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Using GNIR and RNIR Extracted by Digital Images to Detect Different Levels of Nitrogen in Corn

Aline de Carvalho Gasparotto, Marcos Rafael Nanni, Carlos Antonio da Silva Junior, Everson Cesar, Franciele Romagnoli, Anderson Antonio da Silva and Gabriel Cipolaro Guirado
Department of Agronomy, State University of Maringá (UEM), 87020-900, Maringá, Paraná, Brazil

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Corresponding Author:
Carlos Antonio da Silva Junior,
Department of Agronomy,
State University of Maringa, Av.
Colombo, 5790-Bloco J45,
Postal Code 87020-900, Maringá,
Paraná, Brazil

ABSTRACT

This study aimed to evaluate the use of vegetation indices, GNIR and RNIR extracted from digital images and using a spectroradiometer in the adjustment models for discrimination nitrogen levels in corn, evaluate the contents and their relationship with corn production components. The experiment was established in a greenhouse with a corn plant per pot in DIC with 5 treatments (0, 50, 100, 200 and 300 kg ha^{-1} of nitrogen) and 10 repetitions. Evaluations were performed at 15, 30, 45, 60 and 80 DAE, with capturing images using the 720 nm-IR filters, 850 nm-IR and UV-IR cut in a digital camera Fujifilm IS Pro and spectroradiometer readings were used the Spring and Excel software to calculate GNIR and RNIR vegetation indices. The GNIR showed higher sensitivity for assessment of nitrogen deficiency in maize. The use of camera appeared as a promising tool for nitrogen discrimination. The use 720 nm filter was higher to 850 nm. The best times to break down the nitrogen doses evaluated by vegetation indices were 60 and 80 DAE.

Key words: Spectroradiometer, photography, sensor

INTRODUCTION

Agricultural areas of difficult access as well as large tracts generate difficulty in monitoring. Thus, there is a need to develop techniques to assist in identifying nutritional stress and yield components.

In the case of agricultural crops, use remote sensing technology for establishing and monitoring their nutritional status, cultural booth, productivity and production, among others.

Several researchers concluded that vegetation indices correlate with the levels of N and productivity (Sakamoto *et al*., 2002; Han *et al*., 2001).

Obtaining the vegetation indices have been accomplished by using digital image sensors aboard orbital, suborbital and terrestrial platforms. Among the terrestrial sensors stand out spectrometers and spectroradiometers, which do not generate images, but record the reflected reflectance and/or absorbed targets.

However, all these devices have high cost, specialized training and there is not always possible use in areas, where access is limiting. Thus, we seek more economic alternatives, easy to handle and they can access different planting areas. One alternative has been used for aerial photographs.

There are digital cameras on the market that can provide image capture systems in the visible and near infrared (350-1100 nm). However there is no research on the effectiveness of these imaging systems as to their use in assessing the nutritional status of crops.

Bausch and Duke (1996) showed that the use of the radiometer to measure the reflectance in the green corn and near infrared range can be used to predict the amount of nitrogen by plants such as N spectrum bands doses of the differences are sensitive used in corn (Sakamoto *et al*., 2002). Blackmer *et al*. (1996) found that the best range of the spectrum (400-1000 nm) to be used to detect the N deficiency in maize is between 550 and 710 nm.

The variability of corn yield and monitoring timeline, can be predicted and performed by aerial photographs. According to Diker *et al*. (2001), NDVI vegetation index, obtained by false-color infrared film photos with Kodak, presented R² of 0.8 with the corn yield in R5 stage.

According to Gopalapillai *et al*. (1998), the reflectance of the canopy of the maize crop, with photographs areas of high resolution infrared, showed good correlation with the nutritional status of the N element in the canopy at 75 days after sowing; the use of the red range of the spectrum could be used to predict the productivity of corn with a coefficient of determination of 0.96.

A determination coefficient of 0.94 was found on corn in the V6 stage, between the amount of chlorophyll present in maize and vegetation index NIR/green (Tumbo *et al*., 2002).

Varella *et al*. (2003) were able to differentiate between N levels in maize; the study was conducted with photos in the red band, green, blue and near-infrared captured by a digital camera located 50 cm away from the plant. These images were used for the calculation of vegetation indices and there was a multiple linear regression analysis to evaluate the prediction of levels of N.

For that, this study aims to propose linear models GNIR and RNIR extracted from images obtained by conventional digital cameras and spectroradiometer, evaluate the use of GNIR and RNIR for discrimination of nitrogen in corn, assess the relationship between GNIR and RNIR with corn production components.

MATERIAL AND METHODS

Study area: The experiment was conducted in a greenhouse at the State University of Maringá (UEM), was used a Completely Randomized Design (CRD) with 5 treatments (0, 50, 100, 200 and 300 kg ha^{-1} N) and 10 repetitions, each plot had a 10 L capacity with a plant maize cultivar 30A68 Morgan. The N source used was diluted urea in water, the dosage of 30 kg ha^{-1} N in sowing, the remaining total doses were applied in bands at 20 and 27 DAE. The treatment of 0 kg ha^{-1} N did not receive doses of N.

Soil analysis: For completing the experiment vessels we used a B horizon of a typic medium textured dystrophic being adjusted according to the need of fertilization, as recommended by Alves *et al*. (1999). The base saturation (V%) was raised to 60% and sowing took place on 09/13/2013 with 5 seeds per pot, being thinned in V2 growth stage.

Spectral analysis: The radiometric readings were taken at 15, 30, 45, 60 and 80 DAE, through portable spectroradiometer Field Spec 3 with spectral range of 350-2500 nm, using the accessory ASD Plant Probe to perform the readings in the greenhouse. The data was converted from asd extension .txt to the program View Spec Pro ASD (ASD, 2008). With coletatos data was determined RNIR of vegetation index (Richardson and Wiegand, 1977) and GNIR (Bausch and Duke, 1996).

For data acquisition with the camera used the Fujifilm IS Pro camera 5 UVIR (12.1 megapixels) with sensor Super CCD SR Pro (16-bit) with spectral range of 380-1000 nm. To capture the images, first has established one white balance (WB) custom and pre-defined for each filter, with IR 720, 850 nm IR and UV/IRcut. All images were captured with a sensitivity index of ISO100, format Tagged Image File Format (TIFF) and in size L (4256×2848 pixels). The photographic record was made at 15, 30, 45, 60 and 80 DAE with the tripod for camera fixation getting this far 30 cm sheet with an inclination of 45º. The infrared images were modified to grayscale by FinePixViewer software. For each picture there was the average of the digital numbers of the bands RGB, separately, a framework of 21×21 pixels, established by the algorithm "read pixels" in software (Spring version 5.2.3). The average digital numbers for the red channel, green and NIR were determined for photo portion that received higher light intensity. With the digital numbers, we calculate the GNIR and RNIR vegetation indices.

Camera calibration: Plastic sheeting in various colors (red, green, black, gray and beige), were used to calibrate the camera. This is because the image consists of pixels, whose values of their digital number is necessary ("digital numbers") are proportionally related to the amount of energy reflected under certain lighting conditions. For this, the spectral reflectance of the tarpaulins were measured by the spectroradiometer, the values of the average spectral reflectance factor of the bands for green, red and NIR were compared with the average value of the numbers of the pixels from digital images of the same ply.

Corn yield was evaluated at 80 DAE, dry mass, cool mass of shoots being evaluated, leaf area and leaf nitrogen (Semi-micro-Kjeldahl) method with decomposition by sulfuric acid digestion 2nd Malavolta *et al*. (1997).

Statistical analysis: Statistical analyzes of the data obtained during the experiment were evaluated using the Shapiro-Wilk and Levene tests by Sisvar software ($p<0.05$) and regression analysis by the same software and also by pearson correlation and t-test ($p<0.05$) ($p<0.01$).

RESULTS AND DISCUSSION

Digital still camera calibration: The adjusted equations, coefficients of determination and pearson correlation of relations between images and spectroradiometer are presented in Table 1. All the evaluated spectrum bands were highly correlated pearson being greater than 0.9 and significant by t-test ($p<0.01$). Thus, there is a preliminary analysis of the possible use of the camera as a replacement to the spectroradiometer. Furthermore, in correlation with NIR bands of the 2 sensors, it is observed that the filter 720 nm use in camera provided better results than using a 850 nm filter, the green band and also has the highest correlations that the red band.

Small variations should probably lack of standardization of a material with color, since it is common plastic sheets. Even so, the R^2 values were high and significant allowing the continuity.

Respect of the evaluation of corn production components and nitrogen levels to 80DAE: Table 2 presents the results of Levene tests, Shapiro Wilk and the analysis of variance of the

Table 1: Adjusted equations, coefficients of determination and pearson correlation of images with the spectroradiometer

Variables	Fitted equation	R²	r
Red band			
Spectroradiometer vs filter UV-IR cut	y = 38.422+204.99x	0.8961	0.947**
Green band			
Spectroradiometer vs filter UV-IR cut	y = 39.606+299.56x	0.973	0.986**
NIR band			
Spectroradiometer vs filter 720 (nm)	y = 19.246+177.28x	0.961	0.980**
NIR band			
Spectroradiometer vs filter 850 (nm)	y = 26.277+113.07x	0.905	0.951**

**Significant ($p<0.01$)

Table 2: Test result F of regression analysis of variance models

Parameters	Shapiro Wilk (W_{calc})	Levene (F_{calc})	Lack of fit (F_{calc})	Linear regression (F_{calc})	Regression quadratic (F_{calc})
DM	0.957^{ns}	0.907^{ns}	0.421^{ns}	0.201^{ns}	8.891*
CM	0.969^{ns}	2.584*	-	-	-
LA	0.974^{ns}	1.740^{ns}	0.850^{ns}	0.785^{ns}	9.605*
LN	0.975^{ns}	2.103^{ns}	0.295^{ns}	116.277*	1493.0^{ns}

*Significant ($p<0.05$), ns: Not significant, DM: Dry mass values, CM: Cool mass, LA: Leaf area and LN: Leaf nitrogen

Table 3: Equations adjusted for the ratio N and attributes of corn

Attributes	Adjusted equation	R²
Dry mass	$Y = -0.0003x^2+0.1076x+20.847$	0.8373*
Leaf area	$Y = -0.000004x^2+0.0012x+0.1865$	0.9695*
Leaf nitrogen	$Y = 0.0054x+1.2334$	0.9667*

*Significant ($p<0.05$)

regression for the 50 samples of each attribute assessed in maize. The variable cool mass showed no homogeneity of variance invalidating its regression analysis.

Parameters of the coefficients of the adjusted regression equations were signicativos ($p<0.05$) and is therefore valid. The determination coefficient equation and are presented in Table 3.

The dry mass values maize in relation to the N rates, the adjusted equation presented as maximum point value of 157.8 kg ha^{-1} of N applied which provided 29.33 g of dry mass per plant. Similar data were found by Araujo *et al.* (2004) in field conditions found maximum response for dry mass production with 180 kg ha^{-1} of N.

Nitrogen dosages situated above the curve inflection point tended to increase negative values of DM. May be related adverse influence of the excess N, contributing to high denitrification nutrient greater volatilization element toxicity inducing in the plant and soil acidification of the high dose, one time of application of the source was urea.

The leaf area in relation to N rates showed a quadratic behavior with a maximum point of 145.63 kg ha^{-1} of N applied to 0.27 m² of AF. Higher doses provided N decreased leaf area.

For leaf nitrogen content in relation to N rates gave a positive linear behavior of the variable. Cerrato and Blackmer (1991) estimated that the critical N content in maize leaf is 2.1%, the content of the fitted equation matches the dose of 160.5 kg ha^{-1} N, with a value close to average dose found about 150 kg ha^{-1} N which obtained the highest dry mass and leaf area.

The pearson correlations to 80 DAE between the evaluated attributes corn (DM, CM, LA, LN) and the N rates (Table 4) showed 60% of the correlations classified as strong positive and 40% of them classified as moderate positive. The test for the significance, it has to be about 83.3% have r ($p<0.01$), 13.3% have r ($p<0.05$) and only 3.3% were not significant, indicating, thus the strong relationship between the evaluated corn attributes.

Evaluation of the relationship between the nitrogen and GNIR and RNIR obtained by the spectroradiometer and the infrared images obtained with 720 and 850 nm filter: Regression analyzes were performed to check the existence of significant functional relationship between the dependent variables (vegetation indexes) and the independent variable (N levels) in all the analyzed periods (15, 30, 45, 60 and 80 DAE). The range of values obtained by GNIR and RNIR are between 0.4-0.9 and 0.3-0.8, respectively. Indexes GNIR and RNIR are simple ratios between bands of the visible spectrum and the near infrared band with an inverse relationship. Thus, malnourished plants have higher rates than nutritionally balanced plants.

All data presented to 15 DAE homogeneity and normality, and the lack of no significant adjustment validating the regression (Table 5). But regression was not significant by F test, which indicates that for the tested models was not possible to establish a significant functional relationship. This was expected since total fertilizer had not yet been finalized and is the ground only with the N doses used in sowing. Similar results were found by Rozas and Echeverria (1998), who considered the stage 6-7 leaves of corn for the inappropriate use of chlorophyll to separate areas with different fertilization with N, N is not limiting for corn, up to that stage (Argenta, 2001).

Thus, the 15 DAE, with the analysis of the adjusted models, it was found that the N application had no significant effect on the mean values of the studied vegetation indices.

All indices showed showed normality and homogeneity of variance to 30 DAE (Table 6). All setting faults were not significant validating the regressions found. Yet we obtained significant regressions for the studied indices. Thus, the quantity of N application could not be detected to 30 DAE, the studied methods.

Table 7 shows the results of basic statistical assumptions having only lack of homogeneity of variance for RNIR index with the filter using 850 and 720 nm. All indexes showed no lack of significant adjustment, validating the regressions. For

Table 4: Results of pearson correlation coefficients and t-test to 80 DAE

Nitrogen rate	DM×LA	DM×CM	DM×LN	LA×CM	LA×LN	CM×LN
0	0.850**	0.695*	0.544^{ns}	0.754**	0.764**	0.744**
50	0.828**	0.900**	0.766**	0.771**	0.632*	0.603*
100	0.925**	0,774**	0.855**	0.817**	0.864**	0.683*
200	0.908**	0.884**	0.937**	0.769**	0.940**	0.843**
300	0.993**	0.853**	0.839**	0.819**	0.826**	0.912**

**Significant (p<0.01), *significant (p<0.05), ns: not significant, DM: Dry mass, LA: Leaf area, CM: Cool mass and LN: Leaf nitrogen

Table 5: F-test result analysis of variance of regression between N rates and vegetation indexes (VI) for each sensor used to set 15 DAE

	VI	Shapiro-Wilk (W_{calc})	Levene (F_{calc})	Lack of adjustment (F_{calc})	Linear regression (F_{calc})	Quadratic regression (F_{calc})
Filter-720 (nm)	GNIR	0.988^{ns}	0.457^{ns}	1.632^{ns}	0.480^{ns}	0.783^{ns}
	RNIR	0.974^{ns}	0.683^{ns}	2.172^{ns}	0.132^{ns}	0.117^{ns}
Filter-850 (nm)	GNIR	0.975^{ns}	0.317^{ns}	0.543^{ns}	0.107^{ns}	3.663^{ns}
	RNIR	0.986^{ns}	0.872^{ns}	0.297^{ns}	0.009^{ns}	0.320^{ns}
Spectroradiometer	GNIR	0.968^{ns}	1.956^{ns}	1.043^{ns}	0.036^{ns}	2.382^{ns}
	RNIR	0.964^{ns}	1.117^{ns}	0.842^{ns}	0.157^{ns}	0.657

ns: Not significant

Table 6: F-test result analysis of variance of regression between N rates and vegetation indexes for each sensor used to set 30 DAE

	VI	Shapiro-Wilk (W_{calc})	Levene (F_{calc})	Lack of adjustment (F_{calc})	Linear regression (F_{calc})	Quadratic regression (F_{calc})
Filter-720 (nm)	GNIR	0.960^{ns}	1.696^{ns}	0.519^{ns}	3.079^{ns}	0.739^{ns}
	RNIR	0.984^{ns}	0.805^{ns}	0.130^{ns}	1.687^{ns}	0.325^{ns}
Filter-850 (nm)	GNIR	0.983^{ns}	0.611^{ns}	0.134^{ns}	0.003^{ns}	0.184^{ns}
	RNIR	0.874^{ns}	$1,416^{ns}$	0.355^{ns}	0.002^{ns}	1.123^{ns}
Spectroradiometer	GNIR	0.969^{ns}	2.217^{ns}	0.134^{ns}	0.003^{ns}	0.184^{ns}
	RNIR	0.987^{ns}	0.607^{ns}	0.355^{ns}	0.002^{ns}	1.123^{ns}

**Significant (p<0.01), *significant (p<0.05), ns: Not significant

Table 7: F-test result analysis of variance of regression between N rates and vegetation indexes for each sensor used to set 45 DAE

	VI	Shapiro-Wilk (W_{calc})	Levene (F_{calc})	Lack of adjustment (F_{calc})	Linear regression (F_{calc})	Quadratic regression (F^{calc})
Filter-720 (nm)	GNIR	0.971^{ns}	2.360^{ns}	1.055^{ns}	20.173*	6.537*
	RNIR	0.969^{ns}	4.108*	-	-	-
Filter-850 (nm)	GNIR	0.985^{ns}	2.360^{ns}	0.826^{ns}	24.564*	4.951*
	RNIR	0.969^{ns}	4.108*	-	-	-
Spectroradiometer	GNIR	0.991^{ns}	0.326^{ns}	2.105^{ns}	2.816^{ns}	7.871*
	RNIR	0.959^{ns}	0.481^{ns}	1.396^{ns}	1.086^{ns}	2.274^{ns}

*Significant (p<0.05), ns: Not significant

RNIR index obtained by the spectroradiometer was not found a significant model to explain the levels of nitrogen in corn.

To 45 DAE using the GNIR index, we could distinguish the N levels by spectroradiometer use and the digital images. Demonstrating that the use of green electromagnetic spectrum range has greater sensitivity for the detection of nitrogen that the use of the red band of the spectrum. According to Wu *et al*. (2007), the crop development stage for the detection of N is extremely important, because if the identification is very late, there will be no possibility for N deficiency correction in the same production cycle.

In Table 8 shows that all estimates of regression parameters were significant validating the regressions found. All significant and valid regressions presented quadratic behavior and determination coefficients above 70%.

The coefficients of determination of the images with the filter using 720 and 850 nm to 45 DAE were higher than those obtained using the spectroradiometer. This fact can be explained by means better fit the equations generated to explain the variable than a single value obtained by the sensor.

However this rate may be overestimated, because the contents of the images had Variation Coefficient (CV) around 22.07% and were classified as high, while using the spectroradiometer was obtained on average 14.14% classified as medium. Thus we have, in the use of higher accuracy for detecting the N spectroradiometer, as both regressions were significant at 0.05 probability. In addition, larger standard error of the mean values were obtained by regression of images and values using the spectroradiometer.

The behavior of the variable GNIR with 720 nm filter presenting a minimum point of 212.4 kg ha^{-1} N GNIR generating an index of 0.66.

The behavior of the variable GNIR with 850 nm filter with minimum point the amount of 248.4 kg ha^{-1} N providing an index of 1.03. However, this result was different from that obtained by Sakamoto *et al*. (2012) that using the compact digital camera Nikon COOLPIX P5100 and filter 830 nm found for corn in approximately V6 stadium - V7 the value of 0.43 for the GNIR.

The spectroradiometer generated a significant regression for GNIR index, having a minimum point of 153.5 kg ha^{-1} N providing a GNIR index of 0.29.

Table 9 presents the results of basic statistical assumptions and the analysis of variance for regression and lack of adjustment to 60 DAE. Thus, there is the VI's for the three methods showed homogeneity of variance and normality

Table 8: Estimates of the parameters, mean standard error and the t-test for the regression coefficients of linear models adjusted to 45 DAE between vegetation indices and N rates for each sensor used

F-test	VI	Variables	SE	EP	t	R²
Filter-720 (nm)						
	GNIR	β0	5.27E-02	1.02E+00	19.43*	0.9268
		β1	9.29E-04	-3.40E-03	-3.66*	
		β2	2.95E-06	8.00E-06	2.56*	
Filter-850 (nm)						
	GNIR	β0	7.33E-02	1.59E+00	21.68*	0.947
		β1	1.29E-03	-4.47E-03	-3.46*	
Spectroradiometer						
		β2	4.11E-06	9.00E-06	2.23*	
	GNIR	β0	1.11E-02	3.37E-01	30.53*	0.7174
		β1	1.95E-04	-6.14E-04	-3.15*	
		β2	6.20E-07	2.00E-06	2.81*	

*Significant ($p<0.05$)

Table 9: F-test result analysis of variance of regression between N rates and vegetation indices for each sensor used to set 60 DAE

F-test	VI	Shapiro-Wilk (W_{calc})	Levene (F_{calc})	Lack of adjustment (F_{calc})	Linear regression (F_{calc})	Quadratic regression (F_{calc})
Filter-720 (nm)						
	GNIR	0.982^{ns}	0.794^{ns}	0.124^{ns}	53.700*	35.502*
	RNIR	0.990^{ns}	1.063^{ns}	0.190^{ns}	24.923*	17.865*
Filter-850 (nm)						
	GNIR	0.987^{ns}	2.013^{ns}	0.259^{ns}	47.144*	31.305*
	RNIR	0.966^{ns}	1.496^{ns}	0.024^{ns}	27.093*	19.604*
Spectroradiometer						
	GNIR	0.982^{ns}	1.818^{ns}	1.381^{ns}	1.994^{ns}	11.073*
	RNIR	0.965^{ns}	2.634*	-	-	-

*Significant ($p<0.05$), ns: Not significant

Table 10: The EP, SE and the t-test for the regression coefficients of linear models adjusted to 60 DAE between vegetation indices and N rates for each sensor used

t-test	VI	Variables	SE	EP	t	R²
Filter-720 (nm)	GNIR	β0	2.31E-02	6E-01	27.468*	0.9972
		β1	4.07E-04	-3E-03	-7.689*	
		β2	1.29E-06	8E-06	5.958*	
	RNIR	β0	2.74E-02	5E-01	20.021*	0.9912
		β1	4.83E-04	-3E-03	-5.400*	
		β2	1.54E-06	6E-06	4.227*	
Filter-850 (nm)	GNIR	β0	3.18E-02	8E-01	25.795*	0.9935
		β1	5.61E-04	-4E-03	-7.216*	
		β2	1.78E-06	1E-05	5.595*	
	RNIR	β0	3.40E-02	7E-01	20.844*	0.999
		β1	5.99E-04	-3E-03	-5.650*	
		β2	1.90E-06	8E-06	4.428*	
Spectroradiometer	GNIR	β0	1.32E-02	4E-01	26.905*	0.8255
		β1	2.33E-04	-8E-04	-3.583*	
		β2	7.40E-07	2E-06	3.328*	

*Significant ($p<0.05$)

of distribution, except for the spectroradiometer RNIR index that obtained Levene test for significance, without homogeneity of variance.

The lack of regression adjustment were all not significant validating the regressions found.

Table 10 shows the t test for the estimated regression parameters, which are all significant and is therefore valid regressions.

To 60 DAE in all significant regressions found, the VI's presented quadratic behavior and R^2 higher than 80%.

The coefficients of determination of the images with the filter using 720 and 850 nm to 60 DAE were higher than those obtained using the spectroradiometer. This fact can be explained by means better fit the equations generated to explain the variable than a single value obtained by the sensor. However this R² may be overestimated because the contents of the images had CV around 21.64% and were classified as high, while using the spectroradiometer was obtained on average 14.84% classified as medium. Thus we have, in the use of higher accuracy for detecting the N spectroradiometer, as both regressions were significant ($p<0.05$). Furthermore, it has greater SE by using the image rather than using the spectroradiometer.

The GNIR and RNIR variables obtained with the filter of 720 nm to 60 DAE, had a quadratic behavior. The variable GNIR presented as minimum point the value of 195, 75 kg ha^{-1} N to generate an index of 0.33 and the RNIR variable showed a quadratic behavior with minimum point of 217.5 kg ha^{-1} N to an index of 0.26.

The GNIR and RNIR indexes obtained with the filter of 850 nm to 60 DAE had for GNIR a minimum point in 202.45 kg ha^{-1} N and 0.41 index. The RNIR presented a minimum point of 211.5 kg ha^{-1} N providing an index of 0.35. However, this result was different from that obtained by Sakamoto *et al*. (2012) that using the compact digital camera Nikon COOLPIX P5100 and filter 830 nm found for corn at the stadium approximately V8-V10 the value of 0.5 for the GNIR and 0.58 for RNIR.

The VI's GNIR found using the spectroradiometer in relation to N rates, the variable presented as minimum point value of 208.5 kg ha^{-1} N providing an index 0.27.

80 DAE the results of the basic assumptions and regression analysis of variance are presented in Table 11. All variables showed normal errors and homogeneity. All regression deviations were also no significant validating the significant regressions found, except for RNIR index with 720 nm filter that had significance for the lack of adjustment. Table 12 shows the t-test for the parameter estimates of significant regressions. Thus, all regressions were found valid.

Table 8 shows the regression generated from GNIR acquired with the use of images shot with 720 nm filter regarding the N rates, showing the quadratic behavior of GNIR having a minimum point of 200.5 kg ha^{-1} N for an index of 0.34.

Table 9 and 10 show the regressions generated from vegetation indices acquired with the use of images shot with 850 nm filter with respect to N rates showing GNIR and RNIR, respectively and in GNIR a minimum point 215.22 kg ha^{-1} N for an index of 0.43 and a minimum RNIR point of 187.06 kg ha^{-1} N for a rate of 0.37. However, these results were obtained by different ways of Sakamoto *et al*. (2012) that with the use of the compact digital camera and Nikon COOLPIX P5100 filter 830 nm found for maize in the stadium approximately V12-V15 to the value of 0.47 and 0.58 for RNIR and GNIR.

The VI's acquired using the spectroradiometer regarding the N rates, showing the quadratic behavior of GNIR and RNIR variables respectively and in GNIR a minimum point of 221.75 kg ha^{-1} N for an index of 0.25 and a minimum RNIR point of 218.33 kg ha^{-1} N for an index of 0.21. According to Souza *et al*. (2009) V12-V15 in corn stage using the radiometer Crop Circle gave average values of 0.24 GNIR; 0.16 and 0.13 and the values RNIR 0.11, 0.1, 0.08 with the respective doses of N 90, 180 and 270 kg ha^{-1}. Li *et al*. (2014) found using the Crop Circle sensor on average V6-V12 stages RNIR values of 0.06 and 0.04 for the respective doses of N 50 and 100 kg ha^{-1}.

The quadratic behavior of VI's in relation to N rates, due to the fact that the contents are in good agreement with this chlorophyll content in leaves, and thus indirectly related to N. According to content Bullock and Anderson (1998), the green color of the leaves is due to the presence of chlorophyll, thereby increasing the availability of nitrogen to plants leads to an increase in the amount of chlorophyll present, improves the perception of color of the green sheet. This increase in chlorophyll has a quadratic generating the same behavior as the spectral index, has a maximum point called photosynthetic maturity point from, which remains invariable, even with the increase of nitrogen concentration in the tissue. Moreover, the curvilinear plant growth, caused the vegetation indexes to present a better fit of the regression analysis using the linear model of the second degree.

The VI's generally showed slight increase in GNIR and RNIR indices with the application of doses above 200 kg ha^{-1} of N, which may be related to the possibility of nutritional imbalance of the plant with high doses of N applied (Dougherty and Rhykerd, 1985).

The GNIR index allowed the highest coefficients of determination in all DAE. According Gitelson *et al*. (1996).

Table 11: F-test result analysis of variance of regression between N rates and vegetation indices for each sensor used to set 80 DAE

F-test	VI	Shapiro-Wilk (W_{calc})	Levene ($_{Fcalc}$)	Lack of adjustment (F_{calc})	Linear regression (F_{calc})	Quadratic regression (F_{calc})
Filter-720 (nm)	GNIR	0.982^{ns}	1.174^{ns}	1.653^{ns}	65.489*	37.529*
	RNIR	0.980^{ns}	1.195^{ns}	3.819*	55.895*	59.928*
Filter-850 (nm)	GNIR	0.979^{ns}	0.504^{ns}	0.810^{ns}	96.429*	57.131*
	RNIR	0.984^{ns}	0.681^{ns}	29.650^{ns}	63.299*	54.495*
Spectroradiometer	GNIR	0.965^{ns}	0.847^{ns}	2.760^{ns}	135.744*	83.310*
	RNIR	0.967^{ns}	1.476^{ns}	2.598^{ns}	86.612*	64.667*

*Significant (p<0.05), ns: Not significant

Table 12: The EP, SE and the t-test for the regression coefficients of linear models adjusted to 80 DAE between VI and N rates for each sensor used

t-test	VI	Variables	SE	EP	t	R²
Filter-720 (nm)	GNIR	β0	1.98E-02	6.21E-01	31.42*	0.9689
		β1	3.49E-04	-2.81E-03	-8.05*	
		β2	1.11E-06	7.00E-06	6.13*	
Filter-850 (nm)	GNIR	β0	2.22E-02	8.49E-01	38.22*	0.9896
		β1	3.92E-04	-3.87E-03	-9.89*	
		β2	1.24E-06	9.00E-06	7.56*	
	RNIR	β0	2.07E-02	6.90E-01	33.34*	0.9521
		β1	3.65E-04	-3.37E-03	-9.23*	
		β2	1.16E-06	9.00E-06	7.38*	
Spectroradiometer	GNIR	β0	8.46E-03	4.46E-01	52.69*	0.9754
		β1	1.49E-04	-1.77E-03	-11.89*	
		β2	4.70E-07	4.00E-06	9.13*	
	RNIR	β0	7.27E-03	3.53E-01	48.57*	0.9668
		β1	1.28E-04	-1.31E-03	-10.22*	
		β2	4.10E-07	3.00E-06	8.04*	

*Significant (p<0.05)

leaves, therefore, to establish a methodological standard to Similar results were found by Da Silva *et al*. (2007), which concluded that the use of the calculated indices with a green stripe, extracted from digital images were more efficient for determining the leaf N content of pasture than the calculated indices with red band, in all periods studied.

Evaluation of the relationship between the spectroradiometer vegetation indices and infrared images of the vegetation indices obtained with 720 and 850 nm filters: Looking at Table 13 it appears that the smaller pearson correlation coefficients (r) were found to 15 DAE and the highest rates in the 80 DAE having all significance. It is also noticed an increase in correlation between the contents of the spectroradiometer and VI's obtained through the images is associated with the development of culture because, in the later stages of the crop coefficient increases.

As the N deficiency increases the spectroradiometer values over the images correlated better. Thus, the use of the camera to N deficiency detection in corn could be used in 60 DAE and 80 DAE in a significant correlation in all indices studied and with 720 nm filter usage correlations were higher than with the 850 nm filter usage.

The low correlation between the indices in the early development stages of maize can be explained by the high CV of the samples in the first evaluations as camera use. This is probably due to the small filling the field image by corn obtain the images, some areas did not meet the target field, with background of dark areas that may have influenced the values of pixels referring leaves captured in pictures. In the course of development of the maize plant, the target field is being filled substantially only with issues concerning the sheets in the infrared, exhibit high reflectance.

Although the experiment was conducted in a greenhouse, the possibility of minor variations caused by changes in solar radiation and temperatures which may cause unintended errors.

The use of 720 nm filter provided images brighter than images taken with the filter of 850 nm, so the images brighter had smaller areas with dark coloring that theoretically, it could influence the pixels of the images thus providing better correlation coefficients between vegetation indices obtained filter usage by the 720 nm and indexes by the spectroradiometer.

The relationship of vegetation indices rating extracted with 720 nm filter and 850 nm and the spectroradiometer indexes with leaf nitrogen content, cool mass, dry mass and leaf area: The Pearson correlation (r) between the components to 80 DAE evaluated in corn and vegetation indices were high. According to the Table 14 it is observed that the dry mass according to the index obtained through the 720 nm filter showed 50% r ($p<0.01$), 20% of r ($p<0.05$) and 30% r not significant.

Table 13: Pearson correlation coefficients and t test between VI found by using the spectroradiometer and the images using a filter of 720 and 850 nm

	VI spec.vs VI image (720 nm)		VI spec.vs VI image (850 nm)	
t-test and dose	RNIR	GNIR	RNIR	GNIR
15 DAE				
0	0.50^{ns}	0.48^{ns}	0.33^{ns}	0.18^{ns}
50	0.61*	0.67*	0.74**	0.81**
100	0.25^{ns}	0.36^{ns}	0.58*	0.62*
200	0.22^{ns}	0.27^{ns}	0.04^{ns}	0.13^{ns}
300	0.54^{ns}	0.60*	0.04^{ns}	0.00^{ns}
30 DAE				
0	0.26^{ns}	0.18^{ns}	0.23^{ns}	0.17^{ns}
50	0.55^{ns}	0.25^{ns}	0.44^{ns}	0.18^{ns}
100	0.48^{ns}	0.58*	0.52^{ns}	0.69*
200	0.71*	0.65*	0.42^{ns}	0.35^{ns}
300	0.41^{ns}	0.68*	0.52^{ns}	0.61*
45 DAE				
0	0.34^{ns}	0.40^{ns}	0.33^{ns}	0.31^{ns}
50	0.60*	0.73**	0.62*	0.68*
100	0.33^{ns}	0.63*	0.22^{ns}	0.61*
200	0.68*	0.90**	0.60*	0.58*
300	0.64*	0.62*	0.74**	0.60*
60 DAE				
0	0.66*	0.71*	0.56*	0.62*
50	0.88**	0.91**	0.90**	0.91**
100	0.70*	0.78**	0.79**	0.70*
200	0.87**	0.78**	0.84**	0.65*
300	0.63*	0.82**	0.66*	0.81**
80 DAE				
0	0.76**	0.77**	0.65*	0.71*
50	0.87**	0.89**	0.92**	0.91**
100	0.74**	0.78**	0.66*	0.75**
200	0.67*	0.87**	0.71*	0.69*
300	0.74**	0.85**	0.64*	0.86**

**Significant ($p<0.01$), *Significant ($p<0.05$), ns: Not significant

Table 14: Pearson correlation and t test for vegetation indices obtained through the images taken with the filter using 720 nm, every attribute evaluated in maize in different doses of N applied

	VI image (720 nm)		VI image (850 nm)		VI spectroradiometer	
Attributes and dose	RNIR	GNIR	RNIR	GNIR	RNIR	GNIR
DM						
0	-0.84**	-0.53^{ns}	-0.87**	-0.51^{ns}	-0.64*	-0.88**
50	-0.88**	-0.80**	-0.93**	-0.80**	-0.84**	-0.89**
100	-0.79**	-0.77**	-0.63*	-0.67*	-0.92**	-0.97**
200	-0.51^{ns}	-0.55*	-0.62*	-0.40^{ns}	-0.93**	-0.80**
300	-0.42^{ns}	-0.67*	-0.42^{ns}	-0.80**	-0.82**	-0.78**
LA						
0	-0.92**	-0.81**	-0.96**	-0.81**	-0.79**	-0.95**
50	-0.82**	-0.77**	-0.88**	-0.91**	-0.81**	-0.88**
100	-0.82**	-0.78**	-0.60*	-0.58*	-0.81**	-0.89**
200	-0.64*	-0.68*	-0.80**	-0.57*	-0.94**	-0.91**
300	-0.39^{ns}	-0.66*	-0.41^{ns}	-0.77**	-0.79**	-0.76**
CM						
0	-0.78**	-0.58*	-0.74**	-0.49^{ns}	-0.62*	-0.78**
50	-0.72**	-0.59*	-0.82**	-0.65*	-0.73**	-0.74**
100	-0.72**	-0.60*	-0.62*	-0.47^{ns}	-0.79**	-0.73**
200	-0.67*	-0.71*	-0.63*	-0.45^{ns}	-0.86**	-0.81**
300	-0.51^{ns}	-0.80**	-0.36^{ns}	-0.82**	-0.86**	-0.81**
LN						
0	-0.78**	-0.74**	-0.79**	-0.68*	-0.57*	-0.64*
50	-0.75**	-0.67*	-0.65*	-0.49^{ns}	-0.58*	-0.67*
100	-0.83**	-0.70*	-0.66*	-0.49^{ns}	-0.69*	-0.81**
200	-0.64*	-0.61*	-0.78**	-0.53^{ns}	-0.95**	-0.90**
300	-0.38^{ns}	-0.67*	-0.45^{ns}	-0.87**	-0.77**	-0.71*

**Significant (p<0.01), *Significant (p<0.05), ns: Not significant

The leaf area showed 60% with r (p<0.01), 30% of r (p<0.05) and 10% did not correlate significantly. The variable cool mass achieved 40% of r (p<0.01), 50% of r (p<0.05) and 10% r of no significance. The leaf nitrogen content showed 40% of r (p<0.01), 50% of r (p<0.05) and 10% of r no significant correlation.

Thus, it is observed that the variable that larger amounts of significant correlations with 720 nm filter was variable and the leaf area was lower correlations with the dry mass.

In the same table there are the correlations between the 80 DAE indexes obtained by the images that were captured with the use of 850 nm filter and evaluated corn attributes in different doses of N, analyzing it, we have that for the dry matter component showed 40% of coefficients r (p<0.01), 30% of r (p<0.05) and 30% of levels did not correlate significantly. The leaf area showed 60% of r (p<0.01), 30% with r (p <0.05) and 10% not significant. With respect to cool mass is observed that 30% of the correlations presented r (p<0.01), 30% with r (p<0.05) and 40% had no significant correlation. The leaf nitrogen 30% obtained correlation r (p<0.01), 30% with r (p<0.05) and 40% did not correlate significantly.

Thus, it is observed that the leaf area was the variable that had the highest amounts of significant correlations and leaf nitrogen variables and cool mass were those, who had lower amounts of correlation.

Throughout the data presented in Table 14 it is noted that all correlations between the 80 DAE dry mass and the spectroradiometer VI's were classified as strong, with r being 90% (p<0.01) and 10% r (p<0.05). Leaf area also correlated significantly with all vegetation indices studied, with r (p<0.01), being classified as strong. The cool mass showed 90% attribute r (p<0.01) and 10% of r (p<0.05). The leaf nitrogen content showed 40% of r (p<0.01) and 60% r (p<0.05).

Thus, it is known that the assessed component that lower correlation with the studied VI's and obtained by the spectroradiometer was the leaf nitrogen content, this low correlation according to Dwyer *et al.* (1995), can be explained by the fact that the N present in the leaves of plants is not entirely related to chlorophyll molecule is largely associated with the nitrate.

The GNIR vegetation index showed higher correlations between corn yield components using the 720 nm filter and with the spectroradiometer that is the standard equipment used for these determinations, indicating that the spectrum of green belt is more efficient than the red band spectrum, similar data found in a job with cotton submitted to four different doses of N, Zhao *et al.* (2007) in which, assessed the potential of the bands of red and near infrared, with the use of vegetation indexes, to discriminate about the nutritional stress factor N.

Our results showed that the use of the bands of red and near infrared, contradicting the literature, are not necessarily the best bands to be used for discrimination of stress N.

Da Silva *et al.* (2007), in a study with the use of digital images, concluded that the use of the green band for the calculation of the normalized difference vegetation index, was more sensitive in relation to productivity estimation and pasture dry matter than the use of the red band.

It appears that the variable that most stands out in its correlation with vegetation indices is the variable leaf area. All the correlations and ratios of RNIR and GNIR behave as negative, that indicates, the two variables move in opposite directions.

The best correlation coefficients of the corn components with vegetation indices were found using the spectroradiometer. This condition is mainly because there is no influence of the atmosphere, as well as the light intensity at the valuation date, since we used the accessory ASD Plant Probe for measurements in the field.

CONCLUSION

- The GNIR was the index that better results for nitrogen discrimination in maize. With the best method to achieve this index the spectroradiometer
- The use of digital cameras with infrared sensor have a promising future, due to the high correlations and similarity of the regressions found, but they need to further studies in relation to light, exposure time and focal length to capture the images, as this fact generates high coefficient of variation, reducing the accuracy of results
- The use 720nm filter was higher to the filter 850nm, the first being considered higher due to their better correlation with data from the spectroradiometer and the attributes evaluated in corn

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