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USE OF ACTIVE CANOPY SENSORS TO DISCRIMINATE WHEAT RESPONSE TO NITROGEN FERTILIZATION UNDER NO-TILLAGE

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ABSTRACT: Spectral reflectance sensors may be useful in discriminating biomass and nitrogen status in plants. A field experiment was carried out on a loamy Typic Hapludox under no-tillage in Ponta Grossa, Parana State, Brazil, aiming to evaluate the efficiency of active canopy sensors (GreenSeeker 505 and Crop Circle ACS-470) to discriminate wheat response to nitrogen fertilization by determining the dry mass, nitrogen status, and grain yield. A randomized complete block design was used and four treatments were replicated 12 times. The treatments consisted of nitrogen application, as urea, at the rates of 0, 50, 100, and 150 kg ha^{-1}. The nitrogen rates were applied in topdressing at tillering of wheat crop. The readings from the sensors were sensitive to changes caused by nitrogen rates application and yet had close and significant correlations with the dry biomass production and nitrogen uptake by wheat plants. GreenSeeker 505 and Crop Circle ACS-470 sensors showed similar efficiency in discriminating biomass production and the nutritional status in the wheat crop related to nitrogen. Wheat grain yield was high and it did not follow the gains in the production of dry mass in the shoot.

KEY WORDS: *Triticum aestivum* L., GreenSeeker, Crop Circle, NDVI.

INTRODUCTION

The chain of production, processing and marketing of wheat is one of the most important in Brazil and in the world (CANZIANI & GUIMARÃES, 2009). The availability of nutrients for plant growth may be critical to obtain high yield of wheat crop. The nitrogen is the nutrient extracted in larger quantities by plants and can bring benefits to all wheat yield components, except for the plants population. The addition of nitrogen fertilizers in wheat crop results in increases in plant height, concentration of chlorophyll in the leaves, the number of spikelet and grain per spike, and grain yield (ZAGONEL et al., 2002; BENETT et al., 2011; TEIXEIRA FILHO et al., 2011). However, the excess of nitrogen fertilization increases the losses of nitrogen, decreases the nitrogen use efficiency by plants, burdens the production costs and causes environmental damage (BARRACLOUGH et al., 2010; MA et al., 2010).

The plant attributes most used as nitrogen indicators are the intensity of the green color, the nitrogen content in the leaves, biomass production and nitrogen extraction by the plant shoot (RAMBO et al., 2004). Low nitrogen levels may cause chlorophyll deficiency (SALEEM et al., 2010), which can be recognized by whitish or pale colored leaves.

Alternatives to provide specific information about the status of the crops have been pursued in agriculture (MERCANTE et al., 2009). Variations in color and plant growth can be identified through remote sensing (RAMBO et al., 2004). Land optical sensor as GreenSeeker (NTech Industries, Inc., Ukiah, CA) and Crop Circle (Holand Scientific Inc., Lincoln, NE) have been used for this purpose (POVH et al., 2008; GROHS et al., 2009).

The GreenSeeker and Crop Circle active optical sensors emit light in wavelengths of visible and near infrared spectrum regions, and the detectors capture the reflected light. These active sensors provide plant reflectance data at different wavelengths, which enable to calculate different vegetation rates. The normalized difference vegetation index (NDVI) has been one of the most used for monitoring the vegetation cover and the crops stress (MAZZETO et al., 2009; LI et al., 2010; GROFF et al., 2013; MULLA, 2013). The NDVI is the resulting ratio of combining the reflectance

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in the near infrared region (R_{NIR}) and red (R_R) [NDVI = (R_{NIR} – R_R)/(R_{NIR} + R_R)]. However, in most conditions of soil covered with plants, there is an absorption peak in the red band. When this occurs, NDVI becomes insensitive to biomass changes, which may have reflexes on productivity (POVH et al., 2008). For this reason, the simple index ratio (RVI, R_{NIR}/R_R) and inverse ratio (IRVI, R_R/R_{NIR}) have also been studied to predict the biomass in areas with higher intensity of vegetation, since these indexes are less susceptible to saturation (HATFIELD & PRUEGER, 2010; LI et al., 2010; BOLFE et al., 2012).

In no-tillage systems, considerable increases in organic matter take place, mainly in the top layers of the soil, as a result of plant residue deposition and absence of tillage (BAYER et al., 2000; SÁ & LAL, 2009). The higher soil organic matter content under no-tillage may have consequence on the nitrogen use by plants and the crop response to nitrogen fertilization. Because of smaller NDVI differences arising from high soil cover at the beginning of the crop cycle, the ability of the sensors to discriminate biomass production and nitrogen nutritional status of wheat in response to nitrogen fertilization can be affected (FREEMAN et al., 2003).

This study evaluated the efficiency of active canopy sensors (GreenSeeker 505 and Crop Circle ACS-470) to discriminate wheat response to nitrogen fertilization under no-tillage by determining the dry mass, nitrogen status, and grain yield.

MATERIAL AND METHODS

The experiment was carried out in Ponta Grossa, PR, Brazil, in the “Capão da Onça" School Farm, on a loamy Typic Hapludox under no-tillage. The climate, according to Köppen classification, is the Cfb, with mild summers and frequent frosts during the winter. The average altitude is 970 m and the average annual rainfall is 1.550 mm. Before the beginning of the experiment, soil chemical analyses of the 0-0.2 m layer showed the following results: pH ($CaCl_2$ 0,01 mol L^{-1}) of 5.2; total acidity (H + Al) of 49.6 $mmol_c$ dm^{-3}; exchangeable Ca, Mg, and K contents of 41, 22, and 3.7 $mmol_c$ dm^{-3}, respectively; P (Mehlich-1) of 4.0 mg dm^{-3}; organic carbon of 25 g dm^{-3}; cation exchange capacity (CEC) at pH 7.0 of 116.3 $mmol_c$ dm^{-3}; and base saturation of 57%.

The experimental design was a complete randomized block and four treatments were replicated 12 times. At 56 m² plots (7 × 8 m), four nitrogen rates were used as urea, in topdressing (0, 50, 100 and 150 kg ha^{-1}).

Wheat (*Triticum aestivum* L.), cv. Quartzo, was sown on June 13, 2011, using 170 kg ha^{-1} of seed and row spacing of 0.17 m. The cv. Quatzo is classified as bread wheat, has high grain yield potential, good level of resistance to leaf spot and good tolerance to rain in the pre-harvest; it is from intermediate growth to semi-erect habit, moderately resistant to lodging and to frost, and moderately tolerant to natural threshing and aluminum. In sowing was applied 300 kg ha^{-1} of 4-14-8 (N-P_2O_5-K_2O). The nitrogen rates in topdressing were applied at tillering of wheat crop, between the growth of the 4th and 7th leaf. The control of pests, diseases, and weeds was conducted according to the crop needs, in order to allow the proper development of the plants to achieve maximum yield potential.

The average monthly rainfall, during the wheat crop development period in 2011, exceeded the monthly historical average rainfall (48 years) of Ponta Grossa, PR, Brazil. The nitrogen fertilization was carried out in soil with good moisture and there was no rain for two days after the application of N-urea rates. The average air temperature varied from 14° to 19°C.

In each plot, three points represented by lines of wheat plants were chosen randomly. Leaf samples were collected at the beginning of the wheat crop flowering, which occurred at 91 days after sowing, removing the flag leaf in 45 plants in each plot, 15 plants in each row, for foliar analysis purposes. On that occasion, on the same lines of wheat plants chosen, readings through the GreenSeeker 505 and Crop Circle ACS-470 active optical sensor were also held. The GreenSeeker 505 operates in two wavelength centered at the red regions (650 ± 10 nm) and near infrared regions

(770 ± 15 nm). The Crop Circle ACS-470 can emit polychromatic light in wavelengths from 430 to 850 nm. For this study, the filters used in Crop Circle were 670, 730 and 760 nm; we have selected spectral bands of 670 and 760 nm because they have showed better results. With each sensor was performed a total of three readings per plot. The readings were made at a constant speed at a distance of 0.9 m from the plant canopy. The area covered by the two sensors in each reading was 3.6 m^2 (0.6 × 6 m), totaling 10.8 m^2 with three readings in each plot. The following vegetation indexes were used, according to standard output calculations for each sensor: NDVI $[(R_{770} - R_{650})/(R_{770} + R_{650})]$ and IRVI (R_{650}/R_{770}) for the GreenSeeker 505, and NDVI $[(R_{760} - R_{670})/(R_{760} + R_{670})]$ and RVI (R_{760}/R_{670}) for the Crop Circle ACS-470. Soon after the readings with the sensors, two lines of 1.5 m plants (0.51 m^2) were removed in each point of the plot, only the shoot in a total of three points per plot to the evaluation of biomass production.

Samples of leaves and plants were washed with deionized water and put to dry in an oven with forced air circulation at a temperature of 60ºC to obtain constant weight. After the evaluation of dry mass production of the shoot, samples of leaves and plants were ground, and N contents were analyzed through sulphuric acid digestion and determination by the Kjeldahl method (MALAVOLTA et al., 1997). Nitrogen uptake by wheat plant was calculated by multiplying dry mass production by nitrogen content in the shoot.

Wheat grain yield was evaluated after the physiological maturity of the crop, by manual harvesting and threshing in stationary harvester machine. The 20 central rows per 4 m of length of each plot (13.6 m^2) were harvested, discarding 2.0 m from each end. The grain moisture was adjusted to 130 g kg^{-1}.

Data from the nitrogen content in the flag leaf, shoot biomass production, nitrogen uptake by plants, grain yield, and sensors vegetation indexes were subjected to regression analysis, according to the design of randomized blocks, with four nitrogen rates in topdressing and 12 replications. Analysis of correlation between the vegetation indexes of the sensors and the nitrogen content in the flag leaf, the shoot biomass production, the nitrogen uptake by plant and wheat grain yield were also carried out. The criterion adopted for choosing the model was the magnitude of the determination coefficients significant at 5%. The statistical analyses were performed by using the SAEG software (RIBEIRO JÚNIOR, 2001).

RESULTS AND DISCUSSION

Nitrogen content in the flag leaf ($\hat{y}$, in g kg^{-1}) linearly increased with the nitrogen rates applied in topdressing (x, in kg ha^{-1}) in the wheat crop ($\hat{y} = 35.60 + 0.014x$, $P<0.01$). Thus, the highest nitrogen content in the flag leaf was achieved with the highest nitrogen rate (150 kg ha^{-1}) applied in topdressing.

The nitrogen rates applied in topdressing (x, in kg ha^{-1}) increased biomass production of the wheat shoot ($\hat{y}$, in kg ha^{-1}), according to the quadratic model ($\hat{y} = 2978.01 + 14.05x - 0.051x^2$, $P<0.05$). Based on adjusted regression equation, the maximum production of shoot biomass was obtained with the application of 138 kg ha^{-1} of nitrogen in topdressing.

Nitrogen uptake by wheat plants ($\hat{y}$, in kg ha^{-1}) linearly increased with the nitrogen rates applied in topdressing (x, in kg ha^{-1}) in wheat crop ($\hat{y} = 66.70 + 0.242x$, $P<0.01$), showing that the higher nitrogen uptake by plants occurred with the application of 150 kg ha^{-1} of nitrogen in topdressing.

The positive influence of nitrogen fertilization on nitrogen content in the flag leaf, in the production of shoot biomass and in the nitrogen uptake by the wheat plants was expected, since in several studies were found positive responses of the nitrogen fertilization in biomass accumulating and improving the nitrogen nutritional status of wheat (VIANA & KIEHL, 2010; ESPINDULA et al., 2010; NUNES et al., 2011).

Wheat grain yield ($\hat{y}$ in kg ha^{-1}) increased with the nitrogen rates applied in topdressing (x, in kg ha^{-1}) according to the quadratic model ($\hat{y} = 4546.01 + 10.21x - 0.057x^2$, P <0.01). Based on adjusted regression equation, the maximum wheat grain yield (5000 kg ha^{-1}) would be achieved with the nitrogen application in topdressing at 90 kg ha^{-1}. In other studies were also found increases in wheat grain yield with nitrogen fertilization (ZAGONEL et al., 2002; BOSCHINI et al., 2011). However, it stands out in our study, that the wheat yield achieved in the plots without topdressing nitrogen fertilization was relatively high in order of 4500 kg ha^{-1} of grains. It has happened even cultivating wheat after corn and with the use of only 12 kg ha^{-1} of nitrogen at sowing. As the soil used in this study had been managed for a long period under no-tillage (> 20 years) and had 25 g kg^{-1} of organic carbon, the stock of labile nitrogen in the soil must have supplied much of the nitrogen required by the wheat plants. This effect may have influenced the sensors reading results when comparing the attributes evaluated in the wheat crop.

For the GreenSeeker 505 active sensor, the NDVI increased and the inverse ratio index (IRVI) decreased significantly (P<0.01), according to the quadratic model, with the nitrogen rates applied in the wheat crop (Figure 1). The coefficient of determination (R^2) obtained for both indexes, NDVI and IRVI, was 0.96.

The NDVI and simple ratio (RVI) indexes obtained by the Crop Circle ACS-470 active sensor increased linearly (P<0.01) with the nitrogen rates applied in the wheat crop (Figure 2). The determination coefficients (R^2) obtained were 0.91 for the NDVI and 0.96 for the RVI.

The results found for the GreenSeeker (Figure 1) and Crop Circle (Figure 2) active sensors, depending on the nitrogen rates applied in topdressing in the wheat crop, are in agreement with those obtained by AMARAL & MOLIN (2011) using Crop Circle sensor in sugarcane crop, by ROSSATO et al. (2012) using the Crop Circle sensor in cotton crop, and by POVH et al. (2008) using the GreenSeeker sensor in wheat and triticale crops.

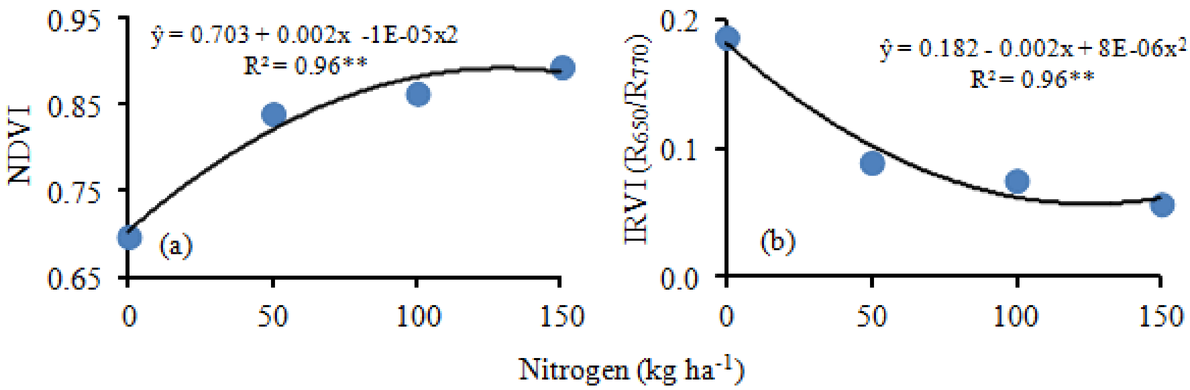

FIGURE 1. Relationships between NDVI (a) and inverse ratio (IRVI) (b) indexes of the GreenSeeker 505 active sensor and the nitrogen rates applied in topdressing in the wheat crop. **: P<0,01.

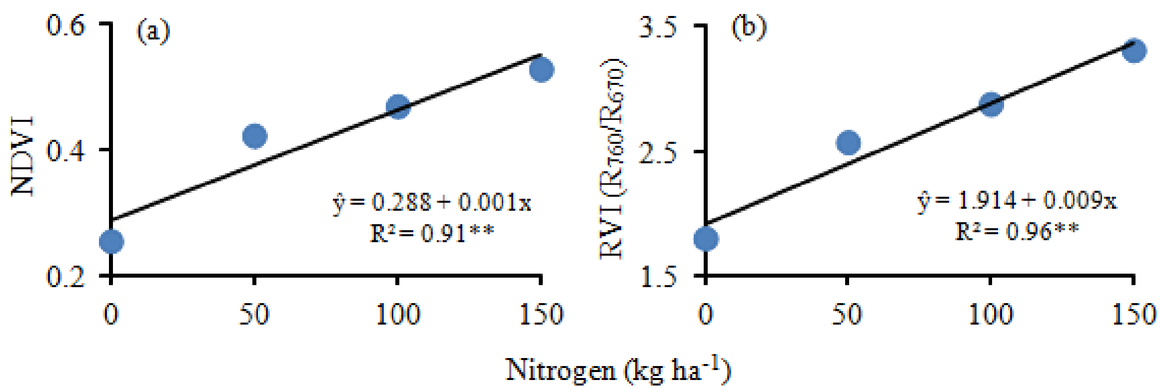

FIGURE 2. Relationships between NDVI (a) and simple ratio (RVI) (b) indexes of the Crop Circle ACS-470 active sensor and the nitrogen rates applied in topdressing in the wheat crop. **: P<0.01.

MOTOMIYA et al. (2009) explain that less nitrogen input results in decreases in chlorophyll and leaf expansion rate, and a decrease in plant development. Since the reflectance in the visible region of the electromagnetic spectrum varies in function of chlorophyll concentration in leaf tissue, the lower the supply of nitrogen to plants, also lower will be the level of chlorophyll and thus lower the absorption of radiation in the visible region, which causes reduction of NDVI and increase of IRVI.

The indexes of the two sensors, GreenSeeker 505 and Crop Circle ACS-470, correlated linearly with the nitrogen content in wheat flag leaf (Figure 3). Both sensors have shown similar responses as the nitrogen content in wheat leaves, but the correlations were not very close. The coefficients of determination (R^2) were 0.34 for the NDVI of the GreenSeeker, 0.33 for the IRVI of the GreenSeeker, 0.38 ~~to~~ for the NDVI of the Crop Circle, and 0.40 for the RVI of the Crop Circle. RISSINI (2011) and FREEMAN et al. (2003) obtained closer correlation between the readings of these sensors and the nitrogen content in the leaves for the same phenological stage of the wheat crop. However, in our study, the nitrogen contents in the wheat flag leaf showed small variations resulting from the nitrogen fertilization in topdressing, 35.6 g kg^{-1} (without nitrogen in topdressing) to 37.7 g kg^{-1} (with 150 kg ha^{-1} of nitrogen in topdressing), probably because of the large use by wheat plants of the soil nitrogen under no-tillage.

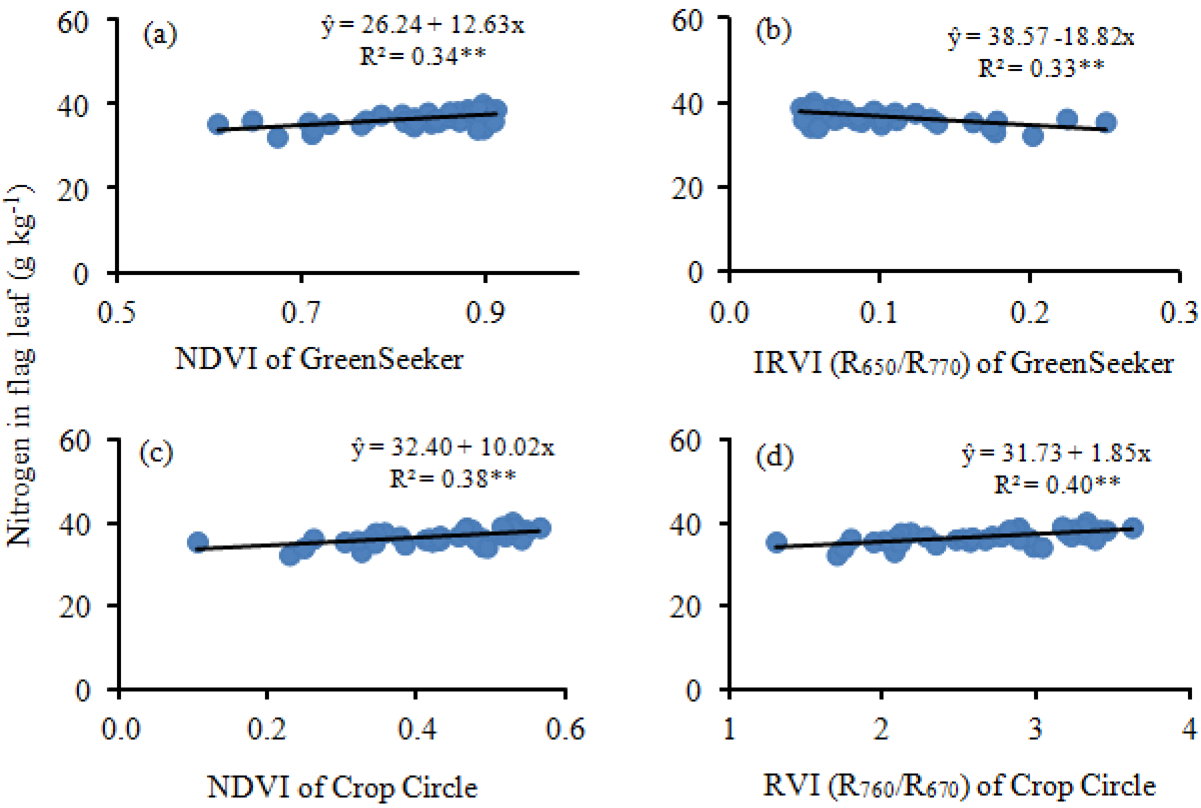

FIGURE 3. Relationships between the readings of the NDVI (a) and the inverse ratio (IRVI) (b) of the GreenSeeker 505 active sensor, and of NDVI (c) and the simple ratio (RVI) (d) of the Crop Circle ACS-470 active sensor, and the nitrogen content in the wheat flag leaf (n = 48). **: P<0.01.

The biomass production of the wheat shoot was correlated linearly (P<0.01) with the indexes obtained by the GreenSeeker 505 and Crop Circle ACS-470 active sensors (Figure 4). The coefficients of determination (R^2) of the adjustments between the sensor readings and biomass production of the wheat shoots were 0.60 for the NDVI of the GreenSeeker, 0.59 for the IRVI of the GreenSeeker, 0.61 for the NDVI of the Crop Circle, and 0.59 for the RVI of the Crop Circle. We noted closed correlations between the biomass production of the wheat shoot and the indexes obtained by the two sensors, showing that the sensors have similar performance for this purpose.

These results agree with the ones found by GROHS et al. (2009) using the GreenSeeker sensor in wheat and barley crops, and RISSINI (2011) using Crop Circle sensor for the same phenological stage of the wheat crop.

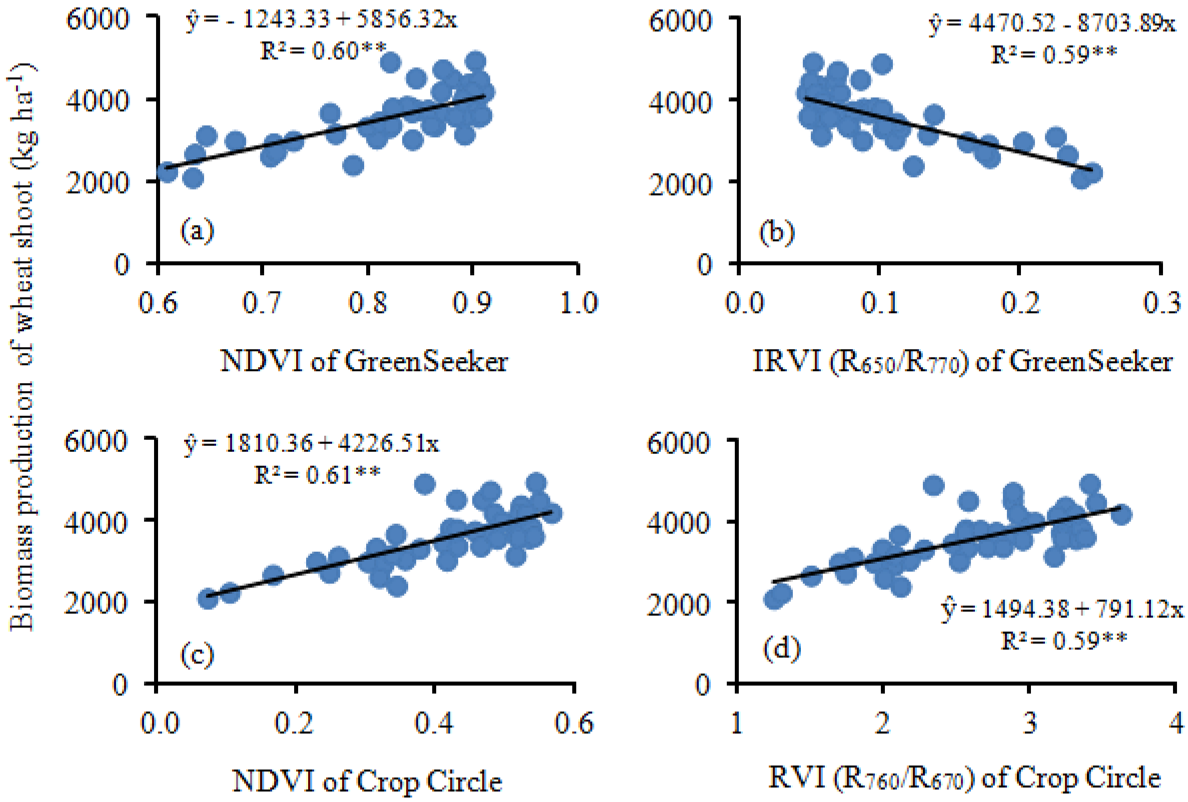

FIGURE 4. Relationships between the readings of the NDVI (a) and the inverse ratio (IRVI) (b) of the GreenSeeker 505 active sensor, and of NDVI (c) and the simple ratio (RVI) (d) of the Crop Circle ACS-470 active sensor, and the biomass production of the wheat shoot (n = 48). **: P<0.01.

Nitrogen uptake by wheat plants also correlated linearly (P<0.01) with the indexes obtained by the GreenSeeker 505 and Crop Circle ACS-470 active sensors (Figure 5). The coefficients of determination (R^2) of the adjustments between the sensor readings and nitrogen uptake by the wheat plants were 0.64 for the NDVI of the GreenSeeker, 0.62 for the IRVI of the GreenSeeker, 0.61 for the NDVI of the Crop Circle, and 0.61 for the RVI of the Crop Circle. Similar to what was observed for biomass production of the shoot (Figure 4), the correlations between nitrogen uptake by wheat plants and the indexes obtained by GreenSeeker and Crop Circle sensors were too closed, and the performance of GreenSeeker sensor was similar to the Crop Circle sensor (Figure 5).

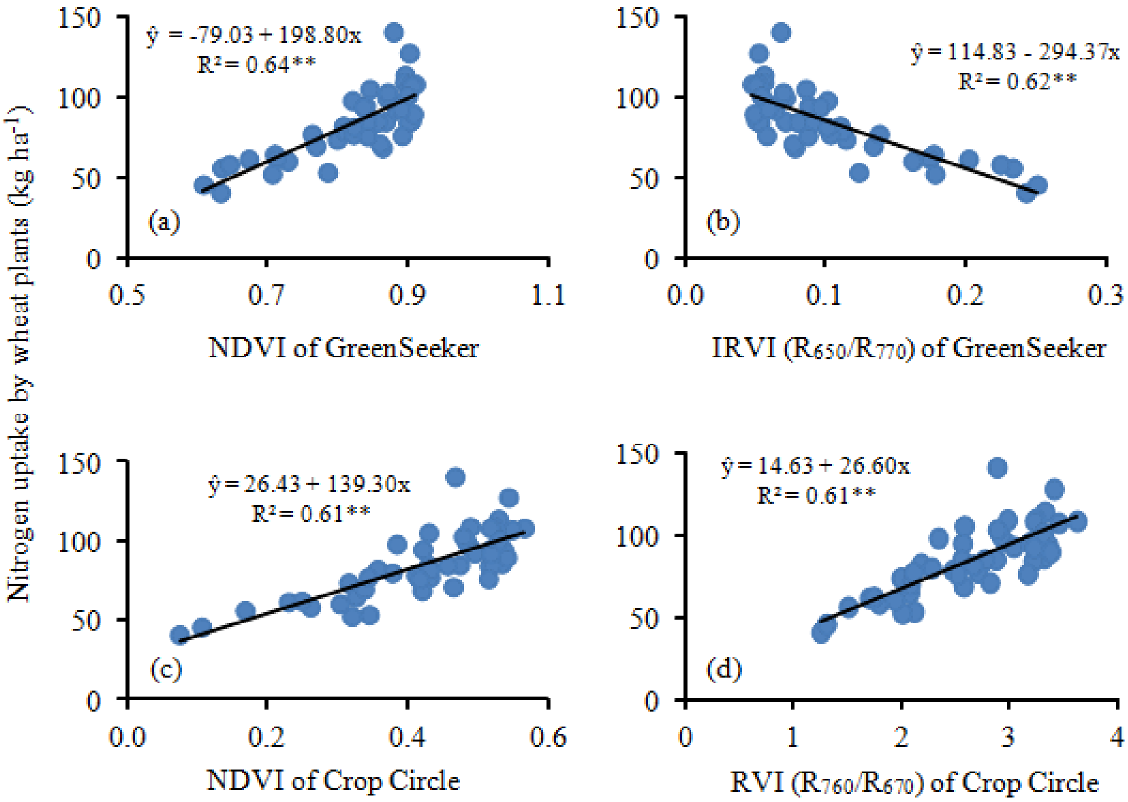

FIGURE 5. Relationships between the readings of the NDVI (a) and the inverse ratio (IRVI) (b) of the GreenSeeker 505 active sensor, and of the NDVI (c) and the simple ratio (RVI) (d) of the Crop Circle ACS-470 active sensor, and the nitrogen extraction by wheat plants (n = 48). **: P<0.01.

Wheat grain yield (x, in kg ha^{-1}) was linearly correlated (P<0.01) with the readings of NDVI ($\hat{y}$) obtained by the GreenSeeker 505 ($\hat{y}$ = 3332 + 2095x) and Crop Circle ACS -470 ($\hat{y}$ = 4500 + 1333x) active sensors, but the coefficients of determination (R^2) were very low, 0.24 and 0.19, respectively. This happened because the biomass production of the shoot evaluated at 91 days after the sowing, it had a very low correlation with the wheat yield (R^2 = 0.08). The GreenSeeker 505 and Crop Circle ACS-470 active sensors were sensitive to discriminate the biomass production of shoots (Figure 4), but the biomass produced was not correlated with wheat yield. However, it stands out in our study that the wheat grain yield was relatively high, around 4500 kg ha^{-1} in the absence of nitrogen fertilization in topdressing. With the nitrogen rates applied in topdressing in the wheat crop there was an increase in biomass production of shoots and, probably, the number of tillers and grains per panicle, but the grain yield did not follow this response because certainly there was no complete filling of the grains in the largest nitrogen rates applied. So, when the wheat grain yields are lower in the absence of topdressing nitrogen, it is possible that the correlation between the biomass production of the shoot and the crop grain yield, in response to nitrogen in topdressing, will be closer (POVH et al., 2008; RISSINI, 2011). Consequently, in this case, it is possible to estimate the grain yield by active optical sensors reading, since these can differentiate the biomass production during the crop cycle. However, our study showed that for high wheat yield this is not possible because the grain yield did not follow directly the gains in the biomass production of the crop shoot.

CONCLUSIONS

The readings of the canopy active sensors (GreenSeeker 505 and Crop Circle ACS-470) were sensitive to the variations of the nitrogen rates applied in topdressing of wheat crop under no-tillage and showed close and significant correlations with the biomass production and nitrogen uptake by wheat plants.

The GreenSeeker 505 and Crop Circle ACS-470 active sensors showed similar efficiency in the discrimination of the shoot biomass production and the nitrogen nutritional status of wheat crop. The wheat grain yield was high and did not follow the gains in the biomass production of the crop shoot.

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