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Prediction Models of Corn Yield by NDVI in Function of the Spacing Arrangement

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Abstract

There is a need for the use of tools to estimate productive potential during corn crop development. Thus, the assistence by means of active optical sensors for the generating of vegetation indexes can provide significant information for the knowledge of the behavior and temporal relation of this index with productive parameters of the agricultural crops. It was aimed to evaluate the temporal behavior of NDVI and its relation with yield of corn in order to generate yield prediction models in plant populations (55, 60 and 65 thousand plants ha^{-1}) in spacing of conventional seeding and twin rows. A factorial 2 × 3 was utilized with four replicates, with a total of 24 experimental plots of 10 m^2 in randomized blocks, performing reading NDVI at 5 seasons (30, 45, 60, 75 and 90 days after emergence of the plants DAE). The spacing in twin rows at 30 and 90 DAE for populations of 55 and 60 thousand plants ha^{-1}, respectively, allowed to generate models for the prediction of productivity based on corn NDVI, while the population of 65 thousand plants ha^{-1} at 45 and 60 DAE there was no adjustment by the prediction model of yield by values close to NDVI for different productivities. In the conventional spacing generating models for the prediction of yield was possible in the populations of 55 and 60 thousand plants ha^{-1} respectively at 30 and 90 DAE.

Keywords: active optical sensor, plant population, precision agriculture, row spacing, *Zea mays* L.

1. Introduction

The use of geotechnologies as remote sensing has been used extensively in Precision Agriculture (PA) in order to obtain information without physical contact with the analyzed target, through different types of sensors (active and passive) that makes it possible to calculate indices to estimate the components of agricultural crop production (Zerbato et al., 2016).

The NDVI is applied at the agricultural level in the quantification of crop response at nitrogen doses (Molin et al., 2010), chlorophyll content, leaf nitrogen content and yield (Motomiya et al., 2012) crop biomass (Kapp Junior et al., 2016) and nitrogen recommendation according to spatial variability (Amaral & Molin, 2011).

The relationship of vegetation indices and yield of agricultural crops has been widely studied by several researchers, such as studies by Zerbato et al. (2016) who remarked the yield of the peanut crop with NDVI, Povh et al. (2008) and Bredemeir et al. (2013) used the NDVI to estimate wheat yield, among other numerous examples of using remote sensing to estimate crop yield.

However, NDVI can be influenced in a number of ways, such as population and spacing between rows of plants (Barker & Sawyer, 2012), nitrogen rates (Bredemeier et al., 2013), by the phenological stage of the crop (Rissini et al., 2015) and among other factors.

Considering that the reading of the sensors for the generation of vegetation indices, can be affected by the factors mentioned above, the evaluation of the NDVI behavior in spatial arrangements can provide significant information regarding the knowledge of the behavior and temporal relation of this index with productive parameters of agricultural crops.

In this context, the objective was to evaluate the temporal behavior of NDVI and its correlation with yield in different populations of maize plants under conventional sowing and twin lines, in order to generate models of yield prediction.

2. Method

2.1 Description of the Experimental Area

The experiment was conducted in an experimental area in the municipality of Jaboticbal in the crop season 2016-2017, state of São Paulo, Brazil, located around coordinates 21°14′ S and 48°16′ W, with an average altitude of 568 m and an average slope of 4%. The soil of the area was classified as typical Eutroferric RED LATOSOLO, A moderate, clayey texture and smooth undulating relief (EMBRAPA, 2013).

2.2 Climate Characteristics

According to the classification of Köppen adapted by Alvares et al. (2013), the climate of the region is classified as Aw, defined as tropical humid, with rainy season in summer and dry in winter, with average annual temperature around 22.2 ºC. The annual thermal amplitude presents with average temperature in the coldest month around 18 ºC and the hottest temperature around 32 ºC. This region presents average annual precipitation of 1424 mm.

During the conduction of the experiment the average temperature was 24.8; 24.7 and 24.0 °C, while humidity was 73.0; 76.35 and 72.2% and precipitation of 430.9; 460.3 and 135.7 mm for the spring, summer and autumn seasons respectively (Figure 1).

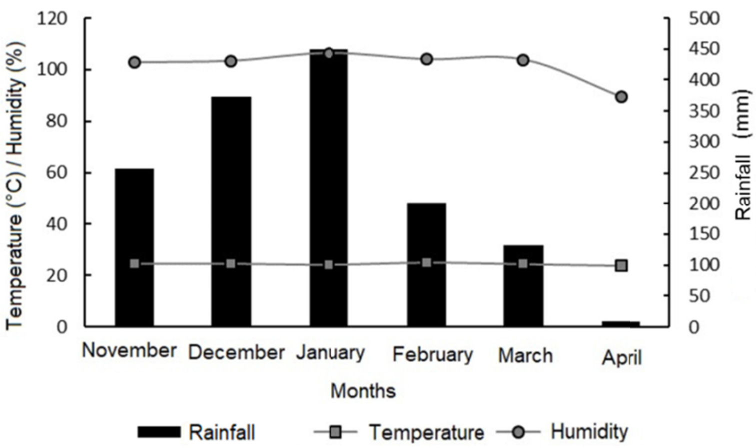

Figure 1. Precipitation (mm), average temperature (ºC) e humidity (%) during the experiment

2.3 Soil Characteristics and Crop Management

The chemical and physical characteristics of the soil of the area where the experiment was performed are presented in Table 1.

Table 1. Chemical and physical soil analysis of the experimental area

M.O.	pH $CaCl_2$	P	C.T.C.	Ca	Mg	K	Sat. Bases	Areia	Silte	Argila
g dm^{-3}		mg dm^{-3}	------------ mmol$_{c\ dm}$$^{-3}$ -----------				------------------------- % -----------------------			
27	5.2	20	58.4	23	11	4.1	65	52	21	27

Pioneer® P3456H cultivar, pre-cycle hybrid, modern plant architecture, standing leaves indicated for areas of high productive potential, tolerant to the main diseases of maize, were used for sowing. As a main characteristic the herculex technology that gives it protection against the main caterpillars and tolerance to herbicides based on glufosinate ammonium.

Seeding was carried out in the 2015/2016 crop in the month of November, in an area planted 16 years ago in the Plantio Direto System. For sowing in reduced spacing (0.45 m) were distributed 3.7; 3.4; 3.1 seeds per meter to reach the populations of 65, 60 and 55 thousand plants ha^{-1} respectively for double-spaced rows (two rows spaced 0.45 m and spaced 0.90 m apart for the others) if the seeding density of 5.5; 5.1; 4.7 seeds per meter to reach populations of 65, 60 and 55 thousand plants ha^{-1} respectively.

The fertilization was applied according to technical bulletin 100 of the state of São Paulo, with 350 kg ha^{-1} of fertilizer formulated 08-28-16 in the sowing furrow. At the V4 stage 22 days after sowing of the crop, cover fertilization with 120 kg of KCl ha^{-1} and 300 kg of Urea ha^{-1} was carried out without incorporation, for expected yield of 10-12 t ha^{-1} the bulletin 100 of the state of São Paulo.

Three days after sowing, 1.2 L ha^{-1} of Paraquat (200 g L^{-1}) were applied to eliminate germinated weeds before corn emergence, after which 2.0 L ha^{-1} of Atrazine was applied, corn selective herbicide for the elimination of germinated weeds after corn, the volume of syrup used for the applications were 200 L ha^{-1} and tip TT11002.

2.4 Used Machines

The Massey Ferguson tractor model MF 7370 with power of 125 kW (170 hp) in the engine, nominal rotation of 2000 rpm that gives 540 rpm in the power take-off, Tractor (4 × 2 TDA), working in the march L3, to realize the sowing of the crop.

For the sowing operation, the prototype Jumil seed drill, model 3070 Exacta Air with seven sowing rows, with pneumatic seed distribution system was used; tires 650 × 16E, 10 canvas; hydraulic line marker; fertilizer distributor system Fertisystem; 17" smooth cutting disc, fertilizer grooving rods, pantographic seeding units with mismatched double discs; depth controller with parallel bands; minimum spacing between 0.45m lines.

For the reduced spacing, seven spacing lines spaced 0.45m were used and for the spacing of double lines two lines were eliminated.

NDVI was evaluated in five seasons (30, 45, 60, 75 and 90 days after emergence of the plants, around 7 days after sowing), with the aid of an active terrestrial optical sensor (GreenSeeker®), emitting radiation electromagnetic in the red band at 660±12 nm and near infrared at 770±12 nm..

The apparatus was positioned approximately 1.0 m above the canopy as recommended by the manufacturer. The readings were performed manually at a velocity of approximately 1 m s^{-1} in any useful area of the plot, with a useful width taken by the sensor of 0.9 m, in the five collection seasons, and the collections were carried out around 10 o'clock. The sensor was coupled to the GNSS Nomad Trimble® collector/receiver for the storage of the georeferenced data.

2.5 Sampling Procedures

For determination of yield, all spikes were collected from the useful area of 10 m^2 of each plot and tracked with the aid of mechanical stationary threshing machine. The grains were separated, weighed in a scale of 0.01 g and the values corrected to 13% moisture and extrapolated to kg ha^{-1}.

2.6 Research Design

The experiment was carried out using two spacings (reduced-0.45 m and double lines intercalated-two lines of 0.45 m by one of 0.90 m) and three plant populations (55, 60 and 65 thousand plants ha^{-1}), composing a 2 × 3 factorial with 4 replicates, making a total of 24 experimental plots of 30 × 4 m (120 m^2) with 10 m^2 of useful area in a randomized block design.

2.6.1 Estatistics

The data were submitted to the Anderson Darling normality test ($p > 0.05$), demonstrating that they had a normal distribution. The results were submitted to regression analysis at 5% probability by the F test, with the aid of the statistical program AgroEstat (Barbosa & Maldonato, 2014).

3. Results and Discussion

For the double row spacing, populations of 55 thousand plants ha^{-1} regression coefficient was significant, and at 90 DAE with determination coefficient (R^2) of 0.74. However, for a population of 65 thousand plants ha^{-1}, the NDVI readings were significant with yield at 45 and 60 DAE, with respective determination coefficients (R^2) 0.83 and 0.72 (Table 2).

Tabele 2. Result of analysis of variance and F test to evaluate the adjustment of NDVI regression and yield of plant populations in relation to days after emergence

Days after emergence (DAE)	Population (thousand plants ha^{-1})					
	Double Row Spacing			Convencional		
	55	60	65	55	60	65
	R²					
30	0.56 ns	0.89*	0.35 ns	0.00 ns	0.78*	0.33 ns
45	0.01 ns	0.44 ns	0.83*	0.00 ns	0.18 ns	0.26 ns
60	0.41 ns	0.39 ns	0.72*	0.05 ns	0.00 ns	0.56 ns
75	0.46 ns	0.00 ns	0.03 ns	0.00 ns	0.00 ns	0.62 ns
90	0.74*	0.04 ns	0.02 ns	0.85*	0.06 ns	0.36 ns

Note. *: significant at 5% probability by the F test; ns: not significant.

In the double lines in the population of 60 thousand plants ha^{-1} the F test was significant only at 30 DAE with R^2 of 0.89. However, in the reduced spacing there was a significance for the coefficient of determination of 0.85 in the population of 55 thousand plants ha^{-1} at 90 DAE and 0.78 for the population of 60 thousand plants ha-1 at 30 DAE (Table 2).

POVH et al. (2008) did not reach models of adjustment of the relationship between NDVI and yield in maize crop due to saturation of NDVI in the population of 65 thousand plants ha^{-1} spaced 0.8 m. However, the results obtained in this experiment show that when the double row spacing was used and reduced in populations of less than 65 thousand plants ha^{-1}, it was possible to adjust yield and NDVI (Table 1).

This contrast of results is explained by the difference of populations used, since the experiment of POVH et al. (2008) used 65 thousand plants ha^{-1} and did not achieve adjustments that consistently explained yield due to saturation of NDVI, since according to Sangoi et al. (2005) with the increase of the population of maize plants has the increase of the leaf area index. This increase in leaf area increases the reflectance of the crop and consequently the NDVI, which can lead to saturation of the index.

For the population of 55 thousand plants ha^{-1} in the spacing of twin lines, an adjustment was obtained that demonstrates the relationship of NDVI and corn yield, demonstrating that NDVI was able to explain 74% of yield (Figure 2).

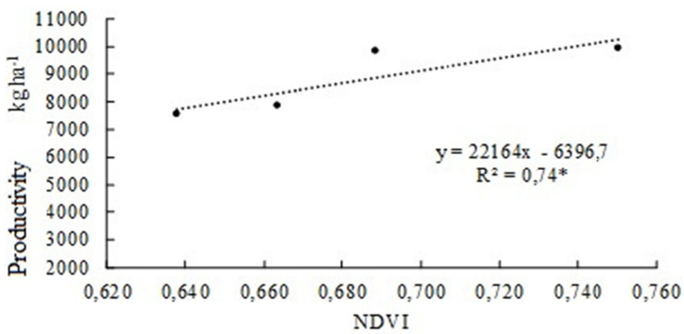

Figura 2. Regression analysis between NDVI and yield in double row spacing at 90 DAE in the population 55 thousand plants ha^{-1}

The NDVI saturation occurs due to the stabilization of the biomass accumulation of the corn crop (Zanzarini et al., 2013), explained by the near-infrared reflectance in comparison to the red (Gitelson et al., 2002). The normalization process makes the NDVI insensitive to near-infrared reflectance variations when it is larger than red (Gitelson, 2004).

In the population of 60 thousand plants ha^{-1} in double rows it generated an adjustment model between NDVI and yield with higher assertiveness (R^2 = 0.88) than for 55 thousand plants ha^{-1} (R^2 = 0.74) (30 DAE) with a higher accumulation of biomass at the beginning of the crop cycle for the larger population in relation to the smaller one (Figure 3).

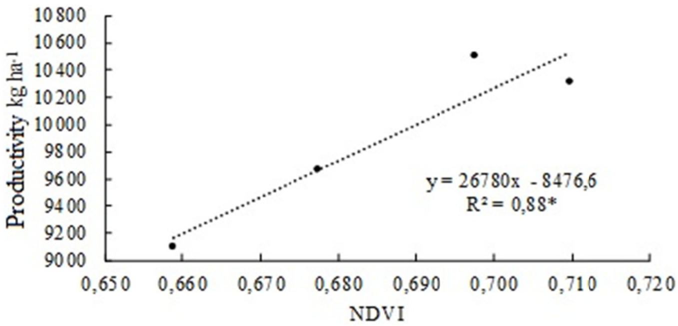

Figure 3. Regression analysis between NDVI and yield in double line spacing at 30 DAE in the population of 60 thousand ha^{-1} plants

The sensor indicated similar NDVI values for the three different productivities in the NDVI readings grouped on one side of the graph in the population of 65 thousand plants ha^{-1} at both 45 and 60 DAE in double row spacing (Figures 4 and 5) and it is not possible to generate a reliable model of yield prediction for this population.

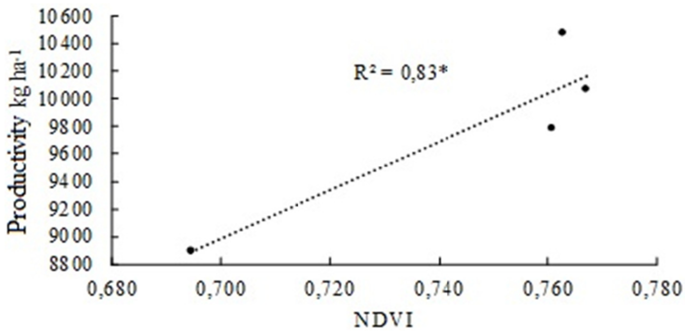

Figure 4. Regression analysis between NDVI and yield in the double line spacing at 45 DAE in the population of 65 thousand ha^{-1} plants

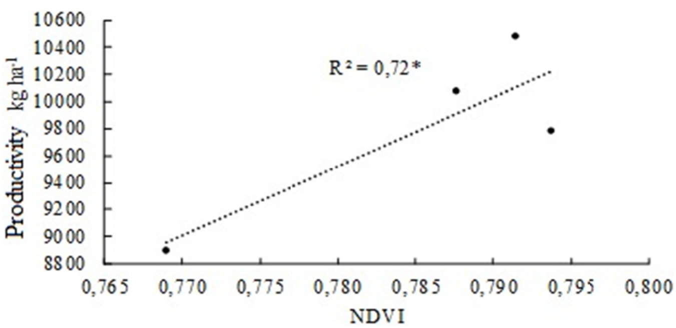

Figure 5. Regression analysis between NDVI and yield in double line spacing at 60 DAE in the population of 65 thousand plants ha^{-1}

The results presented for population of 65 thousand plants ha^{-1} corroborate with Povh et al. (2008) who could not generate a yield prediction model, although the regression adjustment was significant, explained by the different productivities in relation to the values close to NVDI, due to the large amount of biomass produced by the crop.

The nonlinearity of the biophysical characteristics such as biomass and leaf area index, may hinder the generation of a prediction model (Myneni et al., 1995). An alternative would be to work with wavelengths in the green band (500-650 nm) (reflectance greater than red) and reducing the difference between the near visible and infrared (750-900 nm) reflectance (Povh et al., 2008).

Studies have been developed evaluating a spectral region called Red-edge as an alternative for NDVI substitution, ranging from 680-740 nm in the red (600-700 nm) and near infrared (750-900 nm) bands (Kanke et al., 2016). The indices based on this range of the electromagnetic spectrum are more effective compared to the indexes that use the red band for the prediction of yield (Kanke et al., 2016).

The results were satisfactory for the NDVI only in the early stages of development, and when approaching maturity this index begins to perform below the indexes using the Red-edge band in the rice crop (Cao et al., 2016) and soybean (Peng & Gitelson, 2012).

At 90 DAE it was possible to generate a yield prediction model in the reduced population spacing of 55 thousand plants ha^{-1} (Figure 6), being later than in the population of 60 thousand plants ha^{-1} at 30 DAE (Figure 7), attributed to the rapid accumulation of biomass for the largest population reaching the fastest point of the greatest relationship between yield and NDVI.

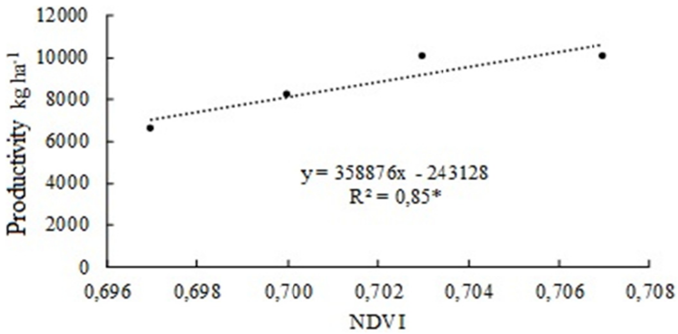

Figure 6. Regression analysis between NDVI and yield at spacing reduced to 90 DAE in the population of 55 thousand plants ha^{-1}

For a population of 60 thousand plants ha^{-1} in the reduced spacing, a yield prediction model was generated at 30 DAE (Figure 7), this date was equal to the double line spacing only with a lower coefficient od determination (R^2 = 0.78) demonstrating that for this population independent of the adopted spacing it is possible to generate a prediction model on the same date.

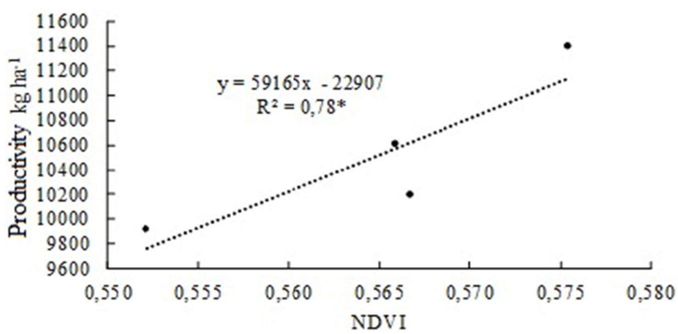

Figure 7. Regression analysis between NDVI and yield in the spacing reduced to 30 DAE in the population of 60 thousand plants ha^{-1}

In general, for the populations of 55 and 60 thousand plants ha^{-1}, the yield behavior as a function of NDVI was the same in the two spacings used, and it was observed that the extent to which NDVI increased yield followed the same trend in a linear fashion, which shows that regardless of the spacing used is reduced or in double lines the prediction of yield was possible in the same dates at 90 DAE for 55 thousand plants ha^{-1} and 30 DAE for 65 thousand plants ha^{-1}.

Indicating that from the population of 65 thousand plants ha^{-1}, other alternatives of yield prediction must be sought, which can be used to change the vegetation index, especially GNDVI and NDRE, which use larger bands reflectance in comparison to the red band, decreasing and difference between the near infrared and the band used for index generation, which allows the index not to saturate easily.

The results obtained in this experiment serve as a subsidy for the development of algorithms for the determination of varied nitrogen doses, since Raun et al. (2005) reported that it is necessary to establish yield prediction models for the development of an algorithm for the determination of nitrogen doses that maximize crop yield.

4. Conclusions

(1) The recommended prediction of yield in maize by NDVI should be performed at 90 and 30 DAE in the populations of 55 and 60 thousand plants ha^{-1} regardless of the spacing adopted.

(2) For the prediction of yield in a population of 65 thousand plants ha^{-1}, the use of NDVI from proximal remote sensors is not recommended.

References

Alvares, C. A., Stape, J. L., Sentelhas, P. C., De Moraes, G., Leonardo, J., & Sparovek, G. (2013). Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift, 22*(6), 711-728. https://doi.org/10.1127/0941-2948/2013/0507

Amaral, L. R., & Molin, J. P. (2011). Sensor óptico no auxílio à recomendação de adubação nitrogenada em cana-de-açúcar. *Pesquisa Agropecuária Brasileira, 46*(12), 1633-1642. https://doi.org/10.1590/S0100-204X2011001200008

Balem, Z., Modolo, A. J., Trezzi, M. M., Vargas, T. De O., Baesso, U. M., Brandelero, ... Trogello, E. (2014). Conventional and twin row spacing in different population densities for maize (*Zea mays* L.). *African Journal of Agricultural Research, 9*(23), 1787-1792. https://doi.org/10.5897/AJAR2014.8714

Barbosa, J. C., & Maldonado Jr, W. (2014). *AgroEstat-Sistema para Análises Estatísticas de Ensaios Agronômicos*. Versão 1.1.0.712.

Barker, D. W., & Sawyer, J. E. (2012). Using active canopy sensing to adjust nitrogen application rate in corn. *Agronomy Journal, 104*(4), 926-933. https://doi.org/10.2134/agronj2012.0030

Bredemeier, C., Variani, C., Almeida, D., & Rosa, A. T. (2013). Estimativa do potencial produtivo em trigo utilizando sensor óptico ativo para adubação nitrogenada em taxa variável. *Ciência Rural, 43*(7), 1147-1154. https://doi.org/10.1590/S0103-84782013005000080

Cao, Q., Miao, Y., Shen, J., Yu, W., Yuan, F., Cheng, S., … Liu, F. (2016). Improving in-season estimation of rice yield potential and responsiveness to topdressing nitrogen application with Crop Circle active crop canopy sensor. *Precision Agriculture, 17*(2), 136-154. https://doi.org/10.1007/s11119-015-9412-y

EMBRAPA (Empresa Brasileira de Pesquisa Agropecuária). (2013). *Sistema Brasileiro de Classificação de Solos* (3rd ed., p. 353). Brasília: EMBRAPA.

Gitelson, A. A. (2004). Wide Dynamic Range Vegetation Index for remote quantification of biophysical characteristics of vegetation. *Journal of Plant Physiology, 161*(2), 165-173. https://doi.org/10.1078/0176-1617-01176

Gitelson, A. A., Kaufman, Y. J., Stark, R., & Rundquist, D. (2002). Novel algorithms for remote estimation of vegetation fraction. *Remote Sensing of Environment, 80*(1), 76-87. https://doi.org/10.1016/S0034-4257(01)00289-9

Kanke, Y., Tubaña, B., Dalen, M., & Harrell, D. (2016). Evaluation of red and red-edge reflectance-based vegetation indices for rice biomass and grain yield prediction models in paddy fields. *Precision Agriculture*, 1-24. https://doi.org/10.1007/s11119-016-9433-1

Kapp Junior, C., Guimarães, A. M., & Caires, E. F. (2016). Use of active canopy sensors to discriminate wheat response to nitrogen fertilization under no-tillage. *Engenharia Agrícola, 36*(5), 886-894. https://doi.org/10.1590/1809-4430-Eng.Agric.v36n5p886-894/2016

Molin, J. P., Frasson, F. R., Amaral, L. R. Do, Povh, F. P., & Salvi, J. V. (2010). Capacidade de um sensor ótico em quantificar a resposta da cana-de-açúcar a doses de nitrogênio. *Revista Brasileira de Engenharia Agrícola e Ambiental, 14*(12), 1345-1349. https://doi.org/10.1590/S1415-43662010001200014

Motomiya, A. V. D. A., Molin, J. P., Motomiya, W. R., & Biscaro, G. A. (2012). Diagnose nutricional com o uso de sensor óptico ativo em algodoeiro. *Revista Brasileira de Engenharia Agrícola e Ambiental, 16*(11), 1159-1165. https://doi.org/10.1590/S1415-43662012001100003

Myneni, R. B., Hall, F. G., Sellers, P. J., & Marshak, A. L. (1995). The interpretation of spectral vegetation indexes. *IEEE Transactions on Geoscience and Remote Sensing, 33*(2), 481-486. https://doi.org/10.1109/36.377948

Peng, Y., & Gitelson, A. A. (2012). Remote estimation of gross primary productivity in soybean and maize based on total crop chlorophyll content. *Remote Sensing of Environment, 117*, 440-448. https://doi.org/10.1016/j.rse.2011.10.021

Povh, F. P., Molin, J. P., Gimenez, L. M., Pauletti, V., Molin, R., & Salvi, J. V. (2008). Comportamento do NDVI obtido por sensor ótico ativo em cereais. *Pesquisa Agropecuária Brasileira, 43*(8), 1075-1083.

Raun, W. R., Solie, J. B., Stone, M. L., Martin, K. L., Freeman, K. W., Mullen, R. W., … Johnson, G. V. (2005). Optical Sensor-Based Algorithm for Crop Nitrogen Fertilization. *Communications in Soil Science and Plant Analysis, 36*, 2759-2781. https://doi.org/10.1080/00103620500303988

Rissini, A. L. L., Kawakami, J., & Genú, A. M. (2015). Índice de vegetação por diferença normalizada e produtividade de cultivares de trigo submetidas a doses de nitrogênio. *Revista Brasileira de Ciência do Solo, 39*(6), 1703-1713. https://doi.org/10.1590/01000683rbcs20140686

Singh, N. K., Ashok, T., & Anshuka, S. (2016). Development and testing of twin row drum planter for maize. *Global Journal of Multidisciplinary Studies, 5*(2).

Takasu, A. T., Rodrigues, R. A. F., Goes, R. J., Haga, K. I., Arf, O., & Gitti D. C. (2014). Características agronômicas da cultura do milho em função do preparo de solo e arranjo espacial de plantas. *Revista Agrarian, 6*(21), 340-345. https://doi.org/10.30612/agrarian.v7i26.2746

Zanzarini, F. V., Pissarra, T. C. T., Brandão, F. J. C., & Teixeira, D. D. B. (2013). Correlação espacial do índice de vegetação (NDVI) de imagem Landsat/ETM + com atributos do solo. *Revista Brasileira de Engenharia Agrícola e Ambiental, 17*(6), 608-614. https://doi.org/10.1590/S1415-43662013000600006

Zerbato, C., Rosalen, D. L., Furlani, C. E. A., Deghaid, J., & Voltarelli, M. A. (2016). Agronomic characteristics associated with the normalized difference vegetation index (NDVI) in the peanut crop. *Australian Journal of Crop Science, 10*(5), 758-764. https://doi.org/10.21475/ajcs.2016.10.05.p7167

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