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Original Research Article

Application of plant indices (red band and near infrared) in avocado plantations

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ABSTRACT

Avocado is a traditional fruit in the diet of Ecuadorians and requires proper management to ensure its production. The implementation of new technological alternatives, such as the use of spectroscopy indices, allows obtaining data that, when correlated, will optimize crop management. This research validated the use of plant indices based on the red band and near infrared with foliar nitrogen content. The following plant indices were used: normalized difference vegetation index (NDVI) and transformed vegetation index (TVI) from two orthomosaics obtained from images capturing red band and near infrared in avocado plantations. Regressions and correlations were performed between the vegetation indices and the results of the foliar analysis of nitrogen content, generating R^2 values of 0.93 for NDVI and 0.95 for TVI. Plant index values can be used to estimate plant vigor based on foliar nitrogen content.

Keywords: leaf nitrogen content; fruit trees; vegetation index; spectroscopy indexes; vigor

1. Introduction

Avocado (Persea americana Mill.) is a traditional fruit in the diet of Ecuadorians, its delicate flavor becomes the perfect complement to accompany typical dishes of the world cuisine and is generally consumed fresh. In Ecuador, the main avocado producing areas are Carchi, Imbabura, Pichincha, Tungurahua, Azuay and Loja (Viera et al., 2016). According to agricultural statistics data for 2018 and 2019, about 6, 164 and 7, 125 ha of avocado were

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cultivated, respectively, with an average production of 2.9 and 3.7 t ha–1, respectively (Instituto Nacional de Estadística y Censos [INEC] 2018; 2019). Unfortunately, the increase in the number of trees does not guarantee a proportional increase in production; in the case of avocado, it is due to the lack of implementation of adequate agronomic management (fertilization, irrigation, phytosanitary controls and cultural work) and the implementation of new technological alternatives that allow a significant increase in production (Viera et al., 2016).

Traditional agriculture is vulnerable to different climatic phenomena and to the occurrence of pests, which are increasingly harmful and resilient to traditional agrochemicals. The use of new technologies in agriculture is aimed at improving production and reducing costs (Berrio Meneses et al., 2018).

The evaluation of some physiological characteristics that reflect the health, nutritional and water status of plants requires sophisticated instruments that allow establishing a systematic measurement to analyze the changes or variations of plants in response to certain stimuli such as the addition of nutrients or some other factor that limits or promotes their development. Currently, there are several spectroscopy indices that are used in the evaluation of the behavior of some crops (López-Aguilar et al., 2016) and they can be related to important elements for plant nutrition, being nitrogen one of the most relevant for avocado crop development (Gaona et al., 2020; Viera et al., 2021).

For the use of these indices, access to orthophotos using traditional multispectral sensors has been an obstacle, given the acquisition costs, information and number of bands generated by this equipment. However, the application of a modified camera for only red-band and near-infrared detection reduces the cost, since it uses bands reflected by the plant surface; this technology allows monitoring of sowings, nutritional diagnosis and yield prediction in several crops (Zheng et al., 2018).

The use of unmanned aerial vehicles, equipped with multispectral cameras, makes it possible to obtain information of an entire plantation with a very precise resolution, allowing the calculation of indices in order to integrate information on different plant aspects (Vilanova de la Torre et al., 2018).

The processing of images with information per pixel to obtain plant indices is mostly provided by licensed software (Martínez and Mendoza España, 2014); therefore, this research made use of free software (QGis 2.18, Agisoft Photo Scan and DroneDeploy) for the elaboration and punctual matrix processing of images with different plant indices: Normalized Difference Vegetation Index (NDVI) and Transformed Vegetation Index (TVI), obtaining a tool to know the state of vigor of fruit species crops. Therefore, the objective of this study was to validate a method to obtain avocado vegetation indices based on the red band and near infrared and correlate them with a scale of visual vigor and foliar nitrogen content.

2. Materials and methods

2.1. Location of the experimental site

The avocado plantation (4.673 m2) is located at the Tumbaco experimental farm of the National Institute of Agricultural Research [INIAP], within the province of Pichincha, canton Quito, coordinates: 0°12'54.19" south, 78°24'48.484" west; 0°12'54.19" south, 78°24'36.543" west, with an annual precipitation of 900 mm, relative humidity 75%, average annual temperature of 18 °C, soil order Andisol, sandy loam texture, slope from 2 to 5%, undulating relief.

2.2. Field image collection

Images were taken using DroneDeploy software, designing the route to be followed by the drone (Inspire 1 model, GLONASS + GPS system) over the plantations under study. In addition, the height at which the drone was raised (70 m) was programmed, and the route to be followed by the drone was used for two flights, the first with the RGB camera (Zenmuse X3) and the second with the red detection and near infrared camera (Zenmuse X3 DJI). The photograph obtained with the RGB camera allowed the visualization of the lot and this was placed over the red and infrared photograph to recognize the control trees. The flights were carried out at midday (12:00m) in order to avoid shadows generated by the trees that could affect the data.

2.3. Orthomosaic classification (RGB, red and near infrared detection)

Before starting the classification of the images taken in the field, it was decided to generate a file containing all the images captured by the drone; this was done with Agisoft Photo Scan software, whose program used the coordinates that each image contains to generate a single file.

- **Image calibration**: Agisoft Photo Scan software generated information from the red (RED) and near infrared (NIR) bands, information that was uploaded into the QGis program to perform light calibration using the QGis add-on, called MAPIR, which reduces the error in the image produced by the effect of solar radiation that distorts the information of each pixel and generates loss of true information (Figure 1).

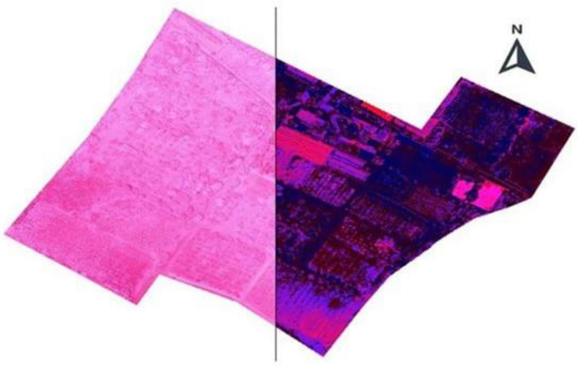

Figure 1. Light calibration in the QGis program

$$TVI = \sqrt{\frac{NIR-RED}{NIR+RED}} + 0,5 \quad [1]$$

- **Calculation of the Transformed Vegetation Index (TVI)**: It was calculated using the equation [1].

2.4. Sample calculation

The avocado plot consisted of a total population of 68 trees, information that was used to determine the sample size using equation [2].

$$\text{Sample size} = \frac{\frac{z^2 * p(1-p)}{e^2}}{1+\left(\frac{z^2 * p(1-p)}{e^2 N}\right)} \quad [2]$$

Where, N is the population size, z is the confidence level, p is the probability of success, and e is the margin of error. The confidence level used was 95%, with a margin of error of 10%, obtaining a sample of 39 trees.

2.5. Control trees

In the trees defined as controls, plant indices (NDVI and TVI) were measured to determine their state of vigor. In addition, leaf samples were taken from these trees to determine their nitrogen content and to corroborate the values of the indices with the nitrogen content by means of a regression, in order to establish the reliability of the indices. For the selection of the control trees, categories (large, intermediate and small) were established based on the diameter of the tree crown. The equatorial diameter was measured from the north to the south end of the tree crown. Trees with a crown smaller than 2 m were considered as small crown, between 2 and 4 m as intermediate crown, and larger than 4 m as large crown. This variable was chosen for categorization because leaf area is directly related to the results of the spectral images. In addition, the height of the plant (m) from ground level to the tip of the crown and the diameter of the stem (m) at a height of 1.2 m from the ground were measured in the control trees.

2.6. Calculation of individual statistics in each tree

Once the orthomosaic of red and near infrared bands was given a classification for each index applied, we proceeded to establish the value of the indexes for each control tree, for which a Shape file was generated in the QGis program, with which the crowns of the control trees were traced. This process was carried out so that the Shape file acts as a mask layer on the orthomosaic, creating a table of contents that only obtains information from a specific area of the layer classified with the applied indexes, generating an average per pixel of the canopies of the control trees.

2.7. Sampling for foliar analysis

For leaf analysis, leaves were selected from those at the average height of the canopy and those distributed around the entire canopy, taking approximately 100 g of leaves per tree. The leaves sampled were mature and were taken with petiole and leaf blade, from branches without fruit. Leaf samples were collected in paper bags with the respective identification, stored in airtight containers and previously dried with absorbent paper (Campos León and Calderón Zaragoza, 2015), and then sent to the INIAP Soil and Water laboratory, where they were processed to determine total nitrogen using the Kjeldahl method.

2.8. Statistical relationship between results of plant indices and foliar nitrogen analysis

The evaluation of the selected trees was carried out by comparing the nitrogen content data with their respective plant index value, for which a regression analysis was performed between the index values for each control tree with its respective nitrogen concentration, which allowed determining the level of vigor in the plantation.

3. Results and discussion

3.1. Image registration

As a result of image registration, 188 photographs were obtained for each orthomosaic (Figure 2). Each individual photograph has 40, 000 reference points in order to accurately generate each mosaic. A total of 376 photographs were recorded for the two orthomosaics used (red and near infrared and RGB), which were calibrated for interpretation.

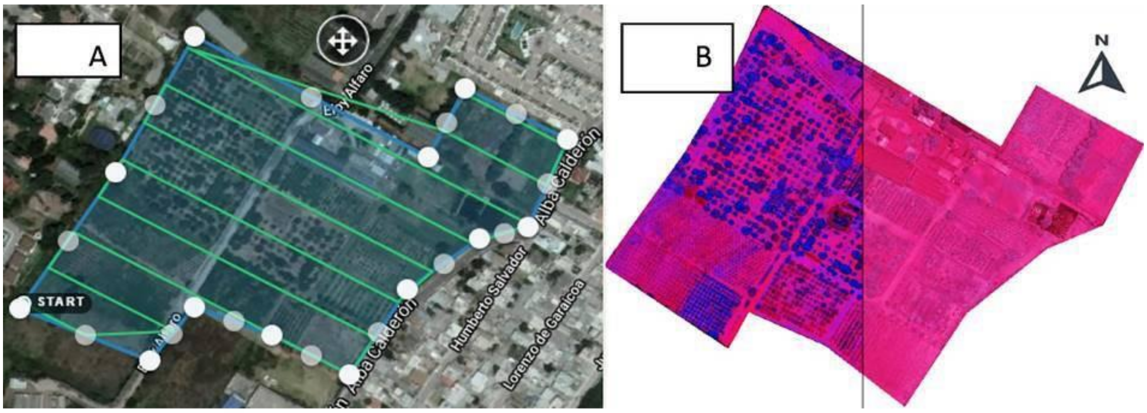

Figure 2. A. Flight plan programmed by DroneDeploy. B. Calibrated image (right). Scale 1:2500

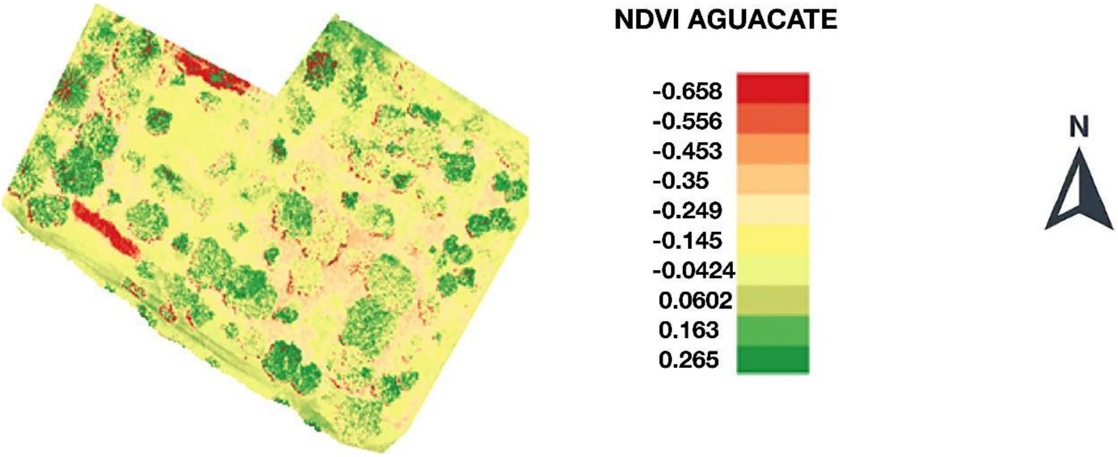

Figure 3. NDVI generated for the evaluated avocado plot. Scale 1:500

3.2. NDVI for avocado trees

As a result of the equation, a gray-scale NDVI layer was obtained for all the plots, which was assigned a different color range to easily identify the indices generated, with values greater than 0.1 for the NDVI index representing the plant material (Meneses Tovar, 2012; Piscoya Pérez, 2019). NDVI values ranging from –0.65 to 0.26 were obtained (Figure 3); it should be mentioned that the images were recorded in the dry season generating low NDVI values and that the negative values were due to the fact that there were dead (dry) trees in the plot due to root wilt attack, but they had not been removed from the field. Studies by Escobar Pardo (2015) and Crusiol et al. (2017), in studies conducted on banana (Musa AAA Simmonds) and soybean (Glycine max), respectively, determined that NDVI tends to vary according to the phenological stage in which the crop is found. If the plant is in a productive phase, NDVI values will decrease, since the concentration of nutrients is directed from the leaves to the fruit.

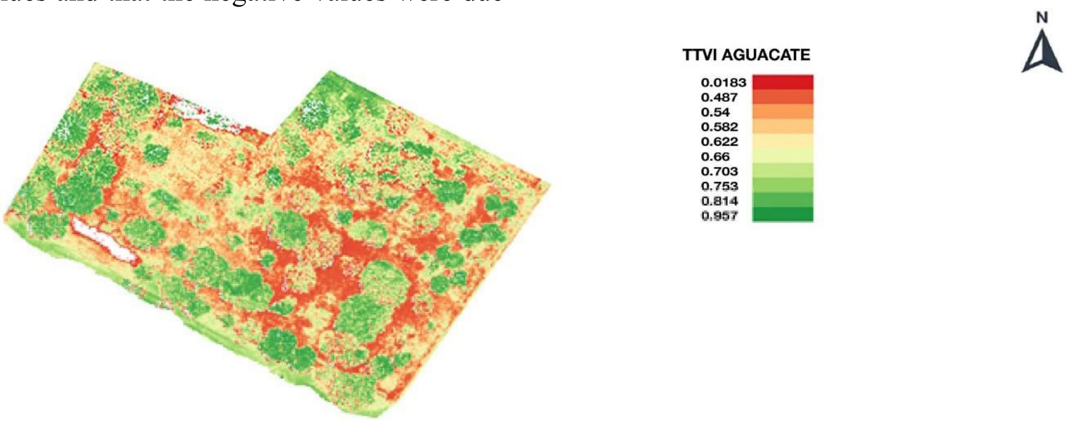

Figure 4. TVI generated for the avocado plot. Scale 1:500

Table 1. Classification of avocado control trees based on tree crown diameter

Code*	Crown diameter (m)	Plant height (m)	Shaft diameter (m)	Code*	Crown diameter (m)	Plant height (m)	Shaft diameter (m)
CG1	4, 82	3, 47	1, 06	CI6	3, 21	4, 06	0, 90
CG2	5, 17	2, 98	1, 30	CI7	3, 52	3, 37	1, 50
CG3	5, 14	2, 57	0, 80	CI8	3, 93	3, 04	0, 89
CG4	4, 31	4, 09	0, 99	CI9	3, 17	3, 81	1, 04
CG5	4, 14	3, 48	1, 58	CI10	3, 61	3, 42	1, 30
CG6	5, 07	3, 07	1, 10	CI11	3, 17	4, 30	1, 36
CG7	4, 17	2, 52	1, 01	CI12	3, 19	3, 69	1, 11
CG8	4, 21	4, 56	1, 49	CI13	3, 17	2, 81	1, 11
CG9	5, 17	3, 94	1, 21	CP1	2, 62	4, 83	1, 54
CG10	4, 19	3, 81	1, 05	CP2	2, 96	3, 72	0, 87

CG11	5, 17	3, 18	1, 12	CP3	2, 69	3, 26	1, 30
CG12	4, 81	3, 59	1, 24	CP4	2, 47	3, 12	0, 95
GC13	4, 01	3, 68	1, 26	CP5	2, 86	3, 05	0, 99
CG14	4, 10	2, 71	0, 70	CP6	2, 72	3, 96	1, 06
CG15	4, 24	3, 93	1, 15	CP7	2, 91	4, 37	0, 95
CI1	3, 17	2, 46	0, 87	CP8	2, 62	3, 19	1, 25
CI2	3, 67	3, 17	1, 48	CP9	2, 04	3, 62	1, 16
CI3	3, 71	4, 51	1, 47	CP10	2, 43	3, 89	0, 71
CI4	3, 89	3, 81	1, 35	CP11	2, 71	3, 41	0, 95
CI5	3, 89	3, 72	0, 71				

* Categories: CG = large, CI = intermediate, CP = small.

3.3. TVI for avocado trees

As a result of the TVI equation, the gray scale layer was obtained, where a different color range was assigned to identify more easily the generated indexes. TVI values do not usually differ from NDVI values; in the case of TVI, a factor of 0.5 was included, which generates positive values for the indices obtained. Values greater than 0.6 reflect vegetation and as long as this value is close to 1 it represents plant material with higher chlorophyll accumulation (Juzga Solanilla, 2016). The TVI index identified the presence of chlorophyll in the canopy of avocado trees which obtained values from 0.01 to 0.95 (Figure 4). Pat Lopez (2015) determined that the values of plant indexes allow having an estimate of the current state of vigor of the crop, including graphically. In the study it was observed that the plants had good vigor.

3.4. Results of control trees

A foliar analysis was performed on the avocado control trees, for which 39 trees were selected (Figure 5), which were distributed in the previously established categories. The control trees were categorized based on crown diameter, and plant height and stem diameter were measured (Table 1). There was no correlation between tree crown with plant height (–0.20) and stem diameter (0.08).

Table 2 shows the values obtained for NDVI, TVI and foliar nitrogen content of the control trees. For the avocado crop, nitrogen content values were found between 1.21 to 2.46%, which is similar to that expressed by Méndez-García et al. (2008) and Sotelo-Nava et al. (2017), who mention that the normal foliar nitrogen content in this crop is between values of 1.60 to 2.80%, which would indicate that the trees are in a state of intermediate vigor. The values of the plant indexes allow establishing productivity trends because they make it possible to estimate, by means of reflectance, the state of vigor of the plant, which is directly related to the nutrient content of the plant, specifically with the element nitrogen (Zenteno Cruz et al., 2017).

Figure 5. Distribution in the avocado control tree plots. Scale 1:500

3.5. Regression between NDVI values and results of foliar analysis

A regression was generated between NDVI values and the nitrogen content of the avocado crop (Figure 6), showing an R^2 value of 0.93. Sanjerehei (2014) obtained similar R^2 values (0.97) in vegetation in a similar study with spectral images. In addition, studies conducted on durum wheat (Triticum turgidum L. var. durum) confirm the relationship between NDVI values and foliar analysis, as they also obtained high R^2 values (0.87 to 0.94) (Cabrera-Bos

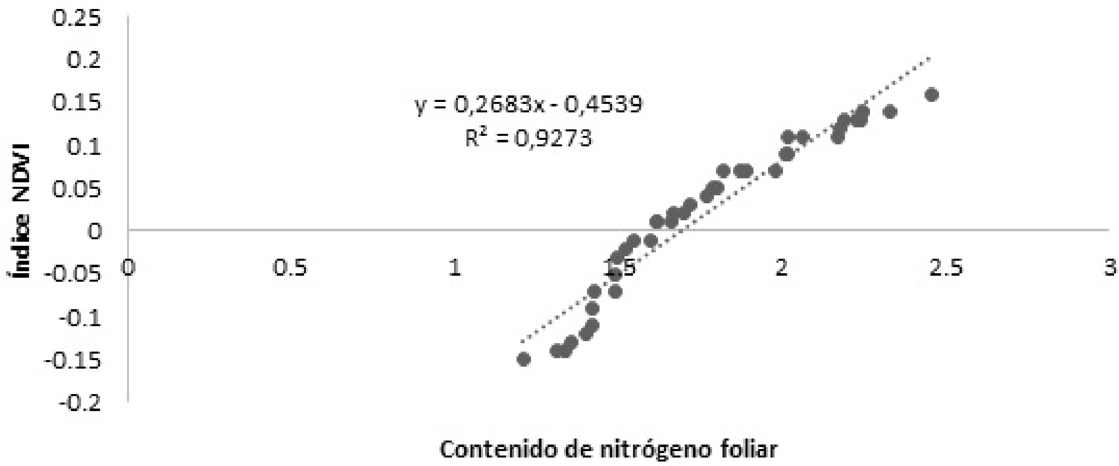

Figure 6. NDVI index contrasted with foliar nitrogen content

Table 2. Values of applied rates and nitrogen content in avocado

Code*	Nitrogen (%)	NDVI	TVI	Code*	Nitrogen (%)	NDVI	TVI
CG1	2,19	0,13	0,81	CI6	1,42	–0,11	0,61
CG2	1,66	0,01	0,71	CI7	2,17	0,11	0,79
CG3	2,18	0,12	0,81	CI8	1,34	–0,14	0,59
CG4	1,98	0,07	0,78	CI9	2,06	0,11	0,79
CG5	1,80	0,05	0,74	CI10	1,50	–0,03	0,67
CG6	1,82	0,07	0,76	CI11	1,79	0,05	0,75
CG7	1,87	0,07	0,75	CI12	1,52	–0,02	0,68
CG8	1,62	0,01	0,77	CI13	2,02	0,11	0,78
CG9	1,89	0,07	0,78	CP1	1,31	–0,14	0,60
CG10	1,72	0,03	0,73	CP2	1,49	–0,07	0,65
CG11	1,60	–0,01	0,70	CP3	1,36	–0,13	0,59
CG12	2,33	0,14	0,81	CP4	2,02	0,09	0,77
GC13	2,23	0,13	0,82	CP5	1,70	0,02	0,72
CG14	1,21	–0,15	0,51	CP6	2,25	0,14	0,82
CG15	2,46	0,16	0,82	CP7	1,77	0,04	0,79
CI1	1,49	–0,05	0,65	CP8	2,24	0,13	0,80
CI2	1,43	–0,07	0,64	CP9	1,40	–0,12	0,60
CI3	2,01	0,09	0,76	CP10	1,67	0,02	0,71
CI4	1,62	0,01	0,71	CP11	1,55	–0,01	0,69
CI5	1,42	–0,09	0,62				

* Categories: CG = large, CI = intermediate, CP = small.

quet et al., 2011; Vian et al., 2018). Similarly, it occurred in studies conducted in maize (Zea mays) where R^2 values of 0.90 were obtained (Maresma et al., 2016). On the other hand, the study conducted by Hashemi et al. (2013) generated R^2 values of 0.45, being lower than the values obtained in this study.

The NDVI values generated can be used to estimate variations in the nitrogen content of avocado trees, which would allow determining the vigor of the plant, which, when it decreases, could be due to a nutritional deficiency or phytosanitary problems. According to Escobar Pardo (2015) and Casassa Bastres (2019), in studies conducted on banana (Musa AAA Simmonds) and forage maize (Zea mays) determined that the interaction between nitrogen content and plant NDVI value produced R^2 values of 0.72 and 0.90, respectively, indicating that these two parameters correlate very well; However, they also indicate that these R^2 values tend to vary according to the phenological stage in which the crops are found, with the correlation being higher in a vegetative stage and lower in a productive stage of the plant.

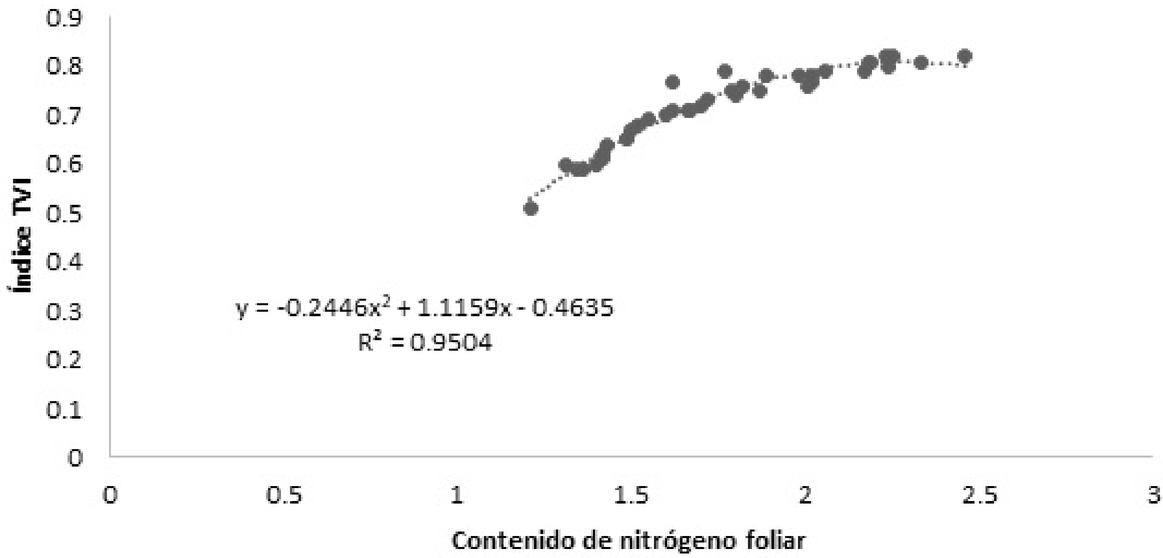

Figure 7. TVI index contrasted with foliar nitrogen content

The increase in NDVI due to increased biomass accumulation is due to increased N_2 availability, which results in increased nitrogen content in the leaves. The greater the accumulation of photosynthetically active biomass, the higher the reflectance of near-infrared radiation and the lower the reflectance of red radiation, resulting in an increase in NDVI (Smith et al., 2017).

Studies by Ramos García (2015) indicate that the reflectance of the red and infrared wavelengths in the plant depend on factors such as: leaf size, nitrogen content, light absorption; however, nitrogen is the element most related to the reflectance of the red and near infrared bands, where it indicates that if the plant is in a state of higher nitrogen accumulation, the reflectance of the red and near infrared bands will be lower, generating indexes with higher values.

3.6. Regression between TVI values and results of foliar analysis

A regression was generated between TVI values and the nitrogen content of the avocado crop (Figure 7), obtaining an R^2 value of 0.95. Studies on corn by Hunt et al. (2013) obtained R^2 values (0.64) lower than those of this study. The TVI does not reach an upper limit, which reduces the effects of asymptotic biomass saturation and makes it better for estimating high biomass; in addition, this index is less effective in differentiation at low biomass due to the decreased sensitivity of the index (Prabhakara et al., 2015). Studies conducted in coffee (Coffea arabica) indicate that the physiological state of the crop is a factor to take into account when determining the nitrogen content and thus its values in plant indices. This is because when the plant is in a productive stage, where the fruits tend to extract more nitrogen from it, and tends to reduce the nitrogen content in the leaves, which results in a lower nitrogen content and thus the reflectance of the red and near infrared waves increases, generating lower values in plant indices, unlike when the plant is in a vegetative growth stage where the accumulation of nitrogen in the leaves is greater causing lower reflectance (Rendón Sáenz and Sadehian Khalajabadi, 2018).

Pat López (2015) determined regression values between nitrogen content and plant index values in avocado, establishing R^2 values of 0.65, a lower value than that obtained in this study. Our results would indicate that a valuation can be established with the use of plant indices, given that they express a state of vigor similar to those expressed by the results of nitrogen content in the plant.

4. Conclusion

There was no correlation between the reference variable (tree crown diameter) and the avocado tree plant growth variables (plant height and stem diameter). The correlation between plant indices and nitrogen content obtained an acceptable R^2 value, so the equations obtained in this research could be used to estimate the content of this element in fruit tree plantations established in areas close to the study zone.

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