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NUTRITIONAL STATUS OF CORN PLANTS ESTIMATED THROUGH DIFFERENT VEGETATION INDICES IN THE GROWTH STAGES

Luiz Felipe Diaz de Carvalho[1], Telmo Jorge Carneiro Amado[2], José Cardoso Sobrinho[3], Lúcio de Paula Amaral[4], Luan Pierre Pott[5], Marcieli Piccin[6] & Vinícius Freitas Pedron[7]

1 - Agronomist, DSc in Soil Science, Assistant Professor at UFSM, felipe@politecnico.ufsm.br
2 - Agronomist, DSc in Soil Science, Full Professor at Soil Department, UFSM, proftelmoamado@gmail.com
3 – Agriculture Engineer, DSc in Agriculture Engineering, Assistant Professor at Colégio Politécnico UFSM, jcardosos@smail.ufsm.br
4 – Forest Engineer, DSc in Forest Engineering, Associated Professor at Rural Engineering Department UFSM, amaralufsm@gmail.com
5 – Agronomist, Doctorate student at Agriculture Engineering Post-graduation program at UFSM, luanpierrepott@hotmail.com
6 – Agronomist, Doctorate student at Soil Science Post-Graduation program at UFSM, marcielipiccin@gmail.com
7 – Agronomist, pedron.vinicius@hotmail.com

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ABSTRACT

Several vegetation indices (VIs) have been proposed in the literature with the objective of exploring the spectral properties of the vegetation as they are usually related to biophysical parameters of the plants. The objective of this study was to evaluate the relationship between VIs, obtained in two different RPAS platforms (Remotely-piloted spacecraft system) and proximity system at different corm growth stages with the nitrogen (N) nutritional status in the plant. Five treatments with different nitrogen fertilizer rates (20, 60, 120, 180 and 240 kg ha-1) were studied in order to generate the variability of nitrogen uptake by the plant in four blocks with five replicates each. Reading of the following VIs were performed: NDRE and NDVI (proximity sensing, Optrix sensor) and NDRE, NDVI, EVI2 and GNDVI (RPAS platform, MicaSense Parrot Sequoia sensor) at the phenological stages V5, V6, V7, V9, V11 and V12. Corn plants were collected to evaluate N content in the aerial part of the plant. The N content was higher in V7 growth stage and lower in V12 stage. The VIs obtained through the RPAS platform presented higher relationship with the corn nutritional status when compared to the proximity sensors. The V12 corn growth stage had higher relationship of VIs and plant N content in comparison to the proximity sensor.

Palavras-chave:
proximal
sensor
SARP

ESTADO NUTRICIONAL DE PLANTAS DE MILHO AVALIADO POR DIFERENTES ÍNDICES DE VEGETAÇÃO NOS ESTÁDIOS FENOLÓGICOS

RESUMO

Diversos índices de vegetação (IVs) têm sido propostos na literatura com o objetivo de explorar as propriedades espectrais da vegetação dado que, em geral, estão relacionados com parâmetros biofísicos das plantas. O objetivo do estudo é avaliar a relação entre IVs, obtidos em duas diferentes plataformas SARP (Sistema de Aeronave Remotamente Pilotada) e sistema proximal em diferentes estádios fenológicos do milho com o estado nutricional de nitrogênio (N) na planta. Foram investigados 5 tratamentos com diferentes doses de nitrogênio, afim de gerar variabilidade de nitrogênio absorvido pela planta, sendo estes: 20, 60, 120, 180 e 240 kg ha^{-1} de N, aplicados em 4 blocos com 5 repetições cada. Foram realizadas leituras dos seguintes IVs: NDRE e NDVI (plataforma proximal, sensor Optrix), e NDRE, NDVI, EVI2 e GNDVI (plataforma SARP, sensor MicaSense Parrot Sequoia) nos estádios fenológicos: V5, V6, V7, V9, V11 e V12. Também foi realizado a coleta de plantas para avaliação do teor de N na parte áerea de planta. O conteúdo de N na planta foi maior no estádio fenológico V7 e o menor no estádio V12. Os IVs gerados através de plataforma SARP apresentaram melhores relações com o estado nutricional das plantas de milho comparado com o sensor proximal. O estádio V12 do milho apresentou os mais elevados valores de correlações de IVs e o teor de N na planta, destacando-se entre estes o índice NDRE com $R^2 = 0,60$ na plataforma SARP.

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INTRODUCTION

Nitrogen (N) fertilization is paramount for the expression of the productive potential of corn plants (*Zea mays* L.) (KAPPES *et al*., 2011; SCHWALBERT *et al*., 2018). Grain yield is one of the main parameters for prescribing nitrogen applications and improving the efficiency of its use (SOLARI *et al*., 2008). Nitrogen is one of the elements most demanded by the plants, therefore it has a high response in corn. This nutrient is directly related to the chlorophyll content in the leaf, so that the higher the N content in the crop leaf, the greater the chlorophyll synthesis, depending on the variety and the production environment (LOPES *et al*., 2012).

The recommendation for N fertilization in Brazil is based on the content of organic matter in the soil, the previous crop and the expected productivity, resulting in a N dose to be applied according to these variables (AMADO *et al*., 2002). The management of nitrogen fertilization is traditionally carried out at a fixed rate, that is, a uniform dose all over the area, disregarding the existence of spatial variability in soil attributes and in plant development (SHANAHAN *et al*., 2008).

The optical sensor that measure crop reflectance is a tool with great potential to improve the management of nitrogen fertilization. Several studies have reported the efficiency of this tool in crops such as corn and wheat (POVH *et al*., 2008, AMADO *et al*., 2017). Optical sensors coupled to aircraft or satellites are a potentially important source of data with sufficient spatial resolution to capture spatial variability (SHANAHAN, 2001; VIAN *et al*., 2018). From the optical sensors, it is possible to produce several vegetation indexes (VIs). Vegetation index (VI) consists of equations combining reflectance at wavelengths usually located in the visible and near infrared range. Among them, the most commonly used is the NDVI (Normalized Difference Vegetation Index), which can be determined by proximity sensors such as Greenseeker and Optrix, or by remote sensing through SARP or satellites.

Based on SARP, remote sensing data of high spatio-temporal resolution can be acquired at low cost for monitoring crops and in a more practical way than the proximity senor (ZHANG; KOVACS, 2012).

For the initial phenological stages of some crops, some VIs have issues with detection because the exposed soil is reflected in the regions of red and near infrared almost at the same intensity as plants, for example, NDVI (JENSEN, 2011). In addition, NDRE (Normalized Difference Red Edge) is a VI used for the sensing of larger plants and has a more structured canopy, that is, a plant that will be in a stage of near physiological maturity, and with a high albedo ratio because in more advanced maturation states, the leaves accumulate high levels of chlorophyll in the leaves. The GNDVI (Green Normalized Difference Vegetation Index), emerges as an index that replaces the red band for the green, associated with infrared and for this reason, it can be used in the sensing of plant health and the amount of chlorophyll in the leaves. Another index, which has been used more recently, is the EVI2 (Enhanced Vegetation Index) to estimate the nitrogen concentration in the leaf (WANG *et al*., 2012).

Despite being viable, the estimation through sensing of the productive potential during the agricultural harvest requires more attention, since the development of algorithms adapted to different crops is still restricted. Thus, studies that investigate the relationship between VIs and the nutritional status of the plants are essential. Therefore, this study evaluated the relationship between VIs, obtained on two different platforms (RPAS - Remote Piloted Aircraft System) and proximal - Optrix ACS 430 (Ag Leader)), at different phenological stages in corn with the nutritional status of nitrogen from plants.

MATERIAL AND METHODS

The experiment was set in the 2017/2018 agricultural year in the experimental area in the Polytechnic College of the Federal University of Santa Maria (Figure 1), latitude 29° 43' S, longitude 53° 44' W at 112 m above sea level. According to the climatic classification of Alvares *et al*. (2013), the climate in the region is “Cfa” with average annual temperatures of 19.3ºC and rainfall of over 1700 mm. The soil in the area s classified as Arenic Red Distrophic Argisol (EMBRAPA, 2013).

Four blocks measuring 20 x 20m were implanted, totaling 400 m², each block divided into treatments measuring 4 x 4m, with five replicates each, totaling 1,600 m² (Figure 2). The treatments arranged in the experimental units had different doses of N fertilizer, aiming at generating variability in the nutritional status (Figure 2), in which, the following was used: T1: 20 kg of N ha^{-1}; T2: 60 kg of N ha^{-1}; T3: 120 kg of N ha^{-1}; T4: 240 kg of N ha^{-1}; T5: 320 kg of N ha^{-1} applied at the experiment setting.

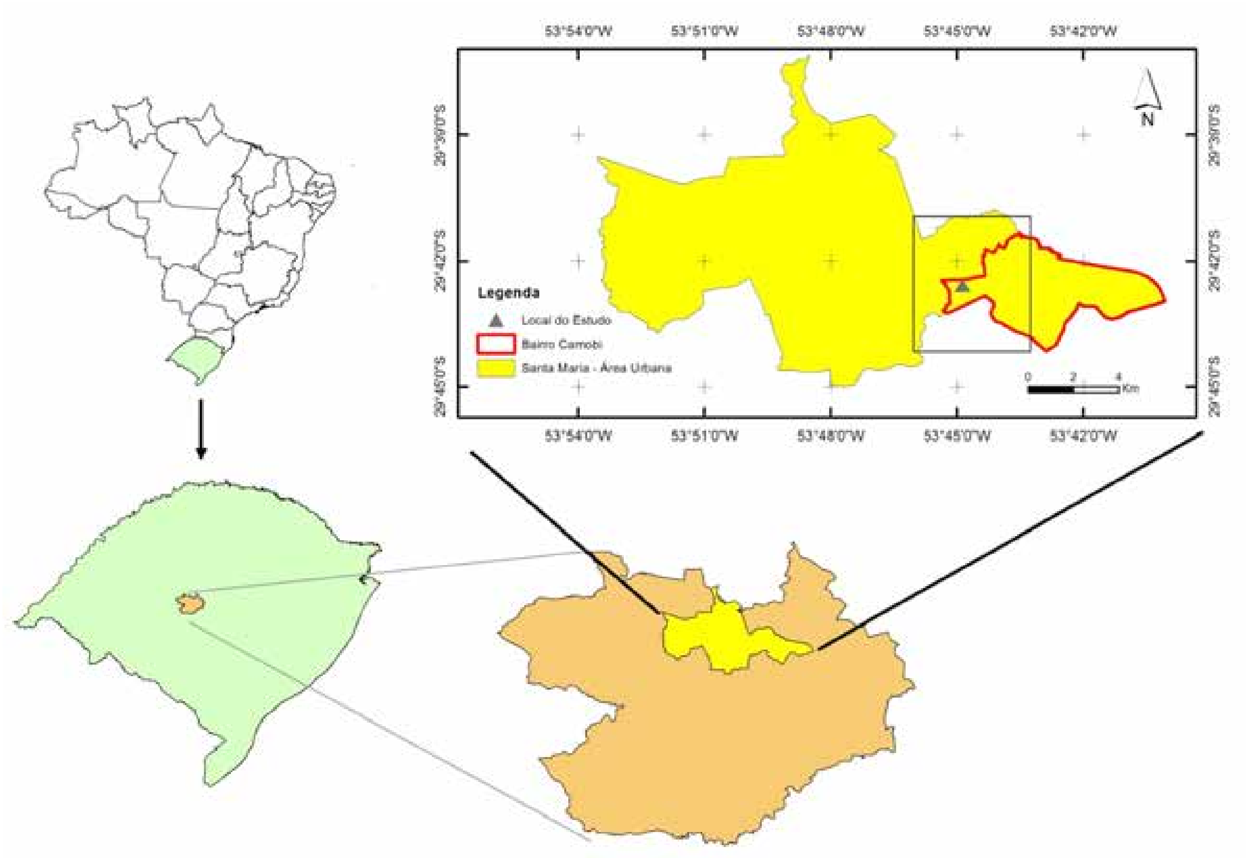

Figure 1. Experimental area location.

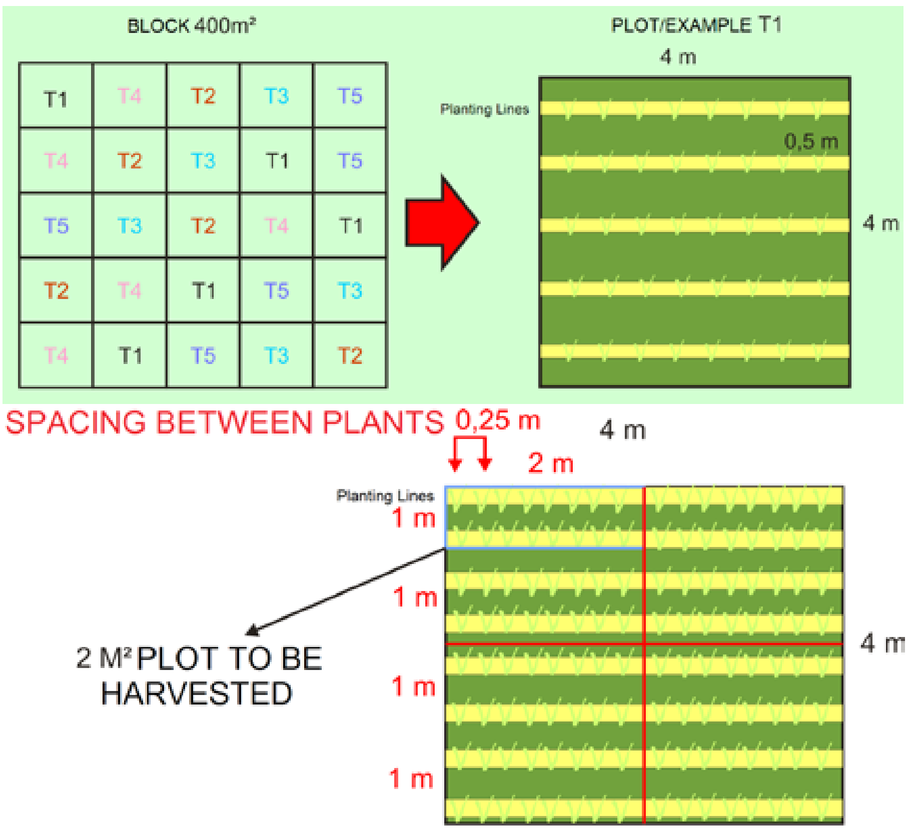

Figure 2. Experimental layout of the plots.

Field work was defined on the basis of the subdivision of the main plots (16 m²) into smaller plots, with 2 m² (Figure 2), thus totaling 200 sample plots per block, totaling 800 samples in total.

Corn was sown on October 24, 2017, using the hybrid Pioneer 30F53 YH, with 0.5 meters between rows and four seeds per meter, adjusted for a population of 80,000 plants per hectare. The basic fertilization was 150 kg ha^{-1} of the formula NPK 05-30-15. The doses of urea (source of N used) referring to the treatments were applied in topdressing in each plot, on November 2, two hours before a rainfall event, which totaled 17.4 mm (data from INMET Santa Maria station). Another rainfall event occurred on the following day, providing another 20.4 mm, contributing to the total solubilization of applied urea without high losses due to leaching, volatization or erosion.

A remotely-piloted aircraft system characterized by an aircraft of the manufacturer DJI, Shenzhen, China, Phanton 4 model, was used for aerial surveys at the corn growth stages V5, V6, V7, V9, V11 and V12. The boarded sensor consisted of a MicaSense Parrot Sequoia camera, capable of recording the reflectance in the wavelength of the green region (550 nm ± 5 nm), red (660 nm ± 5 nm), red edge (735 ± 5 nm) and near infrared (790 ± 5 nm), with 1.2 Mp resolution and 16 Mp RGB resolution, equipped with “Sunshine sensor”.

The readings with the proximity sensor were performed with Optrix ACS 430 (Ag Leader), a sensor that uses the spectral bands of the red (630 ± 5 nm), near infrared (770 ± 5 nm) and in the region of the red edge (730 ± 5 nm).

The flight missions were compiled in the Dronedeploy software, generating an automatic flight over the study area, 15 meters above the canopy of the crop, lasting about 8 minutes each. These missions were always at 15:00 GMT, when the sun was at its zenith, using 80% coverage both on the lateral and longitudinally. The generated pixel was 3.7 cm/px in monochrome and 0.8 cm/px in RGB mode. In each mission, 177 images were obtained per band, totaling a set of 885 images. The software used to process and extract the information from the images was the PIX4D mapper Pro-Educational version 3.3.29.

In the proximity sensing, the readings were taken according to the specifications of the manufacturer’s manual, at a height of 0.6 m from the plant canopy, installed over an equipment positioned parallel to the crop lines, where readings of all corn plants that made up the plots were taken. In order to maintain this regular height and without oscillations, a bicycle with a retractable handlebar was adapted.

Following the execution of the procedures, the following indices were made: NDVI, NDRE, GNDVI and EVI2 (Table 1). These processes were executed in the ArcGIS Desktop software.

Table 1. Vegetation indices (VIs) under study and their respective equations.

Index	Equation
NDRE	$(R_{NIR} - R_{RE}) / (R_{NIR} + R_{RE})$
NDVI	$(R_{NIR} - R_{R}) / (R_{NIR} + R_{R})$
EVI2	$2.4 (R_{NIR} - R_{R}) / (R_{NIR} + R_{R} + 1)$
GNDVI	$(R_{NIR} - R_{G}) / (R_{NIR} + R_{G})$

Legend: R= reflectance. NIR = near infrared, RE = red edge, R = red, G = green.

The data of the VIs values generated for each 2 m²-plot average values that were obtained from the Optrix sensor and from the SARP images. These readings totaled 3.67 pieces of information from the proximity sensor and 4205.2 from the boarded sensor.

The evolution of the growth stages of corn varied at intervals of approximately 5 to 7 days for its change, where the sensing readings occurred at V5, at 20 days after emergence (DAE), V6 at 25 DAE, V7 at 32 DAE, V9 at 44 DAE, V11 at 59 DAE and V12 at 66 DAE. In addition, plants were collected at stages V7, V11 and V12.

Total N in the plant was determined through the Kjeldahl method, where one plant per plot was collected at stages V7, V11 and V12, and then dried in an oven at 65ºC until constant weight, crushed and determined for their N content and dry matter yield. The N content was determined through the digestion of 0.2 grams of vegetable tissue with H_2SO_4 and digestion mixture (Na_2SO_4, $CuSO_4.5H_2O$ and selenium) determined in Kjeldahl semi-micro steam drag distiller (TEDESCO *et al.*, 1995).

A normality test was performed for all collected data, showing that the data distributions did not follow normal distribution. The non-normality was detected and the data was normalized using the BOX COX tool. Afterwards, analysis of variance (ANOVA) and Tukey's means comparison test were performed. Pearson's correlation was also performed with a significance of $P < 0.05$.

RESULTS AND DISCUSSION

As it was previously planned, the applied doses of N caused a variability in the percentage of N uptake in the plant at the different growth stages. The growth stage V7 showed the highest N content in the plant, followed by the stage V11 and, next, V12 (Figure 3). The stages V7 and V11 showed a positive correlation between the doses of N applied in the soil and the percentage of N in the plant, with $R^2 = 0.48$ and $R^2 = 0.43$, respectively. For the V12 growth stage, a negative correlation was obtained, with $R^2 = -0.61$.

It was observed in a study conducted by França *et al*. (2011) that the N uptake in the plant had increased since the emergence of corn, and the highest values was recorded at 74 DAE (milky grain stage). From this maximum value, a reduction of N in the biomass is observed, which is caused by the mobilization of N to the grain, fall of leaves and leaching of N from senescent leaves and stems. Vasconcelos *et al*. (1998) also observed a decrease in the levels of N in the leaves and stems, which characterized the mobilization of the nutrient for the grains from the grain filling stage.

Regarding the VI readings in the different phenological stages of corn growth, a different behavior was observed according to the stage under study (Figure 4). The NDRE and NDVI of VIs, on the proximal platform, showed similar behavior, with an increase in readings until the V11 stage, and with a subsequent decrease in V12. However, these same VIs when boarded on the RPAS platform showed an increase in values until the V7, stabilizing at V9, and increasing again at V11 and V12. Likewise, EVI2 showed growth until V7, stabilization at V9, and growth again at V1 and, mainly, at V12. The GNDVI, on the other hand, showed a growth until V9, with a decrease at V11 and V12. Therefore, the growth stage at which the maximum reading was reached varied according to the index investigated and the platform on which it was boarded.

The RPAS readings on NDRE and NDVI platform showed a similar variation of readings according to the corn growth stage, differently from GNDVI, which showed saturation close to V10. The behavior of NDVI at different phenological stages was similar to that reported by Wilda (2018). According to the spectral behavior reported in this study, the values increased until close to the V9 stage. A high nutrient uptake occurs at the growth stages V8 and V9, particularly potassium and nitrogen, to meet the needs of the corn plant (FANCELLI, 2015; SOUZA *et al*., 2015) explaining the readings with higher values

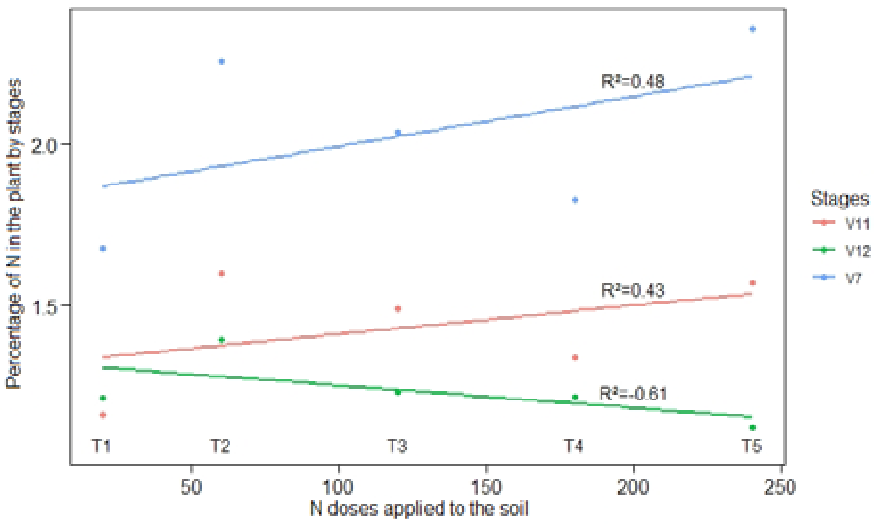

Figure 3. Relationship between N percentage in the plant and N doses applied in the soil.

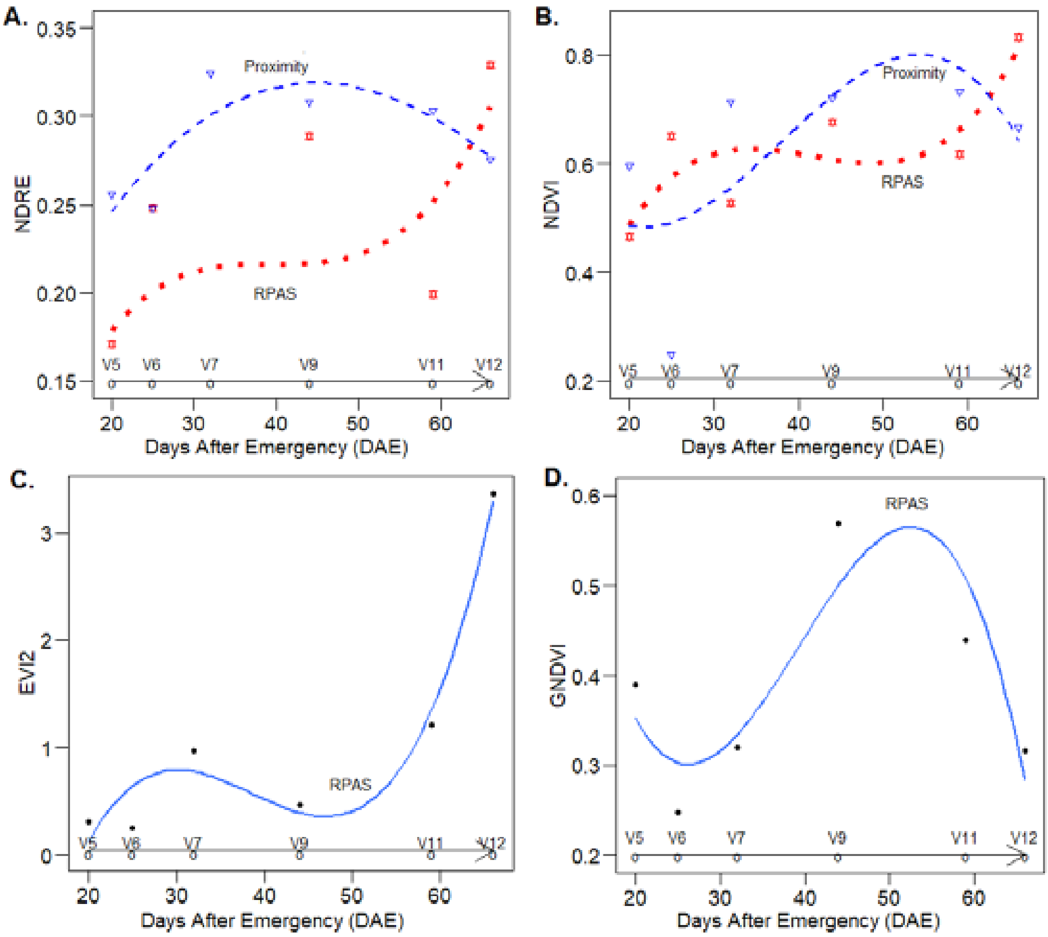

Figure 4. Variation of the values of the investigated vegetation indices (NDRE (A); NDVI (B); EVI2 (C) and GNDVI (D)) at different phenological stages in the corn crop.

close to these stages.

The production of plant biomass and the accumulation of nutrients follow the evolution of the growth stages so that the plant will have approximately 85 to 90% of its leaf area fully developed at the V12 stage (VON PINHO *et al.*, 2009; FANCELLI, 2015). Thus, this growth pattern is consistent with the tendency to reduce the values of IVs in the more advanced vegetative stages, from which the leaves function as a source of nutrients for the reproductive structures of the plant.

Nevertheless, for the NDRE and NDVI indices generated on the proximal platform and EVI2 on the RPAS platform, the index values increased at the end of the growth stages under study (V11 and V12). The same index showed a different behavior, in most growth stages, according to the proximal platform and RPAS, which may be related to the measurement method and the area being sensed.

The relationship between the nutritional nitrogen state (N absorbed) of the plant in the various growth stages with the VIs is of great importance for obtaining parameters for nitrogen recommendations in topdressing, especially in the late nitrogen fertilization strategies, as well as seeking to increase the efficiency of the use of the nutrient.

Physiological changes in modern corn hybrids altered the dynamics of N absorption, therefore increasing the capacity of the plant to absorb N in advanced phenological stages, reaching grain filling. This may justify the late nitrogen fertilization in order to increase productivity (CIAMPITTI; VYN, 2011).

Among the relationships between VIs and the N content absorbed by the plant at the V7 growth stages of the corn crop (Figure 5), V11 (Figure 6) and V12 (Figure 7), the ones that showed the best relationships were those in the V12 stage. For the V7 stage, the indices EVI2 and GNDVI (RPAS platform) showed the best relations, with

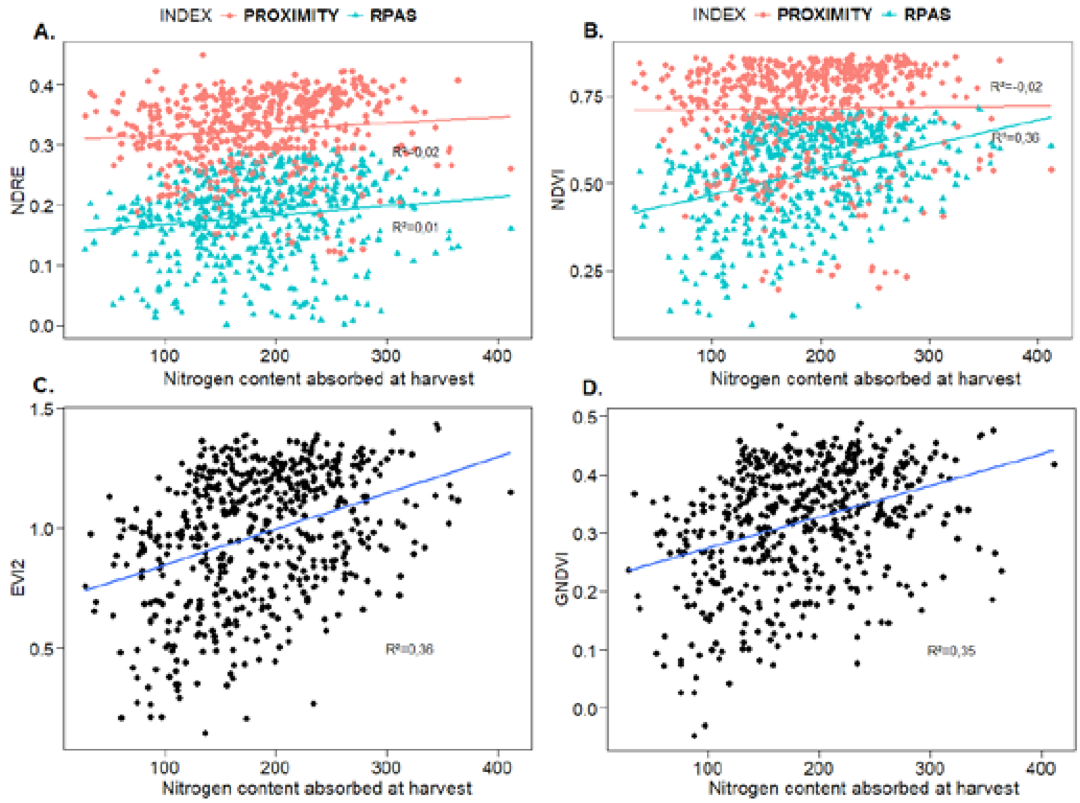

Figure 5. Relationship of vegetation indices with nitrogen content in the plant at stage V7, NDVI (A); NDVI (B); EVI2 (C) and GNDVI (D).

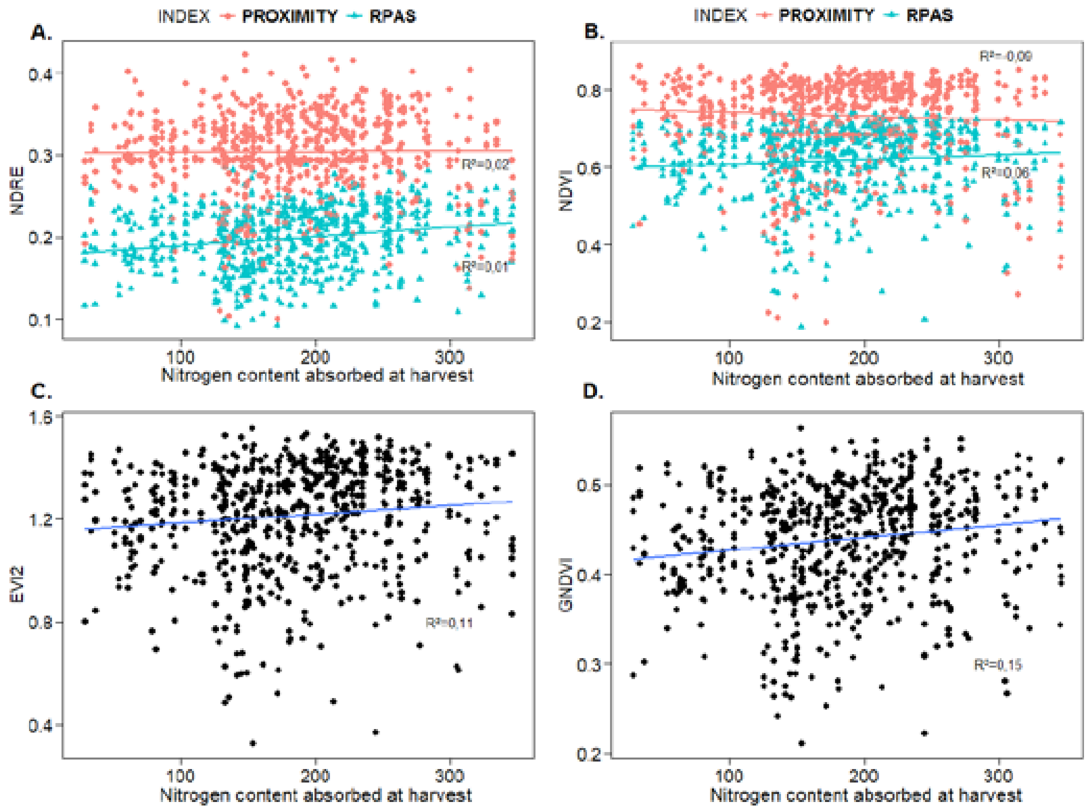

Figure 6. Relationship between the vegetation index and content of N uptake in the plant at stages V11, NDVI (A); NDVI (B); EVI2 (C) and GNDVI (D).

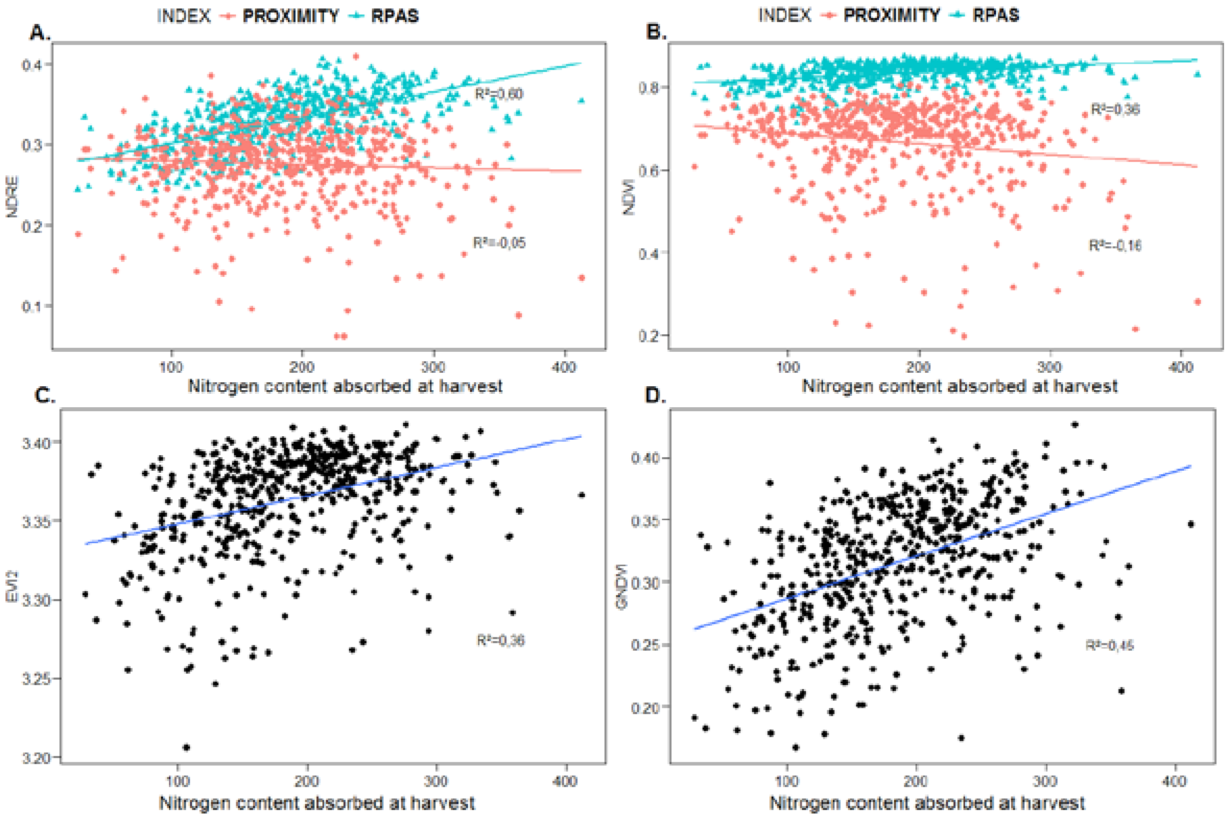

Figure 7. Relationship of VIs with the content of N uptake in the plant at stages V12, NDVI (A); NDVI (B); EVI2 (C) and GNDVI (D).

R^2 = 0.36 and R^2 = 0.35, respectively. At the V11 stage, the corn crop came from a water restriction (water stress) with approximately 20 days with no rainfall, a fact that reduced the sensitivity of the indices in detecting the nutritional status of the corn plants. At the V12 stage, the index with the highest ratio was the NDRE boarded on the RPAS platform with R^2 = 0.60, followed by GNDVI with R^2 = 0.45. Meanwhile, the NDVI and EVI2 indices on the RPAS platform both obtained R^2 = 0.36. The IVs: NDRE and NDVI in proximal sensors, on the other hand, did not have efficient relationships with the nutritional status of nitrogen in the plant, in this same growth stage.

The use of IVs, in the different platforms is an alternative for real-time assessments of the nutritional status of crops and can be an important tool in determining nitrogen fertilizer doses more consistent with the real need for N by plants (VIAN *et al.*, 2018). Schmidt *et al.* (2011) found a satisfactory relationship between the NDVI readings and the nitrogen fertilizer dose demand for corn.

The use of the IV tool allows the real-time and in-situ estimation of the nutritional status of the plants in different growth stages and also the productive potential of the corn crop, allowing the nitrogen fertilization to be adjusted and applied according to the development of the crop (LI *et al.*, 2010; VIAN *et al.*, 2018).

According to Milani *et al.* (2006), the prediction of the nutritional status of plants at a particular growth stage enables the site-specific management in crops, such as variable rate fertilization. In this sense, sensors boarded on remote platforms for assessing reflectance and VIs emerge as important tools to detect the spatial variability of the nutritional status of crops and monitor their evolution during critical phenological stages.

CONCLUSIONS

- The nitrogen content in the plant was higher at the growth stage V7, which reflects the high demand for the nutrient, and lower at the stage V12, where the nutrient was transferred from the plant biomass to the grains.

- The vegetation indices showed different behavior according to the growth stage under study.
- Vegetation indices obtained through the RPAS platform showed better relationships with the nutritional status of corn plants than those obtained from proximity sensor.
- The phenological stage V12 of corn presented the highest values of correlations with the content of N in the aerial part of the plant, where NDRE index ($R^2 = 0.60$) boarded on the SARP platform stood out.

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