreenSeeker Model 505 measurement device determines the relative chlorophyll content in the form of the normalized difference vegetation index (NDVI) calculated on the basis of the intensity of the reflected red and infrared rays of light from the crop population. The measurements were performed in alfalfa population with 10 replications at five measurement heights and four measurement times. The weather parameters were measured by a weather station located in the middle of the alfalfa population, and the correlations between the meteorological data and the NDVI values were examined.

During the statistical evaluation of the results, it was established that the NDVI measurement is primarily influenced by the relative humidity of the air, secondly by air temperature, and thirdly by wind speed. Relative humidity was in strong correlation with the NDVI values which were also influenced by the measurement height and time.

Regression was not significant in the case of the 20 cm measurement height, but the measurements above 40 cm height showed significant correlations. The correlation was shown to be strong at each measurement time, but the influence of humidity was the lowest at 11:00 and 14:00 in local time.

Key-words: alfalfa, NDVI, GreenSeeker, measurement height, measurement time, humidity

1. Introduction

In the vegetation period, the nitrogen demand of plants can be satisfied based on the actual nitrogen need of plants (*Fox et al.,* 1986; *Lemaire et al.,* 2008) determined by destructive laboratory analyses, or with non-destructive optical measurements (*Justes et al.,* 1997; *Feibo et al.,* 1998). The advantage of non-destructive optical measurement methods in comparison with laboratory analyses is that they are less expensive, quicker, and they have less labor need; therefore, it is worth using optical measurement methods in practice (*Blackmer* and *Schepers,* 1994; *Chapman* and *Barreto,* 1997; *Justes et al.,* 1997).

Optical measurement methods are based on the phenomenon that chlorophyll molecules absorb light in the visible red range, while they transmit light in the infrared range (*Brown,* 1969; *Murata* and *Sato,* 1978; *Yadava,* 1986); therefore, the indexes formed by proportionating infrared and red light intensities are in close correlation with chlorophyll content (*Roderick et al.,* 1996; *Zhang et al.,* 2009). The chlorophyll content is also in close correlation with the nitrogen content of leaves (*Evans,* 1983, 1989; *Houlès et al.,* 2007); therefore, the indexes calculated on the basis of the intensity of red light absorbed by chlorophyll molecules make it possible to conclude to the level of nitrogen supply of crops (*Iida et al.,* 2000; *Freeman et al.,* 2007; *Wright et al.,* 2007).

One of the most frequently used indexes is the normalized difference vegetation index (NDVI) which is determined by the following formula:

$$\mathrm{NDVI} = (NIR - RED)/(NIR + RED) \tag{1}$$

where *NIR* is the intensity of infrared light and *RED* is the intensity of red light (*Rouse et al.,* 1973). NDVI can either be determined by the spectral analysis of satellite images which makes it possible to perform regional examinations (*Szabó et al., 1998*; *Wang* and *Tenhunen,* 2004; *Knight et al.,* 2006; *Ren et al.,* 2008), and by using optical measurement devices used in the field that makes it possible to carry out plot-scale evaluation (*Hancock* and *Dougherty,* 2007; *Rambo et al.,* 2010).

The normalized difference vegetation index is in close correlation with the development of the plant population (*Aparicio et al.,* 2000; *Nambuthiri,* 2010), its chlorophyll content (*Roderick et al.,* 1996; *Cui et al.,* 2009), nitrogen content

(*Iida et al.*, 2000; *Wei et al.*, 2010), biomass production (*Hong et al.*, 2007, *Hancock* and *Dougherty*, 2007), and yield (*Teal et al.*, 2006; *Chung et al.*, 2008), therefore, NDVI measurements have practical forms of use. By temporally and spatially determining the normalized difference vegetation index, it is possible to monitor the development of the plant population (*Viña et al.*, 2004; *Martin et al.*, 2007), to survey the health status and level of nitrogen supply of the population (*Boegh et al.*, 2002; *Nambuthiri*, 2010), to determine the nitrogen shortage and replenish nitrogen in a differentiated way (*Singh et al.*, 2006), as well as to estimate the expected yield (*Teal et al.*, 2006).

The measurement results could be affected by the extent of plant coverage which results from the lower or higher reflectance of the soil (*Aparicio et al.*, 2002); therefore, it is important to examine the measurement methods in hoed and closed crop cultures. The primary objective of this research is to find the measurement method that can be used to determine the correlation between NDVI and nitrogen supply most accurately in closed canopy crop cultures. In our previous publications, we described the correlations between NDVI, measurement height, and measurement times (*Víg et al.*, 2010), while in this study, we evaluate the influence of weather parameters on NDVI measurements.

2. Material and methods

The examinations were carried out in the demonstration garden of the Institute of Horticulture of the University of Debrecen on chernozem soil. The measurement location was an alfalfa field of 729.8 m^2 (17.8 m × 41.0 m) in which 10 measurement points were determined by using Trimble GPS Pathfinder ProXH and ArcPad 7.0 software. Within the alfalfa population, 5–5 measurement points were selected with 1.2 m long bamboo sticks on the two sides of the plot, 2 meters from the edge of the plot and 7 meters from each other.

NDVI measurements were performed with GreenSeeker Model 505 on six occasions at four times (08:00, 11:00, 14:00, and 17:00 in local time) per occasion between May 27, 2010 and September 21, 2010 in the vegetation period. All measurements were performed in the previously selected measurement points, 20, 40, 60, 80, and 100 cm above the crop population.

A weather station was placed in the middle of the alfalfa population in order to measure weather parameters. The components of this station are: CR 1000 data logger and memory (Campbell Scientific Ltd., UK), 52202 rain-gauge (R. M. Young Co., USA), CS215 temperature and moisture meter (Campbell Scientific Ltd., UK), 05103-5 wind speed and wind direction meter (R. M. Young Co., USA), CMP3 radiation meter (Kipp & Zonen Inc., USA), LWS leaf moisture meter (Decagon Devices Inc., USA), CS616 soil moisture probe (Campbell Scientific Ltd., UK), and Model 107 soil temperature meter (Campbell Scientific Ltd., UK).

The examination site (Debrecen) is located in the northeastern part of the climate zone 9/a by the classification of *Ángyán* (1985). In the examination year (2010), the mean temperature of the spring-summer season was similar to the typical value of the climate zone (17.8 ^{o}C). The mean temperature in July was 0.8 ^{o}C higher than the 80-year average, while that of April was 0.9 ^{o}C higher. The amount of rainfall over the year (Oktober 1, 2009 – September 30, 2010) was 70% (377 mm) higher than the average value of the climate zone, while that of the autumn-winter period (Oktober 1, 2009 – March 31, 2010) was 44% (100 mm) higher, that of the spring-summer period (April 1, 2010 – September 30, 2010) was 88% (277 mm) higher, and the amount of precipitation during the hottest month of the year was 43% (29 mm) higher than the average of the climate zone.

The evaluation of the measurement results was done with SPSS for Windows 14.0. The correlation between NDVI values, mean difference in NDVI measurements ($MD_{\%}$), the variability of the measurement results ($CV_{\%}$) and various weather parameters were evaluated by using linear, quadratic, third degree exponential and logarithmic regression analyses at the 0.1%, 1.0% and 5.0% levels of significance, of which only the regression equations showing the strongest correlation are published.

The mean difference of the measurement results were expressed in percentages based on the following formula:

$$MD_{\%} = \sum[(M_x - M_y)/(M_y/100)], \qquad (2)$$

where $MD_{\%}$ is the mean difference, M_x is the mean of the results measured at x height, M_y is the mean of the results measured at y height, and $M_x > M_y$. The variability of measurement results were characterized by the coefficient of variation; therefore, standard deviation was expressed as a percentage of the mean value:

$$CV_{\%} = Sd/(M/100), \qquad (3)$$

where $CV_{\%}$ is the coefficient of variation, *Sd* is the standard deviation, *M* is the mean (*Senders,* 1958).

3. Experimental results

During the examination and evaluation of the correlations between the daily mean NDVI values determined in the various measurement points and the daily mean weather values, it was established that the daily mean NDVI values are in close positive correlation with the daily mean humidity. The correlation could be determined most accurately with a significant ($p < 0.01$), third degree regression equation which showed a 96.5% correlation between the daily mean NDVI values and the daily mean humidity. This correlation is strong; therefore, the results of the NDVI measurements can significantly differ from the real values depending on the humidity values. The other examined weather parameters (daily mean temperature, total global solar radiation, daily mean wind speed, evapotranspiration) did not influence the daily mean NDVI value (*Table 1*).

The respective weather parameters were assigned to the NDVI values measured at the various times (08:00, 11:00, 14:00, and 17:00 in local time), then the strength and nature of correlations were determined with regression analysis. There was no significant difference between the actual global solar radiation (measured at the time of the NDVI measurement) and the normalized difference vegetation index (*Table 1*), which reinforces the statement of the GreenSeeker Model 505 developers about the fact that light conditions do not influence the success of the measurement (*NTech Industries Inc.*, 2007). The actual humidity, temperature, and wind speed showed average-strong correlation with the results of the NDVI measurement. The actual humidity and the actual temperature also had significant ($p < 0.001$), close correlation with the normalized difference vegetation index. The value of the quadratic regression was 58.0% between the NDVI values and the actual humidity, and it was 53.3% between the actual temperature and the NDVI values. There was a significant ($p < 0.05$), third degree correlation between the actual wind speed and the NDVI values which shows that wind speed had a 43.5% influence on the success of measurements (*Table 1*).

Table 1. Evaluation of the correlations between NDVI and weather parameters

Weather parameters	R^2	R	F	Regression equation
Correlations between the daily mean NDVI values and the weather parameters				
NAP	0.956	0.978	32.9^{**}	$y = 0.091 + 0.015x - 9{*}10^{-7}x^3$
NÁH	0.344	0.587	0.787^{n}	–
NÖGN	0.168	0.410	0.304^{n}	–
NÁSZ	0.073	0.270	0.052^{n}	–
EPT_P	0.257	0.507	0.230^{n}	–
EPT_{SZ}	0.164	0.405	0.130^{n}	–
Correlations between NDVI values determined at different times and the respective weather parameters				
P	0.580	0.762	13.1^{***}	$y = 0.806 + 5.46{*}10^{-5}x^2 - 6.10{*}10^{-7}x^3$
H	0.533	0.730	10.8^{***}	$y = 0.588 + 0.024x - 4.8{*}10^{-4}x^2$
GS	0.077	0.277	0.5^{n}	–
SZ	0.435	0.660	4.6*	$y = 0.734 + 0.351x - 0.278x^2 + 0.068x^3$

n = no significant correlation, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$, R^2 = coefficient of determination, *R* = coefficient of correlation, *F* = F–test statistics, *NAP* = Daily mean humidity (%), *NÁH* = Daily mean temperature (°C), *NÖGN* = Daily total global solar radiation (KJ m^{-2}), *NÁSZ* = Daily mean wind speed (m s^{-1}), EPT_P = Evapotranspiration (mm day^{-1}) calculated with Penman's formula, EPT_{SZ} = Evapotranspiration (mm day^{-1}) calculated with *Szász*'s formula, *P* = Humidity measured at the time of the NDVI measurement (%), *H* = Temperature measured at the time of the NDVI measurement (°C), *GS* = Global radiation measured at the time of the NDVI measurement (KJ m^{-2}), *SZ* = Wind speed measured at the time of the NDVI measurement (m s^{-1})

A contradiction was found in relation to the fact that NDVI measurements were influenced by the actual humidity to a 58.0% extent, while actual temperature had a 53.3% influence and wind speed had a 43.5% influence. According to our hypothesis, there is an overlap between the correlations due to the fact that weather parameters are not independent of each other. In order to support this hypothesis, a one-way ANOVA was performed to determine the difference shown by the various weather parameters at different measurement times, and a main component analysis was also carried out to determine the correlations between the weather parameters. Significant correlations ($p < 0.001$) were found between the values measured at the four measurement times in the case of humidity, temperature and wind speed. Humidity decreased between 08:00 and 14:00 in local time and then it slightly increased, while temperature and wind speed changed inversely, so that they increased from 08:00 to 14:00 and then started to decrease. The significantly highest humidity was measured at 08:00 and the significantly lowest value was obtained at 04:00. The values logged at 11:00 and 17:00 were significantly higher than the value measured at 14:00 and they were significantly lower than the data measured at 08:00. There was no significant difference between the air temperature measured at 17:00 and 14:00 and the data obtained at 08:00 and 11:00 were significantly lower than the values at 14:00 and 17:00. The significant differences in wind speed measured at different times had the following rank: 14:00 > 11:00 > 08:00 > 17:00 (*Table 2*).

In the main component analysis of the correlations between humidity, air temperature, and wind speed, one component was determined. Based on that, by considering the sign of the main components, it was established that humidity had a negative correlation with temperature and wind speed. The main component weights showed that humidity was closely correlated with wind speed and temperature (*Table 2*).

Table 2. Evaluation of the differences between the weather parameters measured at different times and the correlation between weather parameters

Measurement time (hour in local time)	**Relative humidity (%)**	**Air temperature (°C)**	**Wind speed ($m\ s^{-1}$)**
	Measured values		
08:00	70.6 ± 11.5 a	21.7 ± 5.0 c	0.87 ± 0.43 d
11:00	54.8 ± 2.5 b	25.9 ± 4.2 b	1.45 ± 0.46 b
14:00	48.4 ± 4.6 d	28.1 ± 4.7 a	1.52 ± 0.36 a
17:00	50.5 ± 6.8 c	27.5 ± 4.3 a	1.08 ± 0.36 c
F (5)	539.2^{***}	112.6^{***}	159.9^{***}
	Main component weights (8)		
1st main component	–0.899	0.849	0.663

$^{***}p < 0.001$, *F* = F-test statistics

During the evaluation of the correlations between NDVI and weather parameters (humidity, temperature, wind speed) with a regression analysis and that of the correlation between humidity, air temperature and wind speed with a main component analysis, we came to a conclusion that NDVI measurements are influenced by humidity, temperature and wind speed. Based on the main component analysis, it was shown that humidity is negatively correlated with temperature and wind speed, therefore, air temperature and wind speed affect the results of NDVI measurements through the relative humidity. Based on the coefficients of correlation which were the result of the evaluation of the regression between NDVI values and the examined weather parameters, it can be stated that NDVI values were primarily influenced by the relative humidity (R=762), secondly by air temperature (R=0.730) and thirdly by wind speed (R=0.660).

The correlations between NDVI measurements and humidity were examined against different measurement heights and times, since our previous examinations led us to conclude that the NDVI value is significantly different as a function of the measurement height and time (*Víg et al.,* 2010). During the examination of the correlations between NDVI values and relative humidity by linear, quadratic, third degree, exponential and logarithmic regression analyses, it was established that the closest correlations were described by quadratic and third degree regression equations. There was no significant regression between the NDVI values and humidity at the 20 cm measurement height, while there were significant correlations ($p<0.01$ and $p<0.001$) between NDVI values and humidity at the 40, 60, 80 and 100 cm measurement heights. Depending on the measurement height, humidity was shown to be a strong factor (R=0.819–0.873) and it had a 67.0–76.3% influence ($R^2=0.670–0.763$) on NDVI measurement. As regards the various measurement times, significant ($p<0.01$ and $p<0.001$) and strong (R=0.828–0.986) correlations were shown in all cases. The influence of humidity on NDVI measurement was the strongest ($R^2=0.972$) at 08:00 and it was the weakest ($R^2=0.686$) at 14:00 (*Table 3*).

Table 3. Correlations between the relative humidity and the NDVI values at different measurement heights and times

Measurement height (cm)	R^2	***R***	***F***	**Regression equation**
20	0.065	0.255	0.7^{n}	–
40	0.755	0.869	29.2^{***}	$y = 0.738 - 0.003x - 3.4*10^{-7}x^3$
60	0.763	0.873	30.5^{***}	$y = 0.792 + 6.2*10^{-5}x^2 - 7.0*10^{-7}x^3$
80	0.734	0.857	26.3^{***}	$y = 0.779 + 7.4*10^{-5}x^2 - 8.3*10^{-7}x^3$
100	0.670	0.819	8.4^{**}	$y = 0.783 + 6.9*10^{-5}x^2 - 7.7*10^{-7}x^3$
Measurement time (hour)	R^2 **(2)**	***R*** **(3)**	***F*** **(4)**	**Regression equation**
08:00	0.972	0.986	52.8^{***}	$y = 0.590 - 1.5*10^{-6}x^3$
11:00	0.744	0.863	29.8^{***}	$y = -3.735 + 0.168x - 0.002x^2$
14:00	0.686	0.828	10.3^{**}	$y = -0.770 + 0.66x - 0.001x^2$
17:00	0.850	0.922	46.7^{***}	$y = 0.168 + 0.027x - 2.0*10^{-4}x^2$

n = no significant correlation, $^{**}p<0.01$, $^{***}p<0.001$, R^2 = coefficient of determination, R= correlation of coefficient, F = F-test statistics

In one of our previous publications, it was established that the mean difference ($MD_{\%}$) values determined in relation to the NDVI values measured at different heights are different at the various measurement times and the variability of the measurement results ($CV_{\%}$) depends on the applied measurement height (*Víg et al.*, 2010). In this study, it is shown that the change in the examined parameters is in correlation with the relative humidity.

By evaluating the correlations between the mean difference ($MD_{20\text{-}100}$) of the NDVI values measured at different heights and the variability ($CV20\text{–}100_{\%}$) of the values measured at different heights and humidity by quadratic, third degree, exponential and logarithmic regression analyses, it was established that the correlations can be most accurately described with quadratic and third degree regression equations. There was significant ($p < 0.001$) and strong correlation between the mean difference and humidity, showing that the relative humidity had a 68.1% influence on the mean difference between NDVI values measured at different heights. There was no significant correlation between the variability of the measurements performed at 20 and 40 cm ($CV20_{\%}$, $CV40_{\%}$) and the relative humidity, while there were average correlations in relation to the coefficients of variation of the other measurement heights ($CV60_{\%}$, $CV80_{\%}$, $CV100_{\%}$). The correlations determined at 60 and 80 cm measurement heights are also significant ($p < 0.05$) and the value of the regression coefficient was nearly 0.6, while the significance was $p < 0.01$ and the regression coefficient was above 0.6 in the case of measurements performed at 100 cm. Based on the coefficient of determination, humidity had 35.4% and 35.3% influence the variability of NDVI values at 60 and 80 cm measurement heights, respectively, while the extent of this influence was 38.8% in the case of 100 cm measurement height (*Table 4*).

Table 4. Correlations between the mean difference ($MD_{20\text{–}100}$) and variability ($CV20\text{–}100\%$) and the relative humidity

Examined parameters	R^2	R	F	**Regression equation**
$MD_{20\text{-}100}$	0.681	0.825	20.3^{***}	$y = 5.376 - 0.003x^2 - 4.06 \cdot 10^{-5}x^3$
$CV20_{\%}$	0.087	0.295	0.905^{n}	–
$CV40_{\%}$	0.232	0.482	2.9^{n}	–
$CV60_{\%}$	0.354	0.595	5.2^{*}	$y = 3.478 - 0.002x^2 + 1.59 \cdot 10^{-5}x^3$
$CV80_{\%}$	0.353	0.594	5.2^{*}	$y = 4.407 - 0.075x + 7.29 \cdot 10^{-6}x^3$
$CV100_{\%}$	0.388	0.623	6.0^{**}	$y = 8.574 - 0.221x + 0.002x^2$

n = no significant correlation, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$, R^2 = coefficient of determination, R = coefficient of correlation, F = F–test statistics, $MD_{20\text{–}100}$ = Mean difference between the NDVI values measured at different heights, $CV20_{\%}$ = Variability of NDVI values measured at 20 cm, $CV40_{\%}$ = Variability of NDVI values measured at 40 cm, $CV60_{\%}$ = Variability of NDVI values measured at 60 cm, $CV80_{\%}$ = Variability of NDVI values measured at 80 cm, $CV100_{\%}$ = Variability of NDVI values measured at 100 cm.

4. Conclusions

The obtained research results led to the conclusion that the results of the field NDVI measurement are primarily influenced by the relative humidity. Secondly and thirdly, air temperature and wind speed also influence NDVI values, as temperature and wind speed are negatively correlated to humidity. The effect of humidity on NDVI measurement depends on the measurement height and time. In the case of the 20 cm measurement height, the effect of humidity on NDVI measurement cannot be detected, while if the measurement is carried out above 40 cm, the distortion effect of humidity is strong. The correlation between humidity and NDVI values is the strongest in the case of the measurements performed at 08:00 and 17:00, while it was the weakest at 11:00 and 14:00 in local time. Consequently, by increasing the measurement height and performing measurements in the morning and late in the afternoon, the distortion effect of humidity on NDVI measurements becomes stronger.

It was shown in our previous examinations that the increase of measurement height results in the decrease of the variability of the measurement results (*Víg et al.*, 2010), but the effect of humidity on variability increases with the increase of the measurement height.

In order to more accurately determine the nitrogen supply on the basis of the NDVI value, we consider it necessary to examine the correlations between humidity, NDVI values, and the leaf nitrogen content with the aim to find the correction factors needed for the more accurate determination of nitrogen shortage on the basis of the NDVI values.

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