

**TEMPORAL VARIABILITY IN ACTIVE REFLECTANCE SENSOR-MEASURED NDVI
IN SOYBEAN AND WHEAT CROPS**Doi:<http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v37n4p771-781/2017>**HUMBERTO M. BENEDUZZI¹, EDUARDO G. SOUZA^{2*}, CLAUDIO L. BAZZI³,
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ABSTRACT: Optimization of N management is one of the great challenges to be overcome in grain production, as it is directly related to productivity and can also cause environmental damage. Precision agriculture aims to solve this problem by applying nitrogen fertilizer at varying rates. Reflectance sensors are instruments capable of estimating N needs in various crops, including grain crops. However, it is not clear how these sensors perform under varying solar radiation and cloud cover, due to a lack of research on their temporal variability. Thus, this study examined the temporal variability of the NDVI (normalized difference vegetation index), as measured by an active reflectance sensor, in both soybean and wheat crops. The NDVI data were collected using a GreenSeeker sensor every 15 minutes over 12 or 14 consecutive hours. Incident solar radiation was recorded using an Instrutherm MES-100 pyranometer. In all experiments in soybean and wheat, NDVI was negatively influenced by irradiation, showing higher values at the beginning and end of the day. Changes in cloud cover also affected NDVI values during the experiments.

KEYWORDS: precision agriculture, remote sensing, vegetation index, NDVI

INTRODUCTION

Optimizing N management remains one of the greatest challenges in grain production. Because productivity is directly related to N availability (BARRACLOUGH et al., 2010), N is often applied in excess (DELLINGER et al., 2008, SCHMIDT et al., 2011), causing financial losses and environmental damage due to leaching and groundwater contamination (BURKART & JAMES, 1999; HONG et al., 2007).

Among the technologies used in precision agriculture is the application of fertilizer at varying rates, in which the appropriate amount of fertilizer is identified and applied at each point of the cultivated area (THRIKAWALA et al., 1999; MULLA, 2013; SAPKOTA et al., 2014). This approach can not only increase productivity but also reduce its environmental impact (SCHARF et al., 2011; LI et al., 2014).

Reflectance sensors are a type of instrument that can estimate the N needs of various types of crops, including grain crops (SCHMIDT et al., 2009; WINTERHALTER et al., 2013). These types of instruments have logistical and economic advantages since they can be used to rapidly cover large areas, quickly generating results at a lower cost compared to other techniques (SCHARF et al., 2002, SCHARF et al., 2011).

Several studies have already shown that passive sensors are influenced by the time of day, since their measurements depend on the level of solar radiation (SOUZA et al., 2004; SOUZA et al., 2010; ERDLE et al., 2011). On the other hand, active sensors use their own light source and so have the ability to work at any time of day without interference from solar radiation or atmospheric variations (TRIMBLE, 2013). However, there are studies indicating that even active sensors can be influenced by the time of day and the weather conditions, creating distortions in the collected data (SCHARF et al., 2010; KIPP et al., 2014; OLIVEIRA & SCHARF, 2014; ELSAYED et al., 2015).

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To confront this challenge, this work investigated the changes in the measurements made by an active reflectance sensor in soybean and wheat crops during different times of day, with consequent variation in solar radiation and cloud cover.

MATERIAL AND METHODS

This research was conducted in soybean and wheat fields at different stages of development in an agricultural area located outside of the city of Céu Azul - Paraná state - Brazil, whose approximate central geographic location is 25°06'32" S, 53°49'55" W. The average altitude of this area is 752 m, and the area comprises approximately 15.5 ha on a soil classified as a typic Dystroferic Red Latosol (EMBRAPA, 2013). The area has been cultivated using no-till practices for over 10 years in a rotation of soybean, wheat, corn and oat crops grown for commercial purposes.

Data relating to soybean (variety Dom Mario 5958 RR2) were collected in the R1 and R2 stages, while the data for wheat (variety Catuara) were obtained in stages V3, V8 and V10.5. In the soybean, the R1 stage indicates the beginning of the reproductive phase, and this is marked by the beginning of bloom, when plants have at least one open flower at any node. At the R2 stage full bloom occurs, with an open flower in one of the last two stem nodes with fully developed leaf (EMBRAPA, 2007). The wheat in V3 stage presents tillers formed and spiral wound sheaths. At the V8 stage the flag leaf is visible, but still curled or rolled up. The V10.5 indicates the end of the heading stage, when the plants presents all the ears outside the sheaths (EMBRAPA, 2014).

To collect normalized difference vegetation index (NDVI) data, a GreenSeeker 505 active optical sensor was used. This sensor detects electromagnetic radiation in the (visible) red wavelength of 656 nm and in the near-infrared at 774 nm (NTECH, 2008). The NDVI is then calculated using the following equation:

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (1)$$

where,

NIR is the radiation reflectance measured by the sensor in the near-infrared wavelength, and

RED is the radiation reflectance measured by the sensor in the red wavelength.

Incident solar radiation (or irradiation) measurements were performed with an Instrutherm MES-100 pyranometer. The incident radiation parameter was used to estimate the influence of clouds in each of the data collection periods. We used the ITI (instantaneous transparency index), proposed by SOUZA et. al. (2006), which aims to indicate the percentage of incident radiation of expected irradiation for a given time.

The ITI was calculated using the methodology developed by SOUZA et al. (2006), according to [eq. (2)]:

$$ITI = \frac{I}{I_0} \quad (2)$$

where,

I is the expected theoretical radiation, and

I₀ is the real radiation measured by the pyranometer at the same time.

To estimate the theoretical radiation for the date of data collection within each plant growth stage, a polynomial regression function was developed for each day. This function was based on actual radiation values measured during periods without clouds.

The data were normalized to allow the inclusion of the data of different magnitudes on the same graph. To this end, the average method proposed by SWINDELL (1997) was used:

$$V_n = \frac{V}{\sum_{i=1}^j V_i / j} \quad (3)$$

where,

V_n is the normalized value for a particular sample, found by dividing the sample value by the average sample value;

V is the value of the variable in case I , and

j represents the number of cases.

Data were collected using the same methods for both wheat and soybean. Data were collected with a stationary GreenSeeker sensor positioned parallel to the ground, with the same position maintained throughout the day (Figure 1). Preliminary tests were conducted to ensure that the support used did not influence sensor readings. The sensor was maintained at a distance of 80 cm from the crop canopy, which was within the range recommended by the instrument manufacturer (NTECH, 2008).



FIGURE 1. GreenSeeker sensor mounted on soybean in R1 stage

The times used for the beginning and end of data collection took into account the time of year in order to capture the entire insolation period. In soybean, this period was from 7 am to 9 pm, and in wheat, it was 7 am to 7 pm. During each stage researched, measurements were performed every 15 minutes. Thus, the data were always collected at minutes 0, 15, 30 and 45 of each hour. The NDVI values obtained for each sample were composed of the average of 100 readings taken by the GreenSeeker sensor continuously over 10 seconds.

Analyzing the influence of crop row orientation on vegetation indices, SOUZA et al. (2004) concluded that NDVI variability increased when crops were sown in north-south rows. Thus, in this experiment, data collection was carried out on crops growing in north-south rows. The GreenSeeker sensor was positioned over the row, perpendicular to sunrise and sunset, with the front facing north. Soon after data collection with the GreenSeeker, a pyranometer positioned above the sensor was used to measure incident radiation.

Data collected in the field were statistically analyzed through exploratory analysis. Coefficients of variation (CV) were ranked according to PIMENTEL & GARCIA (2002). CVs $\leq 10\%$ were deemed low (homoscedastic), while $10\% < CV \leq 20\%$ was average, $20\% < CV \leq 30\%$ was high, and $CV > 30\%$ was very high (heteroscedastic). Regression analysis was performed using Statistica 12.0 software (STATSOFT, 2014), with NDVI modeled as a function of the stage of development and irradiation. We used the regression best subsets method, in which the adjusted

coefficient of determination (adjusted R^2) was used as a selection criterion of the best model among all possible subsets (MONTGOMERY et al., 2012).

The following model (Equation 4) was defined by exploratory analysis conducted using data from soybean, and it assumes that the dependent variable, NDVI, is influenced by the developmental stage of the crop, solar irradiation and irradiation * ITI.

$$\text{NDVI} = a + b \cdot \text{stage} + c \cdot \text{irr} + d \cdot (\text{irr} \cdot \text{ITI}) \quad (4)$$

where,

a, b, c, d are parameters generated by the multiple regression model,

stage represents the developmental stage of the crop,

irr is the irradiance (W m^{-2}), and

ITI refers to the instantaneous transparency index.

The model defined by exploratory data analysis for wheat (Equation 5) indicates that NDVI as a dependent variable is influenced by the stage of development of the crop, solar irradiation, ITI and $\text{ITI} \cdot \text{ITI}$.

$$\text{NDVI} = a + b \cdot \text{stage} + c \cdot \text{irr} + d \cdot \text{ITI} + e \cdot \text{ITI}^2 \quad (5)$$

where,

a, b, c, d and e are the parameters generated by the multiple regression model,

stage represents the developmental stage of the crop,

irr is irradiance (W m^{-2}), and

ITI is the instantaneous transparency index.

RESULTS AND DISCUSSION

Soybean

The NDVI coefficients of variation determined in soybean stages R1 and R2 were 2.8% and 1.8%, respectively, which can be considered low (Table 1). The variability of NDVI was significantly smaller than the variability of its constituent bands, what is to be expected (TUCKER, 1979; PINTER et al., 1985). The red band (656 nm) showed a much higher coefficient of variation than that for the near-infrared band (774 nm).

TABLE 1. Descriptive statistics for the data grouped by soybean stage.

Stage	Variable	Minimum	Average	Median	Maximum	StdDev	CV
R1	NDVI	0,838	0,885	0,887	0,920	0,025	2,8%
	Red	0,027	0,043	0,043	0,062	0,009	21,0%
	Near-infrared - NIR	0,560	0,713	0,714	0,848	0,070	9,9%
	Irradiation, W m^{-2}	0	485	352	1112	412	84,9%
R2	NDVI	0,845	0,880	0,880	0,911	0,016	1,8%
	Red	0,028	0,042	0,043	0,054	0,006	14,1%
	Near-infrared - NIR	0,550	0,653	0,648	0,743	0,045	6,9%
	Irradiation, W m^{-2}	0	439	397	1076	331	75,3%

In both growth stages, the soybean NDVI curve showed similar behavior throughout the day, with higher values at the beginning and end of the day and smaller values close to noon, when solar irradiation was greater (Figure 2a). This observation is in agreement with the results obtained by OLIVEIRA & SCHARF (2014). It was also determined that there was a greater dispersion of NDVI

values in the R1 stage than in the R2 stage, which indicates that as crop development continues, NDVI variability decreases (Table 1, Figures 2a and 2b).

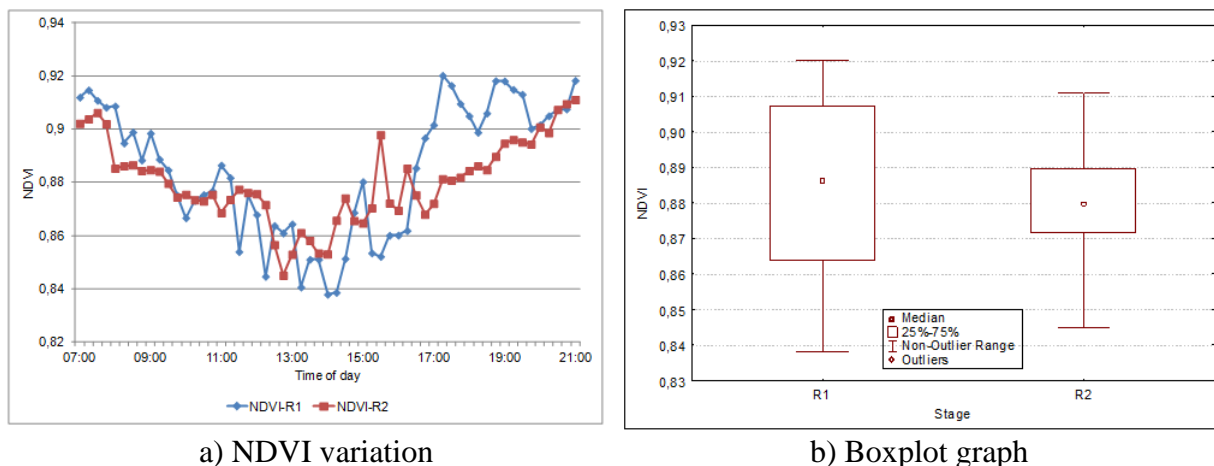


FIGURE 2. a) Variation in NDVI throughout the day for each soybean stage; b) Boxplot graphics for NDVI grouped by stage.

The R^2 values obtained for the theoretical irradiation fitting curve for the R1 and R2 soybean stages were greater than 99%. The ITI was calculated as a function of the time of day (Figures 3a and 3b). Irradiation was further reduced by cloud cover during the experiment in R2 stage compared with R1.

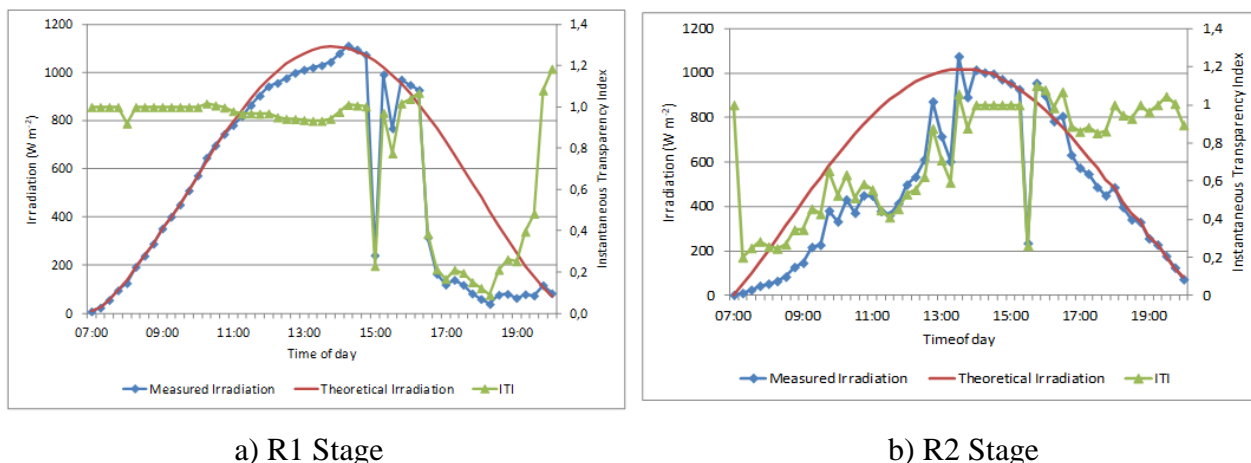


FIGURE 3. Measured irradiation, theoretical irradiation and instantaneous transparency index (ITI) for R1 (a) and R2 (b) soybean development stages.

Comparing Figures 2a and 4a, it can be seen that during the experiment on R1 stage, at approximately 15:00, a sharp drop in irradiation occurred, with a simultaneous and marked increase in NDVI, indicating a clear association between these two variables. This can also be seen in the experiment on R2 stage, by comparing the graphs in Figures 2a and 4b, particularly at 15:30, when again, a sharp drop in irradiation occurs together with a peak in NDVI. The variation of the solar radiation throughout the day affected the red band more than the near-infrared band (Figures 4a and 4b). In addition, sudden changes in cloud cover captured by ITI also held more influence over the red band. This response agrees with what SOUZA et. al. (2006) have shown.

The NDVI was inversely correlated with ITI (Figure 4c) and irradiation (Figure 4d), in both stages. From the model that was produced from regression analysis (Equation 6), the R^2 value was 0.842, i.e., 84.2% of the variability in NDVI can be explained by the stage of development, irradiation and ITI. The fact that the variability in NDVI cannot be fully explained using these three

variables suggests that additional research may need to consider other variables, such as temperature and humidity.

$$NDVI = 0.9153 - 0.004280 \cdot \text{stage} - 0.0001123 \cdot \text{irr} + 0.00006211 \cdot \text{irr} \cdot \text{ITI} \quad (6)$$

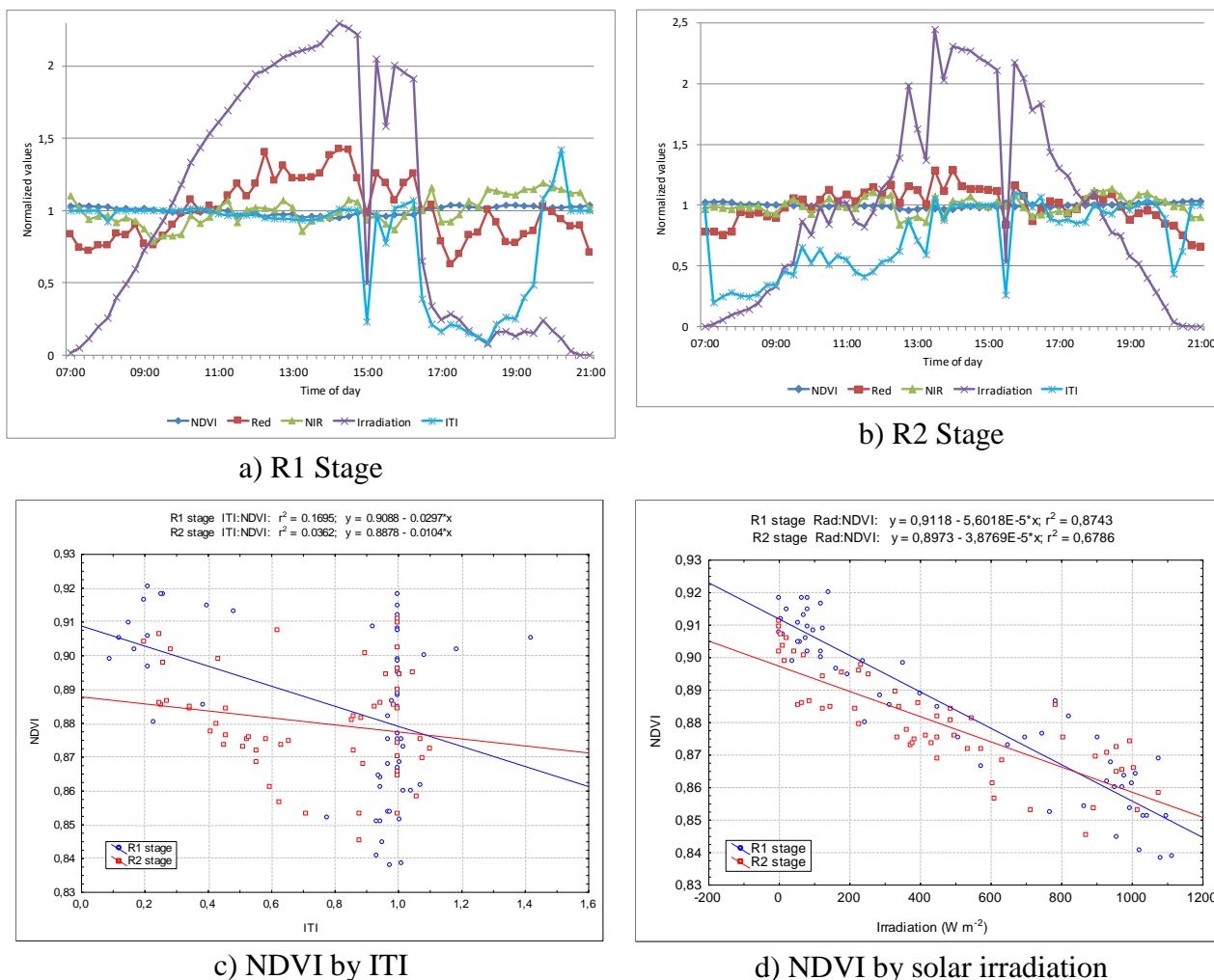


FIGURE 4. NDVI, red, near-infrared (NIR), irradiation and instantaneous transparency index (ITI) as a function of time of day during R1 (a) and R2 (b) stages of soybean development (normalized data); NDVI as a function of ITI (c); Correlation between NDVI and solar irradiation (d).

Wheat

In wheat, the NDVI coefficients of variation recorded in stages V3, V8 and V10.5 were 2.8%, 3.3% and 6.8%, respectively. The rise in variability as the season progressed contrasts with the trend observed in soybean. Furthermore, the average NDVI values were lower in later stages (Table 2, Figure 5b). The decline in NDVI in stage V10.5 can be partially explained by the attenuation of the green tint inherent to a maturing wheat crop, which in turn causes increased reflectance in the red band. Nonetheless, the reason why the NDVI in V8 stage was less than that for V3 was not clear.

Similar to the results obtained in soybean, the variability recorded in the red band (656 nm) was much higher than that in the near-infrared band (774 nm). The variability of NDVI, in turn, was less than that of the individual bands at stages V3 and V8 but greater than the variability in red at stage V10.5.

TABLE 2. Descriptive statistics for the data grouped by wheat stage.

Stage	Variable	Minimum	Average	Median	Maximum	StdDev	CV
V3	NDVI	0,805	0,846	0,849	0,882	0,023	2,8%
	Red	0,028	0,039	0,036	0,056	0,008	21,7%
	Near-infrared - NIR	0,385	0,462	0,474	0,517	0,039	8,4%
	Irradiation, W m ⁻²	0	220	168	696	208	94,3%
V8	NDVI	0,780	0,828	0,826	0,872	0,027	3,3%
	Red	0,019	0,025	0,025	0,032	0,004	15,4%
	Near-infrared - NIR	0,245	0,267	0,265	0,292	0,014	5,2%
	Irradiation, W m ⁻²	0	324	333	804	247	76,2%
V10.5	NDVI	0,620	0,706	0,696	0,813	0,048	6,8%
	Red	0,019	0,030	0,029	0,042	0,006	20,1%
	Near-infrared - NIR	0,159	0,175	0,174	0,190	0,008	4,4%
	Irradiation, W m ⁻²	0	312	247	878	258	82,5%

In all three wheat experiments, the NDVI values were higher at the beginning and end of the day, similar to what was observed in soybean. In stage V10.5, NDVI was well below that recorded in the other two stages; it also fell more quickly with each passing hour, followed by a sharp rise at the end of the day (Figure 5a).

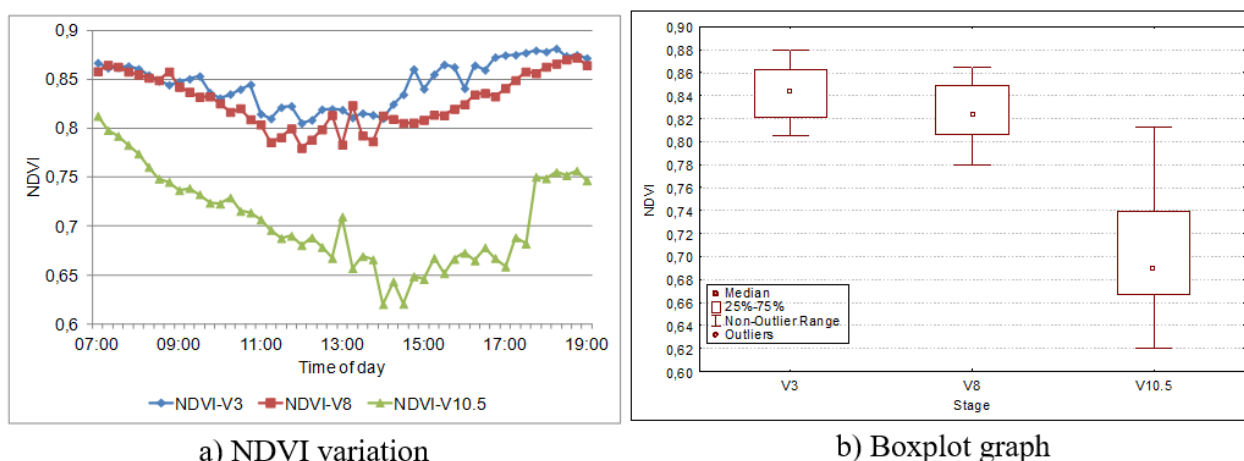


FIGURE 5. a) Variation in NDVI throughout the day for each stage; b) Boxplots for NDVI grouped by wheat stage.

The R² values obtained for the adjustment curve of the theoretical irradiation (Figures 6a, 6b and 6c) in stages V3, V8 and V10.5 were all above 99.9%. The instantaneous transparency index (ITI) was then calculated as a function of time of day. Cloud cover reduced irradiation the most in stage V3, followed by stages V10.5 and V8.

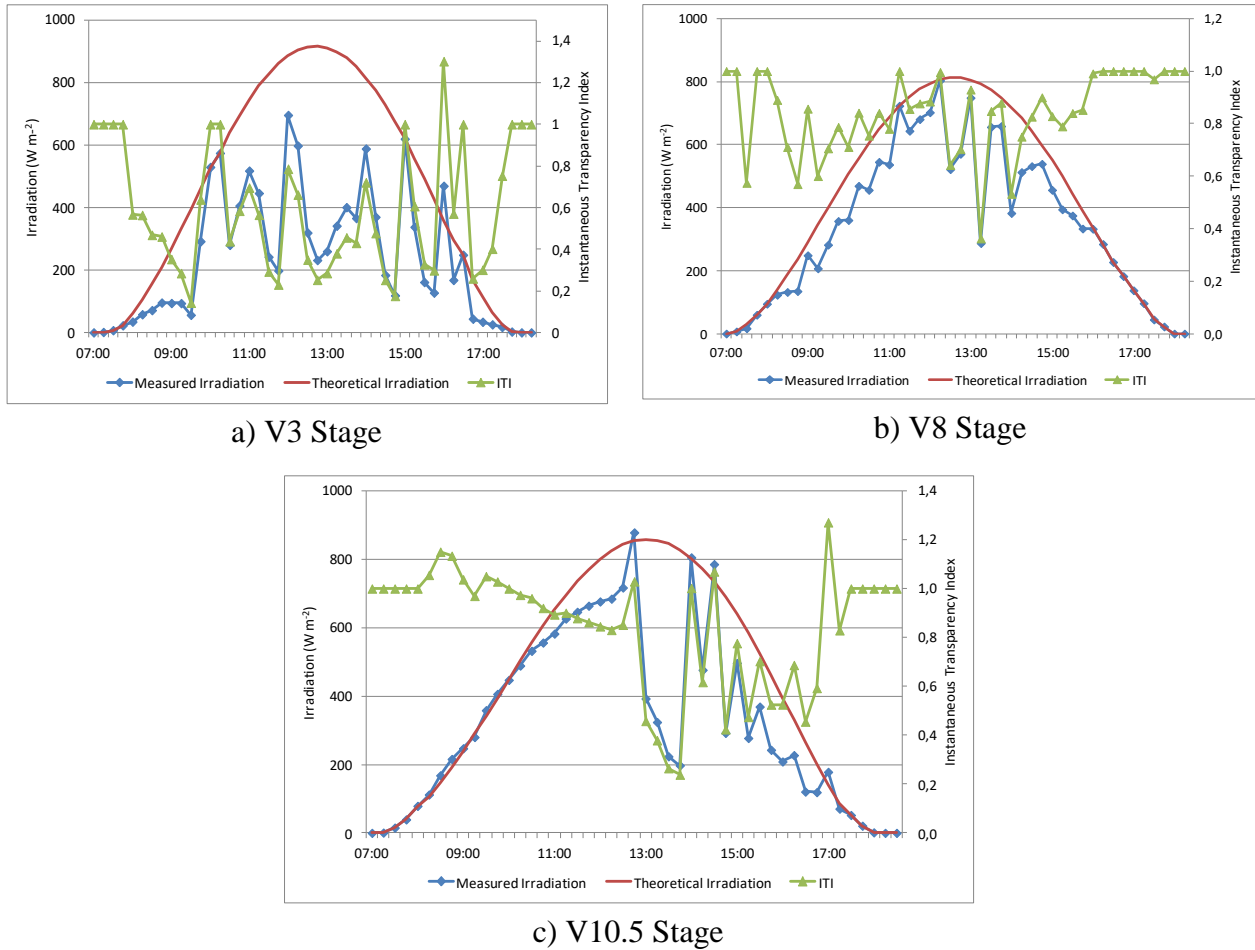
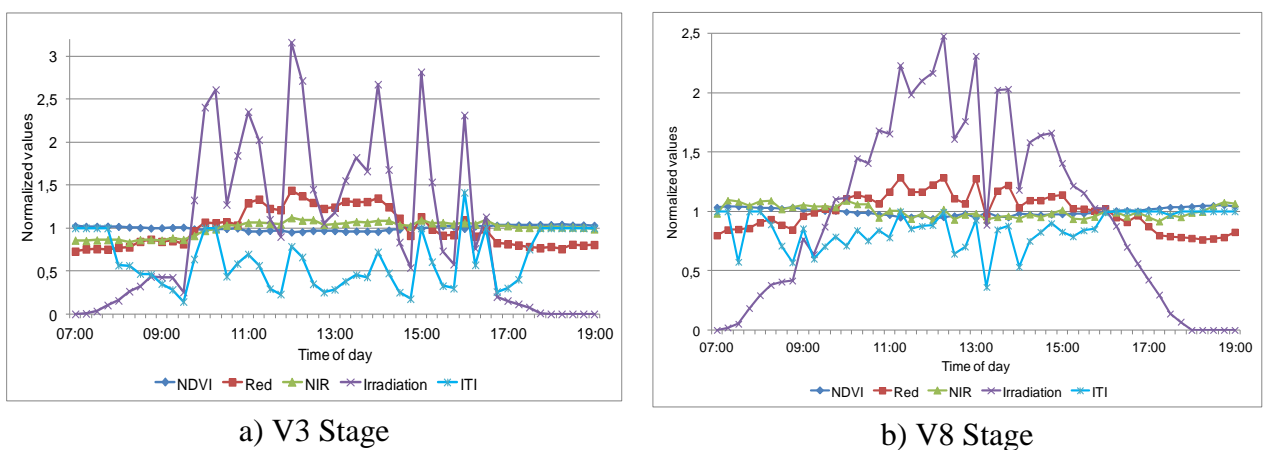


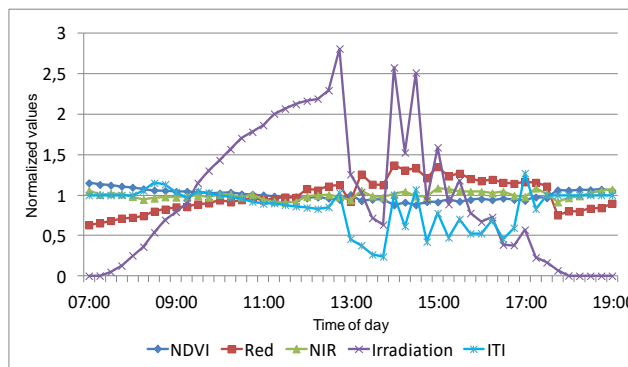
FIGURE 6. Measured irradiation, theoretical irradiation and instantaneous transparency index (ITI) for V3 (a), V8 (b) and V10.5 (c) wheat development stages.

In wheat, the variation in the solar radiation throughout the day also affected the red band more than near-infrared band (Figures 7a, 7b and 7c), similar to what was observed in soybean. Abrupt changes in cloud cover, indicated by the ITI readings, also held more influence over the red band.

The NDVI was inversely correlated with irradiation (Figure 8b) in all three stages, and it showed a direct correlation with ITI only in stage V10.5 (Figure 8a). The regression model (Equation 7) had an R^2 value of 0.803; i.e., 80.3% of the variability in NDVI could be explained by the developmental stage of the crop, irradiation and ITI. Again, the fact that the variability of NDVI cannot be explained by these variables indicates the need for studies that also consider other variables, such as temperature and humidity.

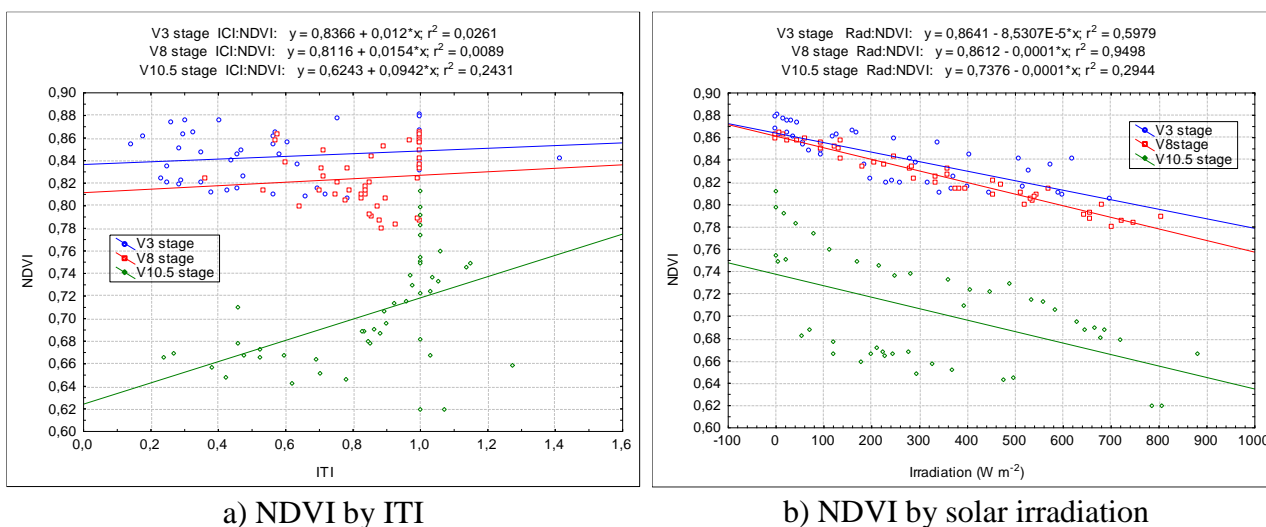
$$NDVI = 0.871578 - 0.076001 * stage - 0.000100 * irr + 0.231785 * ITI - 0.114141 * ITI^2 \quad (7)$$





c) V10.5 Stage

FIGURE 7. Normalized data collected in wheat V3 (a), V8 (b) and V10.5 (c) stages: NDVI, red, near-infrared, irradiation and ITI.



a) NDVI by ITI

b) NDVI by solar irradiation

FIGURE 8. NDVI as a function of ITI (a); Correlation between NDVI and solar irradiation (b)

CONCLUSIONS

NDVI values measured by the GreenSeeker sensor on soybean and wheat crops throughout the day were negatively influenced by irradiation and were higher in the early morning and at the end of the day. The NDVI was also affected by changes in cloud cover during the experiments, which had a positive influence on the values for wheat but a negative influence on the values for soybean. Among the variables studied, solar irradiation best explained the variation in NDVI for both crops.

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