Research paper

Multi-spectral Image processing in coffee and cocoa crops

Procesamiento de imágenes multiespectrales en cultivos de café y cacao

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Abstract

A methodology is presented that, through the digital processing of images made with the Matlab software and the use of satellite multispectral images acquired from the United States Geological Survey (USGS), is applied to areas of the Department of Santander where cocoa and coffee crops are grown. Those are representative in the economy of the region, especially in the last two decades. The biometric characteristics of the coffee and cocoa crops were determined in order to put them in a database of satellite images, characterized by their content and by an algorithm implemented to diagnose the state of the crops. It was possible to identify and delimit the areas of the dry plant area, of the best hydrated ones. With this technological technology, we are looking for answers to the concerns of the use of precision agriculture, by farmers who seek better results than automation in agriculture and the most productive, without losses and greater benefits.

Key words: *Precision agriculture, NDVI, NDRE, water stress, image processing.*

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Resumen

Se presenta una metodología que mediante el procesamiento digital de imágenes realizada con el software Matlab y el uso de imágenes multiespectrales satelitales adquiridas del Servicio Geológico de los Estados Unidos (USGS), se aplica a zonas del Departamento de Santander donde los cultivos de cacao y café son representativos en la economía de la región, especialmente en las últimas dos décadas. Se parte de determinar las características biométricas de los cultivos de café y cacao para aplicarlas a una base de datos de imágenes satelitales, que se caracterizan según su contenido y mediante un algoritmo implementado diagnosticar el estado de los cultivos. Se lograron identificar y delimitar las zonas de área vegetal secas, de las mejor hidratadas. Se busca con esta implementación tecnológica ofrecer respuestas a las inquietudes del uso de la agricultura de precisión, por parte de los agricultores que buscan cada vez mejores desarrollos que logren la automatización en el agro y lo hagan más productivo, con menos pérdidas y mayores beneficios.

Palabras claves: *Agricultura de precisión, NDVI, NDRE, estrés hídrico, satelital image*

1. Introduction

Precision agriculture and multispectral image processing are related with remote sensing and crop survey by means of automated vehicles, which got a favorable reception worldwide [1]. Using vegetation indexes and digital images processing can be performed by periodical inspection of the vegetation, to obtain an appropriated and correct study of the crop evolution [2], improving its productivity and yield, because the farmer doesn't have to spend time at field searching deficiencies or yield problems [3]. Other important benefits of these techniques are: improvement and efficient water management, an optimal use of fertilizers, a localized use of herbicides and an early detection of plant illnesses.

Vegetation indexes are the result of the evaluated images by means of algebraic operations between the spectral bands that allows to determine the type of yield, amount of biomass, plant vitality, evolution, changes on the vegetation, by means of the calculation of the radiation that deliver or reflect. The result of these operations, generate a new image, which allows analyzing graphically pixels or image cells related with some vegetal cover parameters. Multispectral images allow to obtain data from the infrared spectrum additionally to the visual spectrum which allows to mix both spectrums generating a new image of the crop that allow to differentiate plants on good state from the ill, when it cannot even be seen by the human eye. [3].

Reflectance concerns when energy interacts with a no transparent surface and correspond to the capacity to the surface to reflect the incident energy. It is measured by means of reflectivity as the ratio between the incident flux and the reflection power flux [8].

Chlorophyll has two types of absorption on the visible wavelenght, one of the blue light environment (400-500 nm of wavelength) and on the red part of the spectrum (600-700 nm); however, it reflects the medium part of the spectrum, the richest spectrum corresponds to the green color (500-600 nm). This is the reason because the chlorophylls have green color and give this color to the organisms or to the tissues that have chloroplasts active in their cells [10]. Carotenes are antioxidant pigments that capture photons on the visible spectrum and protect the vegetal tissues against the photo-oxidation, which is related to the photosynthetic tax and crop performance [11]. These are accessory pigments of the plants, which help to impulse the photosynthesis by means of the compilation of the light of determined wavelengths which is not easily absorbed by the chlorophyll [12].

A study focused into illnesses and pests research by means of multispectral images[13], allowed sooner detection of damages even before plant show visual discolorations.

The current study was directed to coffee and cocoa crop research, due to their supply and demand on the study site, Santander region. It is important the application of these new techniques to these crops because there is little research and applied by means of precision agriculture, which could lead in future to a reduction of C emissions because an optimal use of the resources.

2. Methodologies

This study was divided in several stages: first stage was to determine the biometric features of coffee and cocoa that could be implemented to the multi-spectral imaging. The second stage was to acquire and characterize the multi-spectral images and to implement an algorithm by Matlab to diagnose the state of the crops. The third phase was to validate the algorithm by means of the obtained images, and the last phase was to propose a system of image acquisition of multiple band.

2.1 Cacao and coffee crops multi-spectral images obtaining

2.1.1 Study sites

- **Coffee crops**

  The study site of coffee plantations was located in Mesa de los Santos (Santander, Colombia) at the coordinates (06° 52' 00'' N / 73° 03' 09'' E), specifically at the farm "Hacienda del Roble", size 320 ha. This study site was selected due to the advantages that could offer to this research as: easy accessibility, extent of the plantation, enabling the detection of the study site on the satellite images.

- **Cocoa crops**

  The selected cocoa plantations are located in Rionegro (Santander, Colombia) at the coordinates (7° 16' 6.25''N /73° 10' 4.54''W) which were selected due to Rionegro is one of the largest producing municipalities of cocoa in Colombia, and contributes with a huge part of the cocoa income to the country. Additionally, the association Fedecacao (Cocoa National Fund, is an special account established by law for the collection and management of resources from the Development Fee Cacaotero, whose purpose is to finance programs and projects that benefit the national cacao activity) has interest on this municipality, investing and increasing cocoa purchases [4]. Another reason to have selected this study site was that the cocoa farms on this municipality have easy accessibility, energy, water supply and the proximity of main centers of cocoa consumption [5].

2.1.2 Multi-Spectral images processing

The multi-spectral images used were obtained by the Landsat 8, from the USGS (United States Geological Survey), which was empowered from 30 October 2008, which has a sampling frequency of images between 16 and 18 days [6].

It is needed to realize a conversion to calculate the vegetation indexes, because the equations of the NDVI (Normalized difference Vegetation Index), NDRE (Normalized Difference Red Edge) and MSI (Modified Surface Index), are applied to this kind of conversion. The OLI sensor data can be converted to spectral rescaled reflectance, provided by the metadata archive MTL, which is found in the downloading archive.

The equation (1) was used to convert the digital values (ND) to reflectance values

$$\rho\lambda' = M\rho * Q\ cal + A\rho \quad (1)$$

Where,

$\rho\lambda'$: Planet reflectance, without solar angle correction.

$M\rho$: Scaling multiplicative component by band, obtained by the reflectance multispectral per band

$A\rho$: Specific scaling aggregating component

Q cal: standardized quantified and calibrated product, per pixel (ND) and by band of the multi-spectral image [7].

2.2 Coffee and Cocoa spectral behavior characterization

2.2.1 Reflectivity

On this study, to determine reflectivity flux on coffee and cocoa leafs, a spectrometer Move 100 was used. This device measures the proportional amount of reflected light in a determined surface according to the wavelength to produce a reflectance spectrum. Leaf samples (healthy and diseased) were measured randomly on the study sites, which had a treatment to expose them to the spectrophotometer, diseased leafs seemed to be subjected to excessive heat and traces of fungus action. A leaf fraction was used, preferably from the medium part of the leaf. This fraction was located to the spectrophotometer sample carrier. The procedure consisted to illuminate each leaf sample with white light and calculate the amount of light reflected on an interval series of wavelength, from the visible band until the near infrared band NIR and medium infrared MIR. The absorbance was registered by analysis on µg/L as concentration unit from the calibration curve using chlorophyll 1 mg of Anacystis nodulans Sigma as pattern and a posterior reading of the extract on the spectrophotometer at wavelenght:664 and 750 (pH was adjusted by HCl solution at 0,1 N). Sample was recorded before and after this adjustment, with the finality to verify that the pigment extracted is stable on several pH ranks, verifying the buffer effect characteristic for the photosynthetic pigments [9]. Afterwards, it was reviewed the lecture of the solutions that conform the calibration curve and a lineal regression to obtain the concentration of the chlorophyll pigment.

2.2.2 Chlorophyll and carotenes content

With the spectrophotometer, the chlorophyll content was determined on healthy and diseased coffee and cocoa leafs. It was taken 10 gr of each leaf sample, which then was conditioned to extract the chlorophyll content, by means of the realized calibration curve of the spectrophotometer. To determine the carotenes, it was used the same procedure than in the chlorophyll, as well as the conditioning, extracting, absorbance and concentration determination by means of the spectrophotometer.

2.3 Vegetation indexes application to the multi-spectral images

2.3.1 Normalized difference Vegetation Index (NDVI).

Vegetation indexes are obtained by means of the multi-spectral images, to those algebraic operations are realized between the existent spectral bands that allow to diagnose the vegetation surface, biomass amount, plant vitality, evolution and changes into the vegetation according the radiation that reflect. The result of those calculations generate a new image that allows analyzing graphically determined pixels associated to vegetal cover. NDVI values are linked to the absorbed or reflected light by plants into the electromagnetic spectra. The spectral answer of the healthy vegetation on the visible spectra shows a hug energy absorption due to the plant pigments, chlorophyll molecule, which absorb between 70 and 90 % of the incident light red and blue, to be used on photosynthesis, and on lower proportion green light as alive vegetation [2].

In the near infrared, the light reflection is dominated by the spongy tissue structure of leafs, when the vegetal cell walls present have good health conditions are full of water and reflect higher energy amount. On the visible spectra border, red light absorption by means of chlorophyll diminishes and the reflection on the near infrared increases considerably. Because of this, peak of reflection is in the infrared spectrum instead of the visible spectrum. NDVI is calculated by means of the equation (2)

$$NDVI = \frac{NIR - R}{NIR + R} \quad (2)$$

R= Pixel value of red band

NIR = Pixel value of near infrared[13]

NDVI estimates are always between –a and +a, being the highest values the different vegetation states mores vigorous. It can be asserted that values higher than 0,3 and 0,4 it implies living vegetation. NDVI values lower than 0,1 correspond to sterile areas as rocks, sand or snow. NDVI values between 0,2 and 0,3 correspond to pastures, tillage and forests, and high values between 0,6 and 0,8 indicate forests on temperate areas and tropical areas with dense and vigorous vegetation [14].

2.3.2 Normalized Difference Red Edge index (NDRE)

This index is calculated in a similar manner to NDVI, but using RedEdge band instead of the red band on Equation (2), this kind of band is found mainly on the multispectral cameras. As vegetation matures, NDVI may stabilize and can be less useful to measure the vegetation health status. NDRE, shown on equation (3), can be a more convenient index to compile data related to measure stress and health on mature plants.

$$MSI = \frac{NIR - SWIR}{NIR + SWIR} \quad (3)$$

NIR = Pixel value of near infrared

RedEdge = Pixel value of near red band [15]

Red edge is the transition zone between red and NIR of the reflectance spectrum of the vegetation, and indicate the boundary between chlorophyll absorption into the visible red region and the dispersion due to the intern structure of leafs on NIR region. This allow to determine parameters related to tillage management [15].

2.3.3 Color-infrared (CIR).

Color infrared imagery consist of a combination of red and green NIR bands and has this denomination due to the resulting colors of the images that are really similar of the obtained photographs with an infrared radiation. This technique implies that all red tones, from dark red to pink are described as vegetation such as: most intense tones of red are related to dense forest cover, light red tones indicate tillage and vigorous pastures. Pink tones belong to thin vegetation. Baby blue is related to nude soil, dry or rocky areas. Pale blue corresponds to urban zones. Dark blue to Black is related to clear water on streams or bodies of water. Green to bluish green tones corresponds to ploughed plots or nude soil with varying degrees of soil moisture [16].

2.3.4 Moisture Stress Index (MSI)

It is possible to diagnose water action on crops, considering the biophysical development of those, and the management of water irrigation. This can be determined by means of the spectral behavior of the vegetation on the medium infrared zone (SWIR or Short-wave infrared) of the electromagnetic spectrum, where water content on leafs cause lower reflectivity on SWIR band. This is related to the biomass from agricultural crops, captured by the near infrared. Thus, a moisture stress index is generated, easy to calculate and perform (equation (4)). Values fluctuate between -1 and +1, increasing the index as vegetation becomes drier. Usually, a crop with good water status shows values between 0.2 and 0.45 of MSI, while vegetation under hydric stress has values between 0.45 and 0.6 MSI. Values close to 0 and negatives refer mainly to nude soil or permanent bodies of water. MSI values higher than 0.7 are considered extreme and rarely are found [17].

$$MSI = \frac{NIR - SWIR}{NIR + WSWIR} \tag{4}$$

NIR = Pixel value of near infrared

SWIR = Pixel value on short wave infrared [19].

2.4 Algorithm design.

2.4.1 Matlab application to cocoa and coffee multi-spectral images

On multi-spectral images processing by means of MATLAB, it is important to consider all the commands that could be used during crop analysis on precision agriculture. An important command to use is "multibandread" which requires to know several specifications in terms of the image to process (from satellite or multispectral camera) as: files and columns number of each image, band number, character vector that specifies the format of data storage (BSQ: Sequential Band, BIL: Band Interleaved by Line and BIP: Band Interleaved by Pixel), in addition to know the image format preferably with the archive extension: *.lan [19][20]]. Considering all this information, the graphic interface of Matlab (GUI) was used to visualize and realize calculations referring NDVI; MSI and NDRE calculations on coffee and cocoa crops on the study sites (figure 1)

This application generated a general state of the studied crops identifying ranks of the indexes, which helps to make decisions at field. It has to be mentioned that satellite images can be affected by climatic, ecologic factors that could deviate the obtained values.

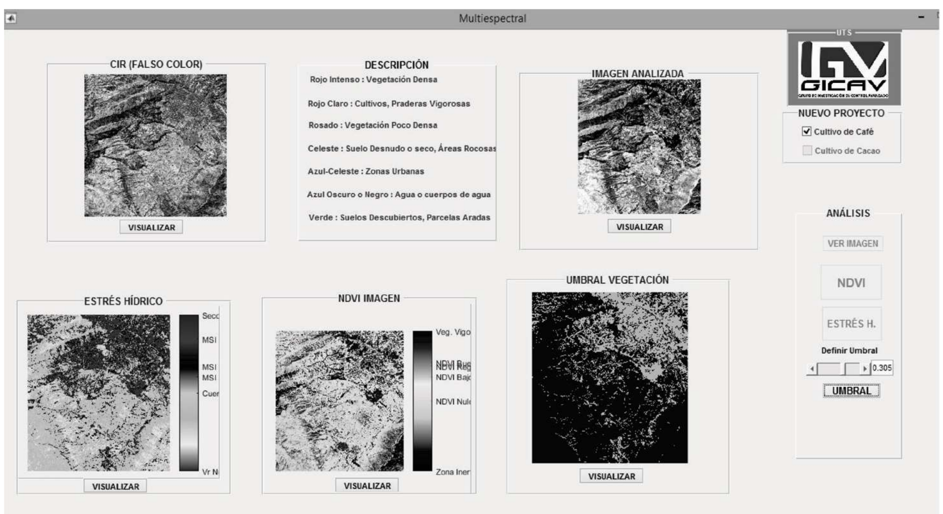

FIGURE 1. GRAPHIC INTERFACE OF VEGETATION INDEXES

Setting process, consists to define the algorithm on NDVI and MSI ranks according to the results of the sampling at field and its analysis by means of the spectrophotometer.

3. Results

The field data obtained by means of the coffee and cocoa samples measured with the spectrophotometer and to those equation (2) was applied, are shown on table 1. MSI values are calculated by means of SWIR band, using equation (4).

Table 1. Coffee and Cocoa NDVI and MSI values

	HEALTH	NDVI	MSI
COFFEE	HEALTHY	0.55	0.21 - 0.34
	DISEASED	0.52	0.35
COCOA	HEALTHY	0.54	0.15 - 0.54
	DISEASED	0.42	0.66

Considering the obtained results at field, the study area was located and selected on the Landsat multi-spectral images and the same indexes were calculated and posteriorly compared with the results of table 1, and to adjust the images data a conversion of digital number to reflectance was applied.

3.1 Reflectivity and spectral behavior

Figure 2 shows the spectral behavior of the healthy and diseased coffee. The answer of healthy leafs shows an absorption peak on the blue region (0,45 μm) and another peak on the red region (0,65 μm). Both peaks are due to the pigment presence into the chloroplasts as: chlorophyll, xanthophyll (type of carotene) and carotenes. However, the highest answer is shown on the near infrared at wavelength between 1,0 and 1,4 μm.

These spectral characteristics are mainly related with photosynthetic pigments and the amount of water stored into leafs. Low reflectivity on the visible spectrum is due to the absorbent effect of the leaf pigments as chlorophyll, xanthophyll and carotenes. Reflectivity on the near infrared NIR shows an increase possibly due to the cellular structure, on healthy leafs, where healthy tissue disperse highest amount of incident radiation on this part of the spectrum [2].

Similar behavior is observed in Figure 3, which represent health and diseased cocoa leafs. Additionally, as expected, on diseased leafs reflectivity values decrease severely, due to tissue damages and a reduction of the starch amount on the area of upper and back sides of leaves. Starch helps to orientate rotation movements of leafs, searching the best positions to solve lighting needs [21].

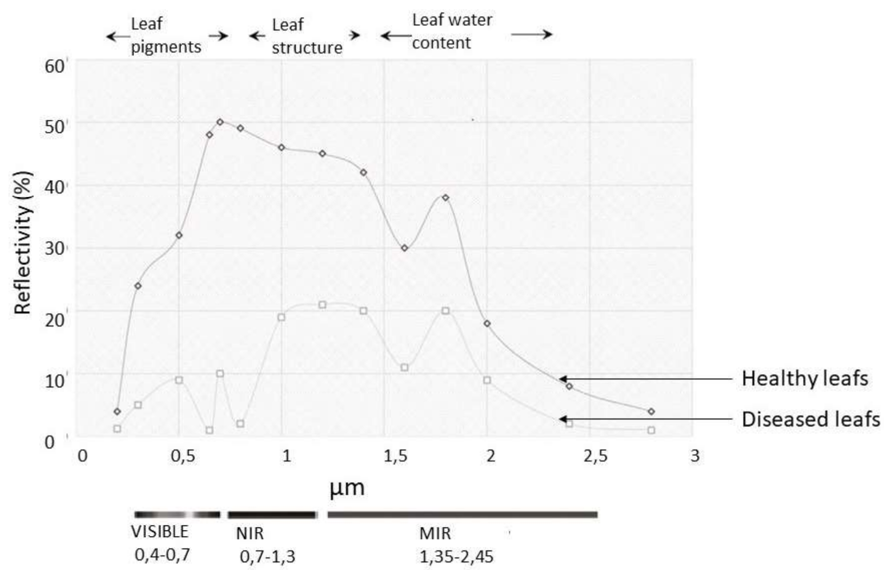

FIGURE. 2. COFFEE LEAFS REFLECTIVITY.

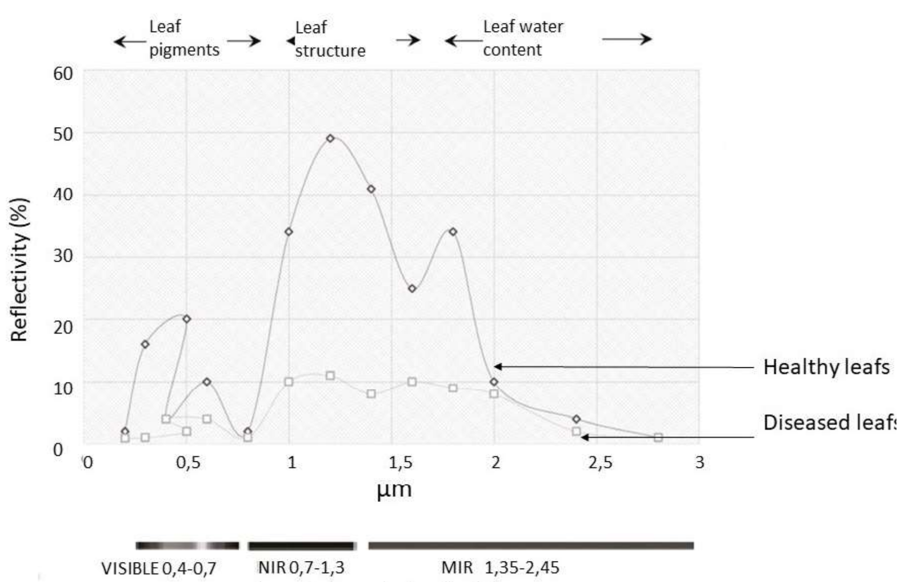

FIGURE 3. COCOA LEAFS REFLECTIVITY

nm	Healthy leafs	Diseased leafs
200	8,23	1,2
300	10,3	0,9
400	2,3	0,75
500	2,45	0,34
600	4,56	0,23
700	9,23	1,9
800	9,02	1,3
900	3,2	0,23

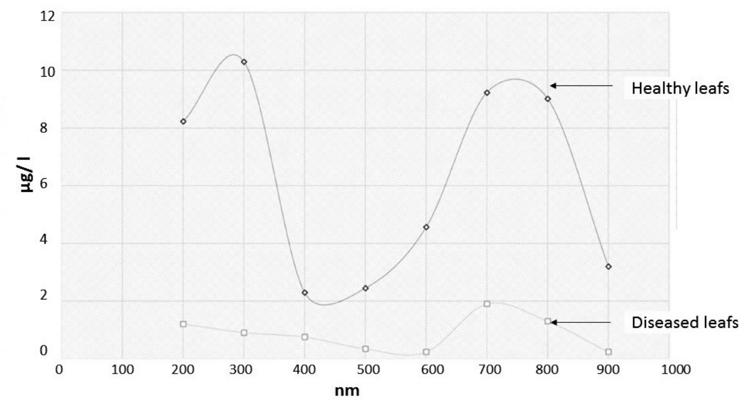

Figure 4. Coffe leafs chlorphyll content

nm	Healthy leafs	Diseased leafs
200	2,3	1,2
300	6,12	3,5
400	1,23	0,2
500	1,45	0,3
600	3,68	1,2
700	7,22	2,56
800	6,34	1,3
900	1,2	0,23

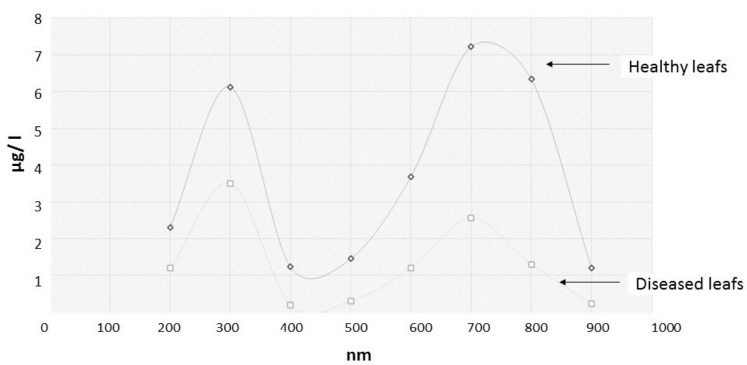

Figure 5. Clorophyll content of cocoa leafs

By another hand, as observed in Figures 2 and 3 from the value 1.4 µm of reflectivity on healthy leafs, reflectivity starts to decrease considerably due to the absorption action of water on MIR zone. This behavior is verified when the moister content of leafs is measured on healthy and diseased leafs on this spectrum zone, which involves a higher moisture content (43%) at 1.8 µm wavelength.

3.2 Chlorophyll content on coffee and cocoa.

Photosynthesis seriously affected by the hydric stress, and because of this reason light absorption decreases [22], suffering a carotene accumulation as an adaptive answer to the impact, developing a biochemical defense system, originating oxidation on the chlorophyll [23], which is coincident with the results find on this study, shown on figures 4 and 5, where chlorophyll concentration of health and diseased leafs can be seen, being higher on coffee than in cocoa leafs, possibly due to on coffee leafs, starch is highest than in cocoa leafs. Additionally, the pigment content depends also to the carbon dioxide levels, oxygen content, temperature, air circulation, hydric state of the plant, leaf morphology, activities and crop management, which is coincident with the obtained results, being the better quality of plants the highest chlorophyll content (in Hacienda el Roble). According the data recorded it can be seen that the visible spectrum is characterized by low reflectivity on cocoa and coffee due to a high absorption realized by the foliar pigments (for example, chlorophyll absorb violet-blue light (0,3 μm) and red light (0,7 μm) as it can be seen on Figure 3. Reflectivity spectrum of green vegetation show two peaks around 0,42 μm and 0,6 μm caused by means of a high absorption of chlorophyll. When is a diseased leaf, chlorophyll is fastest degraded than carotenes, which generate a reflectivity increase on the red wavelength, due to the chlorophyll absorption reduction, as register Figure 2 and 3 respectively [25]

3.3 Carotene content on coffee and cocoa.

nm	Healthy leafs	Diseased Leafs
200	1,5	0,3
300	2,3	0,45
400	5,2	0,074
500	6,3	0,1
550	3,5	0,05
600	0,32	0,052
700	0,43	0,092
800	0,46	0,097
900	0,52	0,1

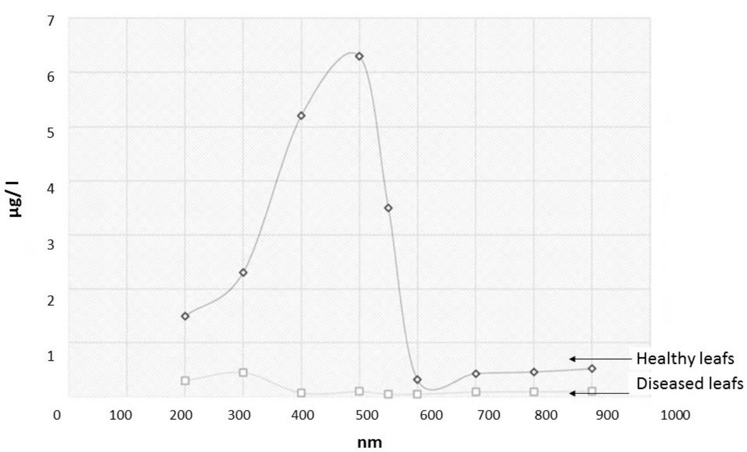

FIGURE 6. CAROTENE PRESENCE ON COFFEE LEAFS

nm	Healthy leafs	Diseased Leafs
200	2,3	0,1
300	1,8	0,08
400	3,6	0,063
500	0,099	0,2
600	1,1	0,023
700	0,13	0,012
800	0,23	0,032
900	0,072	0,014

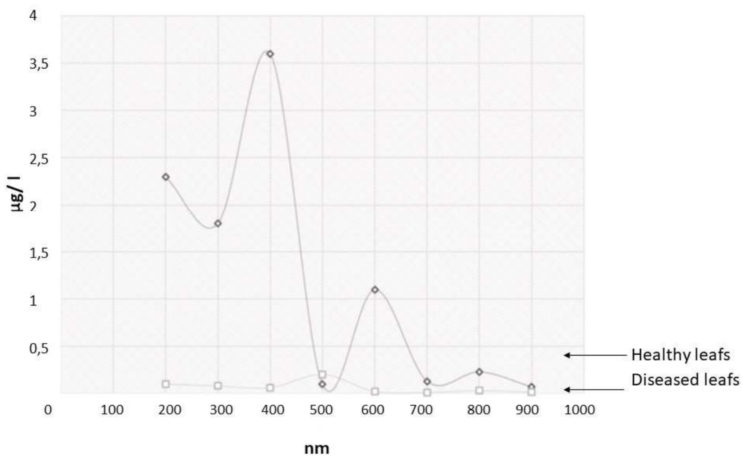

FIGURE 7. CAROTENE PRESENCE ON COCOA LEAFS

When chlorophyll is more abundant on leafs it hides the carotene colors. When leafs fall, chlorophyll is more unstable to oxidation and is decomposed faster, showing yellow tones on leafs, representative from carotene and xanthophyll. On diseased leafs, when chlorophyll is degraded carotenes are more resistant to oxidation processes generating an increase of reflectivity on red wavelength due to lower chlorophyll absorption [2].When leafs are yellow is due to carotenes absorb blue light and reflect green and red light, as can be seen on figure 6 and 7. Coffee and cocoa behavior, however on the spectrum, coffee has a higher incidence on the field readings between 0,4µm and 0,55µm, possibly due to crop quality, highest starch content and tissues thickness of leaves. When diseased leafs died, his reflectivity decrease between 0,4 µm and 0,6 µm as it can be shown on figures 1 and 2. On the red band around 0,8 µm it can be seen a carotene concentration and high reflectivity, behavior associated to the intern structure and water content of plants [2].

The obtained results at laboratory, by means of the spectrophotometer, allowed to detect vigorous areas of the study sites, coinciding with the satellite images.

4. Conclusions

- Spectral behavior of coffee and cocoa healthy and diseased leafs shows that the reflectivity, chlorophyll, carotene content has different behavior.
- As result of this study leafs spectrum can be characterized, as well as the hydric stress, chlorophyll and carotene concentration on healthy and diseased leafs, founding differences on the spectral reflectivity. Each studied variable was identified by spectral region to be determined by means of spectrophotometric quantification, with huge variation according the health of leaf (until 5 times).
- The existence of reflectivity variance and the concentrations of chlorophyll and carotenes which allowed to determine spectral regions at field, according the nutritional state of leafs, as it was expected where the health tissue spreads more incident radiation on the infrared region, as well on the diseased leafs where the reflectivity decreases drastically specially on cocoa leafs.
- It could be determined that due to chlorophyll presence the absorption phenomena increases on coffee and cocoa healthy leafs, which obligatory diminish the reflectivity. As shown on the analysis, on the visible spectrum region the vegetation is characterized by low reflectivity, this reason is coincident with the effect that leafs have lower absorption on the leaf revers than the upper part of the leaf. However, when there are diseased leafs, chlorophyll is faster oxidized than carotenes generating an increase on InfraRed region, due to the chlorophyll reduction.

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