Field Spectroradiometry for African Oil Palm Plantations in the Pacific of Costa Rica

Ramón Masís Campos[1]

Jonnathan Reyes Chaves[2]

Rafael Arce Mesén[3]

Rubén Martínez Barbáchano[4]

Abstract

This study allowed the leaf-scale spectral characterization of African oil palm by conducting field work with a portable spectroradiometer in plantations of the Central and South Pacific of Costa Rica. Spectral signatures of healthy, diseased and nutrient-deficient oil palms were collected. A geodatabase was designed and implemented for geographical, spectral and phytosanitary records. Determination of spectral signatures allows developing spectral libraries of different types of vegetation, soils and water. It also improves the classification of satellite images for thematic cartography and provides the calculation of multiple indices, among others. Healthy vegetation presents low reflectivity in the visible, although there is a peak in the green wavelength due to the presence of chlorophyll. The spectral behavior of diseased vegetation shows a reflectivity curve with a decrease in the infrared and an increase in the red and blue wavelengths. Reflectivity also depends on the water content of the plant.

Keywords: Field spectrometry. Spectral behavior. Plantations of Palma. Costa Rica.

Introduction

Vegetation has a spectral behavior based on plant species, moisture content, foliage structure, health, phenological status, and pigmentation (chlorophyll, xanthophyll, or carotenoids). In agriculture, spectral analyses are increasingly important for producers of the main crops of Costa Rica (coffee, banana, sugar cane, pineapple, oil palm, rice, etc.). Spectral analyses also facilitate the technical intervention of agronomists and plant physiologists as they can make inferences about the phytosanitary status (early detection of pests, diseases, nutrient deficiencies, and water availability).

By means of several studies, initiatives have been implemented in the country with the aim of creating libraries based on different spectral behaviors collected through field spectrometry. For example, the purpose of the Airborne and Remote Sensing Research Program (PRIAS) is to develop a methodology to determine spectral behaviors in various vegetation covers (coffee, pineapple, minerals) for further incorporation into hyperspectral images.

Similarly, the CARTA 2005 technical team experimentally collected data on 45 types of spectral behaviors (asphalt, sugar cane, cassava, grass, corn, rocks, ashes, water, among others) distributed

1 Universidad de Costa Rica (UCR), máster en SIG y TD. ramon.masiscampos@ucr.ac.cr.

2 Universidad de Costa Rica (UCR), máster en SIG y TD. jonnathan.reyeschaves@ucr.ac.cr.

3 Universidad de Laval, doctor en Geografía. rafael.arce@ucr.ac.cr.

4 Universidad de Valladolid, máster en SIG y TD. ruben.martinezbarbachano@ucr.ac.cr.

throughout the country in places such as Turrialba, Arenal Volcano, Irazu Volcano, Sierpe, La Selva, Santa Rosa, Los Inocentes, Ciruelas, and Tilarán. This collection was intended to be used in the classification of Hymap hyperspectral images. Alfaro (2009) also used field spectroradiometry for detection of plantain and banana diseases in a farm located in the Osa county, as part of the final graduation project to obtain a master's degree in GIS and Remote Sensing, UNA-UCR.

The added value of determining spectral signatures in the field allows the analysts of hyperspectral imagery (Hyperion, Hymap, AVIRIS, HYDICE, etc.) to make radiometric corrections, to develop spectral libraries of covers (vegetation, soils, water), to make better classifications of covers for cartography of forests, crops and pastures in large geographical areas, and to generate different types of indices for vegetation, leaf area, biomass, etc.

Study area

In 1944, the United Fruit Company introduced oil palm crops into Quepos, Costa Rica. Two decades later, Grupo NUMAR company expanded the plantations to the Coto region, where 2,800 hectares were planted (CORTÉS, 1994).

The last 2014 Agricultural Census of Costa Rica recorded that the country had approximately 66,419 hectares planted with oil palm. Most of the farms were concentrated on the Pacific slope (Parrita, Quepos, Osa, Corredores, Golfito, and Perez Zeledón), covering 87% of the plantations, and also on some areas of the Caribbean, especially in Matina and Guácimo.

In both Central and South Pacific, the crop is produced by cooperatives, companies, and farmers. According to the National Chamber of Palm Producers - CANAPALMA (2014), 63.7% of the oil palm plantations in the country belong to small independent producers and cooperatives. At a national level, it is estimated there are about 2,100 producers related to this crop.

Some of the most important agro-producers in the study area are Coopecalifornia, Coopesilencio, Palmatica, CoopeAgropal, Coopevaquita, CIPA, Coopeguaycará, Coopesur, Sermucoop, Coopegamba, Coopetriunfo, Coodesa, Coopeintegración, Coopesierreacantillo, Surcoop, and Coopetriunfo, among others.

The producing counties within the delimited area of this research (FIGURE 1) include Parrita, Aguirre, Osa, Golfito, and Corredores, all of them in the province of Puntarenas. This region has a west to southwest orientation between the following geographical coordinates: 9°38'N, 84°33''W and 8°2'N, 82°49''W. The area extends along 220 km and covers 5,347 km² approximately (i.e. almost 9.5% of the national territory).

Figure 1 – Study area: Central and South Pacific of Costa Rica

Study crop

In the country, there are at least 8 "traditional" oil palm varieties (Deli x Nigeria, Deli x Ghana, Deli x Ekona, Deli x Lame, Deli x Yangambi, Deli x Avros, Tanzania x Ekona, Bamenda x Ekona); however, since 2004, high-density clones such as Themba, Zeus, Titan, and Tornado (ASD Costa Rica) have also been commercialized (TABLE 1).

Table 1 – Varieties of African oil palm identified in the field work

Feature	Compact x Nigeria	Ghana	Themba	Evolution	Tornado Amarillo	Sunrise Clone	Drake A
Trunk growth (cm/year)	40-45	-	58	50-55	24.1	28.4	32
Oil per bunch (%)	20-30	31.2	27.5	>30	26.7	28.6	32.2
Fruit size	9-11 g	-	Large	>11 g	12.9 g	8.2 g	9.2 g
Bunch weight (kg)	18-22	-	5.6 (first year) to 13.1 (fifth year)	>22	14.9	-	18.5 (average of 5-7 years)
Sunlight tolerance	Moderate lo low	-	Adapted to low sunlight	Moderate to low	-	-	-
Temperature tolerance	Moderate tolerance to low temperature	Tolerant to low temperature	-	Moderate tolerance to low temperature	-	-	-
Drought tolerance	Moderate-High	Tolerant to water deficit	Adapted to an annual water deficit of 300 mm	Moderate	-	-	-
Leaf length	660-690 cm	Short	630 cm (leaf 17 in the fifth year)		598 cm (9 years)	727 cm (9 years)	699 cm (10 years)
Pest/Disease resistance	Moderate tolerance to PC disorder or bud rot	Tolerant to common spear rot	Tolerant to spear rot/ crown disease and low incidence of the red ring	Moderate resistance to spear rot	-	-	Tolerant to bud rot
Density (plants/ha)	160-180	-	160	-	190 (Tornado clone)	-	-
Yield	3.5 (first year) and 27.5 (fifth year) ton/ha	93.8 kg/palm/year	-	97 kg/palm/year	43.6 ton/ha	41.1 ton/ha	40 ton/ha (average of 8-11 years)

Source: ASD Costa Rica (2017).

For optimal development of oil palm in Costa Rica, CANAPALMA suggests the following agro-ecological conditions:

Plantations at 0 to 400 meters above the sea level, with deep and well-drained silt soils.

Average annual temperatures between 23° C and 27° C, and approximately 5 hours of bright sunshine per day.

Annual precipitation between 1,750 and 2,000 mm, with a distribution of 150 mm per month.

Despite this, the production system of African oil palm is susceptible to various pests, diseases, nutrient deficiencies, and stress (TABLE 2).

Table 2 – Pests, diseases, nutrient deficiencies, and stress in African oil palm

Pests	Diseases	Nutrient deficiencies	Stress
Ants, *Opsiphanes cassina*, *Acharia hyperoche*, *Oiketicus kirby*, *Stenoma cecropia*, *Automeris sp*, Homopterans (sucking insects), *Rhynchophorus palmarum*, *Strategus aloeus*, *Rhinosthomus barbirostris*, *Sagalassa valida*, rats, and pocket gophers	Red ring, Pestalotiopsis, *Mycosphaerella elaeidis*, sudden wilt, chlorotic ring spot, common spear rot, crown disease, severe bud rot, classical bud rot, annular spot, dry and wet basal stem rot, Fusarium wilt	N, K, Mg, B, P	Water deficit

Source: Chinchilla (date unknown).

Material and methods

For field work, the project used an ASD FieldSpec HandHeld 2 spectroradiometer (analytical spectral device), with a 325 nm -1075 nm spectral range and an accuracy of 1 nm, approximately covering from the blue wavelength to the near infrared.

Chuvieco (2002) indicates that a number of factors can modify the collection of data on spectral behaviors, for instance: the angle of sunlight (the time and the date must be considered), the slope orientation in relation to the angle of sunlight, the influence of the atmosphere (particularly the role of clouds on absorption or dispersion of different wavelengths), the phenological status, soils, and other environmental conditions.

The spectral behavior data collection process was carried out under sunny atmospheric conditions, specifically at 8:00 am and 2:00 pm. A Spectralon white reference panel of 5.1 x 5.1 cm to 30.5 cm x 30.5 cm (made of synthetic polytetrafluoroethylene) was used for calibration purposes and for optimization of the instrument, regulating the integration time according to the light intensity used in order not to saturate the FieldSpec HandHeld 2 (FIGURE 2).

**Figure 2** – Field spectroradiometer.

Source: Project B6003. University of Costa Rica (2017)

The palm spectral behavior was measured on leaf number 9 for those plants under 3 years and on leaf number 17 for adult plants. These leaves were selected as the most representative based on their current phenological status. Moreover, in order to improve the description of the spectral behavior, an ESRI geodatabase (FIGURE 3) was designed and implemented to collect data related to each plant under study, for instance: height, diameter, age, date, hour, atmospheric condition, variety, owner, photos and on-site phytopathological and phenological assessment. In the field, information was gathered by using the Survey123 app for Android and then managed with ArcGis Online.

For data processing purposes, the information on spectral behaviors provided by the spectroradiometer was downloaded by using the RS[3] software, and the file extensions (*asd) were managed with ViewSpec Pro. The use of this tool allowed making graphs of the spectral behaviors and converting the data to ASCII or txt files in order to attach them to the database.

In addition, the SAMS software developed by the University of California, Davis, was also required to manage and analyze spectral databases and their metadata for incorporation into spectral libraries to be used by the ENVI software. This type of study is more related to graphic representations and data storage to serve as input for further studies.

Figure 3 – Design and implementation of the spatial database for spectral signatures.
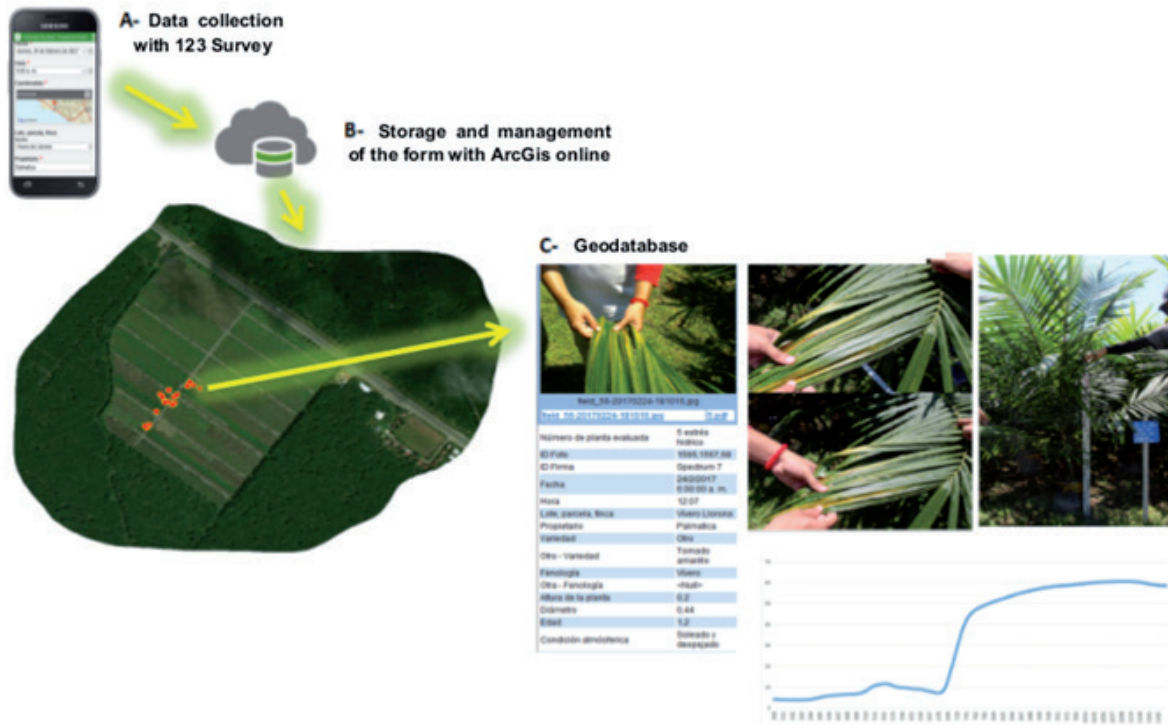

Source: Project B6003. University of Costa Rica (2017).

Results and discussion

In general, the spectral behaviors of vegetation showed variability due to the presence of pigments, the cell structure (leaf shape and type), and the moisture content. In the visible spectrum, the plants were characterized by a low reflectivity curve since all the pigments absorb the wavelengths between 445 nm and 645 nm, except for the intermediate band of 550 nm (green), where a little more electromagnetic energy is reflected (FIGURE 4).

On the other hand, in the case diseased leaves, the presence of carotenes increases and chlorophyll decreases. There is also an increase in reflectivity in the red wavelength. High reflectivity in the near infrared results from the low absorptivity of chlorophyll, the cell structure, and the water content in the leaf.

Figure 4 – General spectral response provided by healthy and stressed vegetation.
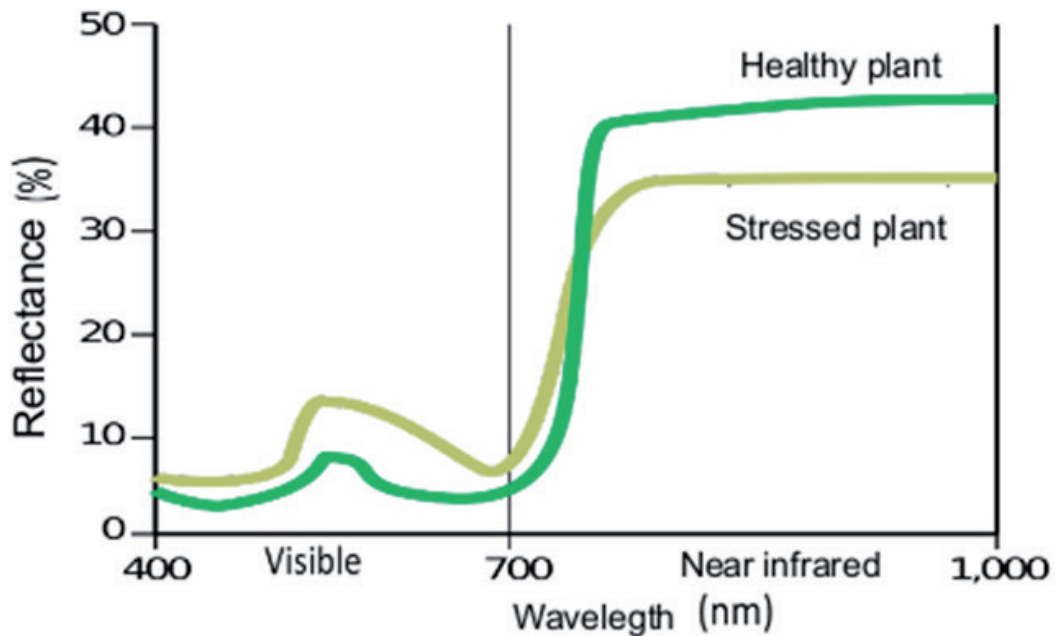
Spectral characterization of healthy oil palm

Healthy vegetation presents low reflectivity in the visible; however, there is a peak in the green wavelength due to the presence of chlorophyll. Additionally, reflectivity is very high in the near infrared due to the lack of energy absorption by the plants in this band.

Figure 5 corresponds to a young healthy oil palm with reflectance in the green wavelength (525 nm-605 nm) that is 3 to 4% higher than the wavelengths of the visible spectrum between the blue (325-525 nm) and the red (655-700 nm). Nevertheless, in the near infrared (700 nm-1025 nm), there is more energy reflected than absorbed (over 50% of energy is reflected in this region of the electromagnetic spectrum).

**Figure 5** – Average spectral behavior of healthy oil palm in the nursery (phenological status).
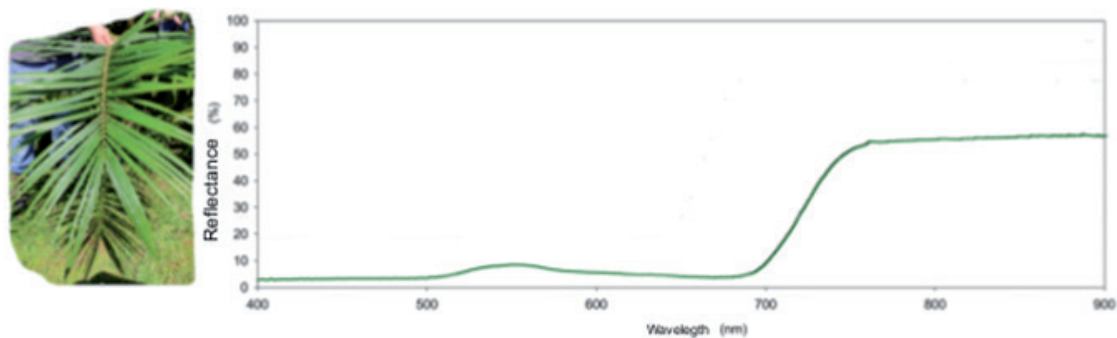
Spectral characterization of diseased or dead oil palm

The spectral behavior of diseased vegetation has a reflectivity curve that decreases in the infrared and increases in the red and blue wavelengths. Reflectivity also depends on the water content in the plant. When the moisture content increases, there is a decrease in reflectivity because the water contained in the plant absorbs more radiation.

Water-deficit stress (FIGURE 6) becomes evident with the yellowing and death of the oil palm leaves and even with the bending of the bud. The spectral behavior shows low reflectance in the visible and the near infrared in comparison with a healthy oil palm. However, in the region between 700 and 750 nm (far red), reflectance increases between 30 and 50%.

Figure 6 – Spectral behavior of oil palm with water-deficit stress in the nursery.
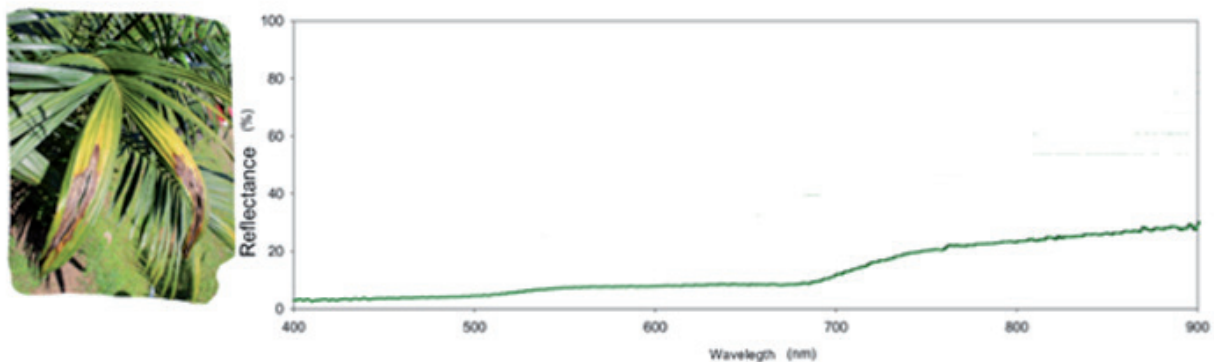
Source: Project B6003. University of Costa Rica (2017).

Anthracnose is a common disease in young plants. Dominguez et al. (2012) state that the most frequent lesion is located in the distal part of the leaflets. This disease involves the development of dark brown spots surrounded by a yellowish halo (FIGURE 7).

Figure 7 – Spectral behavior of oil palm with anthracnose in the nursery (phenological status).
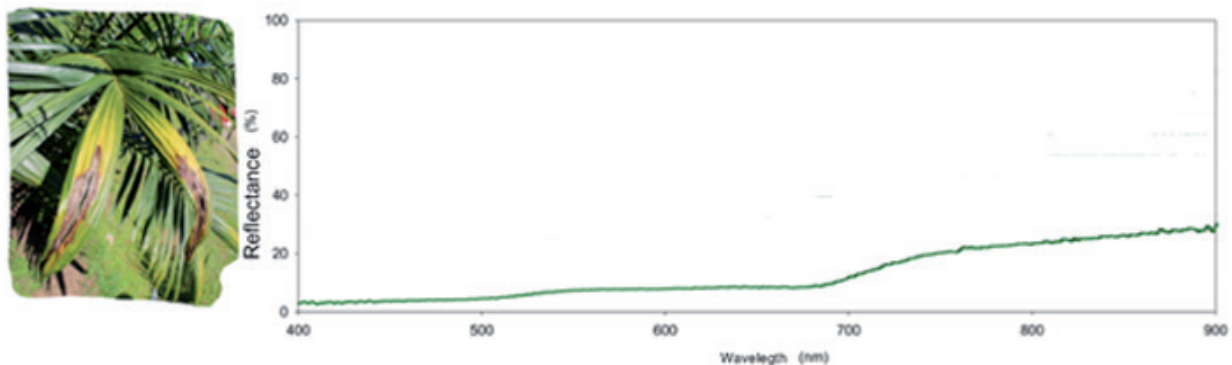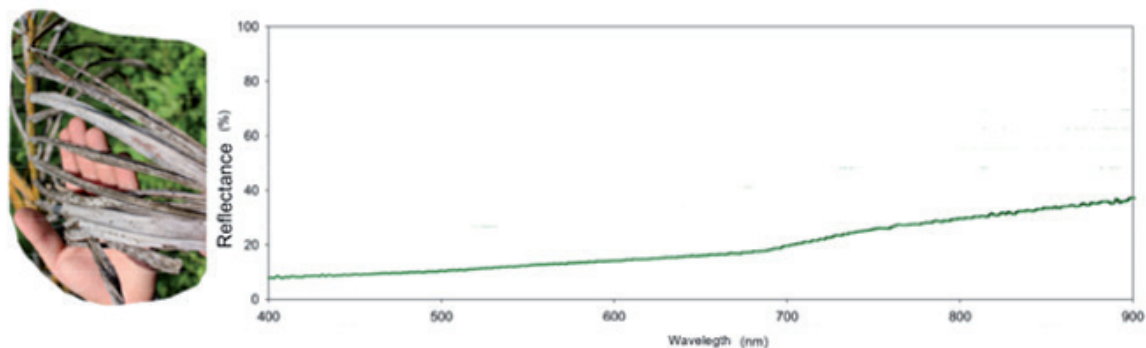

Source: Project B6003. University of Costa Rica (2017).

Moreover, in diseased leaves, the presence of chlorophyll becomes weaker, and the dominance of yellow, ocher, red and orange pigments increases. When the leaves die (FIGURE 8), energy is

reflected in all the regions between 325 and 1.025 nm, especially in the near infrared, at which reflectance is close to 70%.

Figure 8 – Spectral behavior of dead oil palm.

Source: Project B6003. University of Costa Rica (2017).

4.3 Spectral characterization of nutrient-deficient oil palm

Nutrient deficiencies in oil palm are identified by means of particular assessments. In the case of leaves, they can turn yellow and orange or present white stripes due to the lack of nitrogen (N), magnesium (Mg), phosphorous (P), boron (B), or potassium (K).

Nitrogen is a vital element in photosynthesis. Its lack turns the foliage pale yellow and reduces the size of leaves and leaflets. The spectral response shows that the leaves become yellow because carotenes and xanthophylls, which are the dominant pigments (specifically 645-685 nm), absorb blue light and reflect green and red light (FIGURE 9).

Figure 9 – Spectral behavior of N-deficient oil palm in the nursery (phenological status).
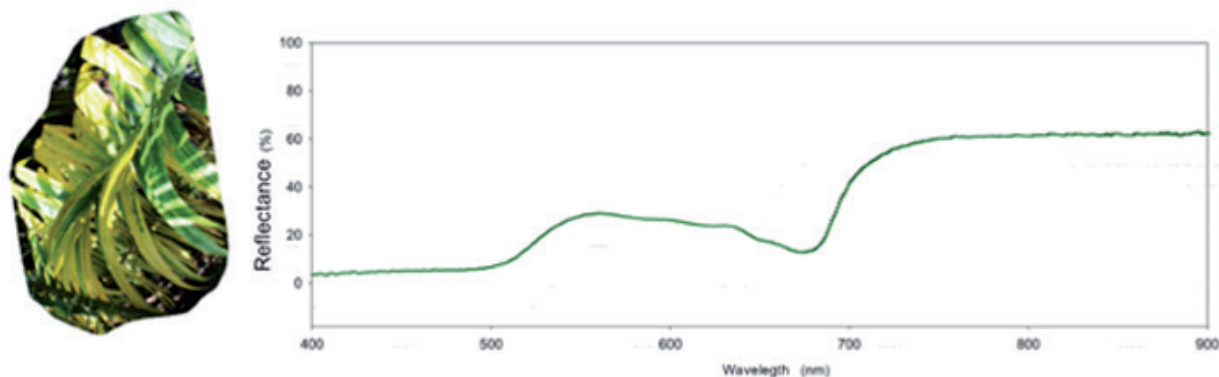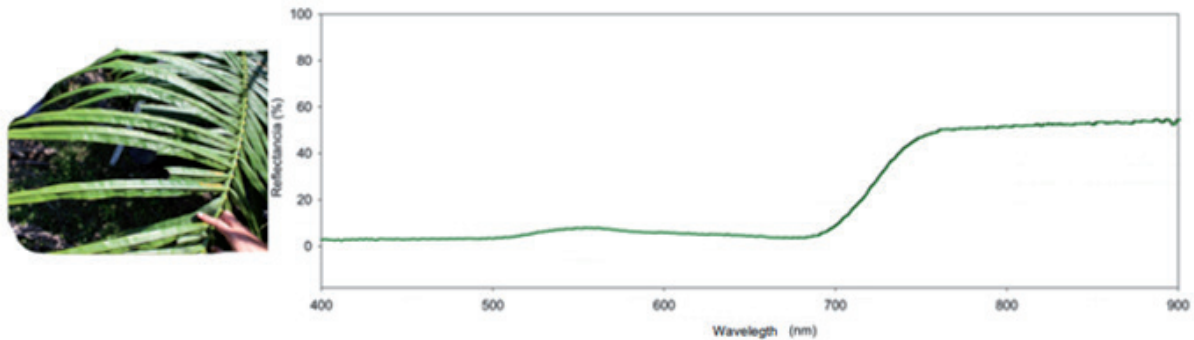

Source: Project B6003. University of Costa Rica (2017).

Leaf deformations and corrugations are responses to the lack of boron (FIGURE 10). Oil palm is sensitive to the low concentrations of this element, which cause abnormalities in the plant growth,

development and reproduction. Gutiérrez and Torres (2013) indicate that leaflets often show a more intense greenish color and wrinkled or curly textures.

Figure 10 – Spectral behavior of B-deficient oil palm in the nursery (phenological status).

Source: Project B6003. University of Costa Rica (2017).

Regarding orange spots, they are a sign of low potassium concentrations (FIGURE 11), and they usually appear in old leaves. In severe cases, the yellow and orange spots become necrotic. The lack of potassium can be identified in the region of 650-780 nm, especially with reflectances of 440, 520, 600 and 720 nm.

**Figure 11** – Spectral behavior of K-deficient oil palm.
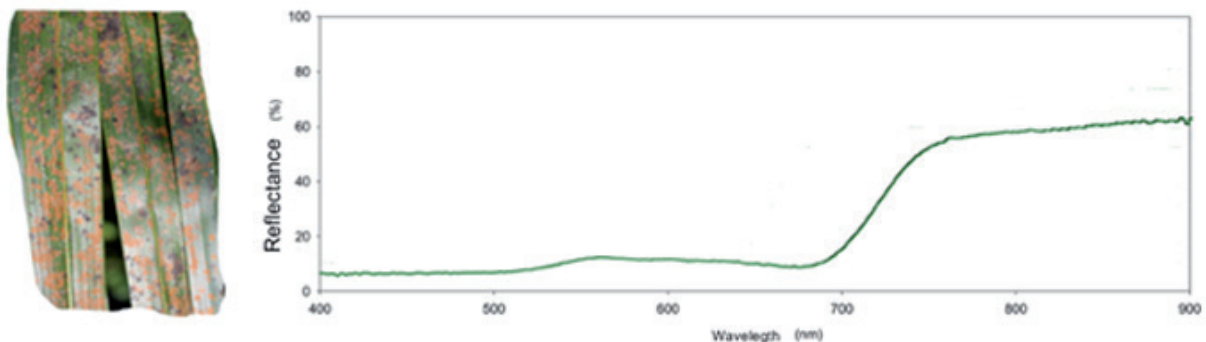
Source: Project B6003. University of Costa Rica (2017).

All these observations were incorporated into a graph that describes the oil palm behavior. According to Figure 12, reflectance in the wavelength between 500 nm and 600 nm shows the highest percentage, particularly in the case of nitrogen-deficient leaves. The opposite situation occurs for leaves with *Anthracnose sp*.

As for plants with water-deficit stress and dead plants, they present a moderately increasing curve in the reflectance percentage as the near infrared is approached.

The initial region of the near-infrared marks an abrupt change in the behavior of oil palm leaves with nitrogen, potassium and boron deficiencies and even in healthy plants, as they reach reflectance values higher than 40%.

Figure 12 – Spectral behavior of oil palm under different conditions.
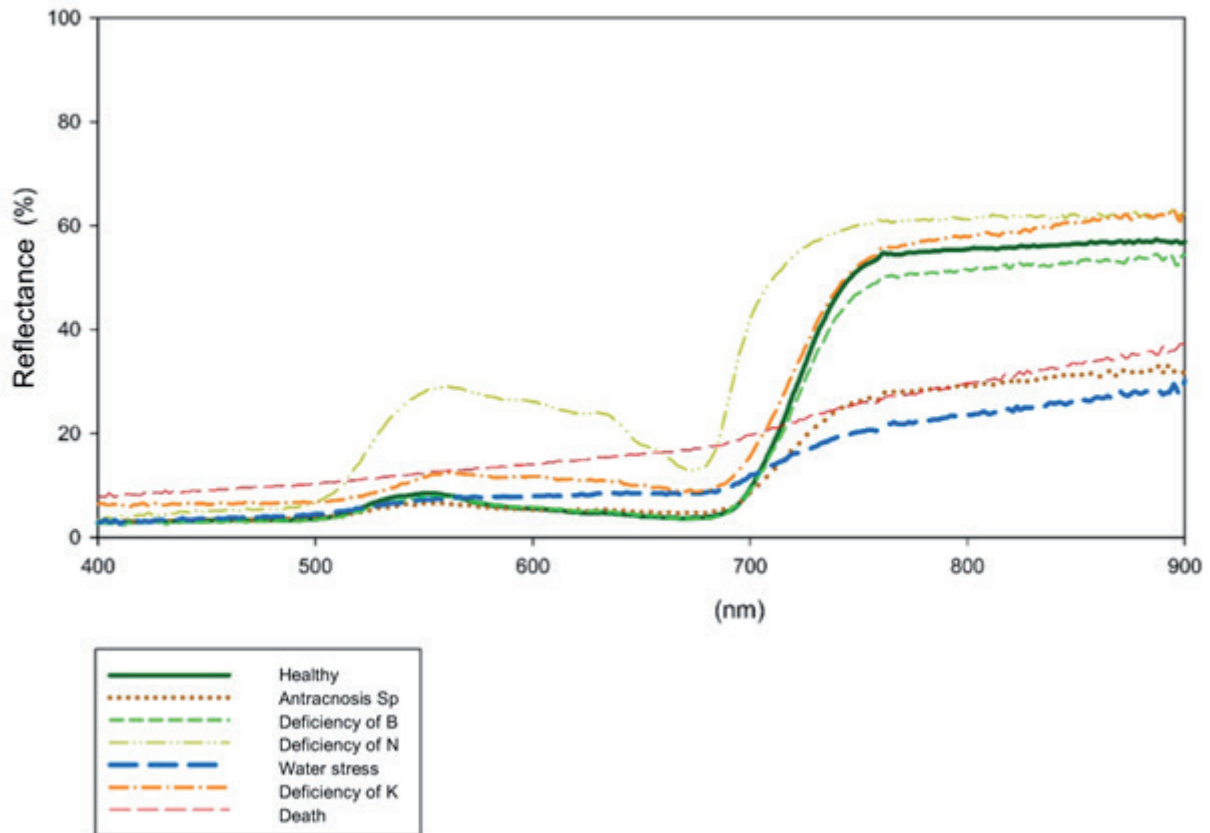
Source: Project B6003. University of Costa Rica (2017).

Final considerations

The objective of the spectral characterization of oil palm is to promote the use of this information in spectral libraries of programs such as ENVI in order to make future classifications as more images from satellites or RPAs become available. Thus, the collected data allows using cross-validation to improve the classification process of images and the local or regional analyses of the oil palm agro-productive sector (cooperatives, companies, and CANAPALMA in Costa Rica).

A technical limitation found during the collection of spectral signatures in the field was weather variability in short periods of time (humidity, clouds, rain, etc.); therefore, it is recommended that the measurement be made with a leaf-clip device connected to a separate battery in order to reduce noise between 325-400 nm and 900-1075 nm of the FieldSpec HandHeld 2.

Another suggestion is that these spectral studies should measure wavelengths between 1075 nm and 2500 nm with the aim of identifying the moisture content in the plants and analyzing water stress. For such purposes, laboratory spectrophotometers can be used for measuring and recording leaflet samples in the field. An additional key aspect to be considered in future research is to carry out the analysis and to verify if the spectral variations (mean value and standard deviation) have sufficient discrepancies in an image, since this research focuses on the data collected in the field.

Finally, it is important to take into account professionals from different fields of knowledge (Geography, Agronomy, Biology, Physics etc.) as part of the teams working in the development of spectral libraries.

Acknowledgments

Radioespectroscopía de campo para áreas de resiembra de palma aceitera africana en el Pacífico de Costa Rica

Resumen

El presente trabajo permitió caracterizar espectralmente la palma africana a escala foliar, por medio de trabajo de campo con un radioespectrometro portátil en plantaciones en el Pacífico Central y Sur de Costa Rica. Se recopiló firmas espectrales de palmas sanas, enfermas y con deficiencias nutricionales. Para su registro geográfico, espectral y fitosanitario se diseñó e implementó una Geodatabase. La determinación de firmas permite desarrollar bibliotecas espectrales de diferentes tipos de vegetación, suelos y aguas. Además permite mejores clasificaciones de imágenes satelitales que derivan cartografía temática o calcular múltiples índices de vegetación, entre otros. La vegetación sana tiene una reflectividad baja en el visible aunque tiene un pico en el verde debido a la presencia de la clorofila. El comportamiento espectral en la vegetación enferma tiene una baja en la curva de reflectividad en el infrarrojo y aumenta la reflectividad en las longitudes de onda del rojo y azul. También la reflectividad de una planta depende de su contenido en agua.

Palabras clave: Espectrometría de campo. Comportamiento espectral. Plantaciones de Palma. Costa Rica.

References

ACUÑA-RUZ, T.; MATTAR, C.; HERNÁNDEZ, H. J. Caracterización espectral de Quillaja saponaria (Mol). **Revista de Teledetección,** v. 47, p. 65-73, 2016. Disponible en: http://polipapers.upv.es/index.php/raet/article/view/6488/7137. Consultado en: 10 marzo 2017.

ALFARO, M. **Uso de espectroradiometría de campo en la detección de enfermedades en cultivos de musáceas: plátano y banano en Osa, Puntarenas, Costa Rica.** Disertación (Magíster en Sistemas de Información Geográfica y Teledetección), Universidad Nacional-Universidad de Costa Rica, 2009.

ARAQUE, L.; JIMÉNEZ, A. Caracterización de firma espectral a partir de sensores remotos para el manejo de sanidad vegetal en el cultivo de palma de aceite. **Revista Palmas**, v. 30, n. 3, 2009. Disponible en: https://publicaciones.fedepalma.org/index.php/palmas/article/view/1455. Consultado el: 14 marzo 2017.

CANAPALMA. **Información del Cultivo de Palma en Costa Rica.** 2014. Disponible en: http://www.canapalma.cr/images/CANAPALMA_Informacion_Cultivo_de_PA_en_Costa_Rica_12Dic2014.pdf. Consultado en: 14 marzo 2017.

CHINCHILLA, C. **Una propuesta para el registro de la información durante de las visitas fitosanitar-ias a las plantaciones de palma aceitera en América Tropical**. Disponible en: http://www.asd-cr.com/images/Propuesta_de_claves_Ene_11.pdf. Consultado en: 8 diciembre 2016.

CHUVIECO, E. **Teledetección Ambiental**, Barcelona, Editorial Ariel, 2002.

CORTÉS, G. **Atlas Agropecuario de Costa Rica.** San José, C. R.: EUNED, 1994.

DOMÍNGUEZ, I.; MOHALI, S.; MARÍN, M.; PINO, H. Caracterización y variabilidad genética de Colletotrichum gloeosporioides sensu lato en plantaciones de palma aceitera (Elaeis guineensis Jacq) en Venezuela. **Tropical Plant Pathology**, v. 37, n. 2, p. 108-122, 2012.

GIRALDO, R.; MOLINA, A.; TORRES-LEON, J. L.; ACOSTA, M.; MARTÍNEZ, S. Estudio de firmas espectrales de palmas de aceite afectadas con la Marchitez letal, usando análisis estadísticos de datos funcionales. **Revista Palmas**, v. 37, n. especial, p. 131-139, 2016. Disponible en: https://publicaciones.fedepalma.org/index.php/palmas/article/view/11897. Consultado el: 16 de abril de 2017.

GUTIÉRREZ, M.; TORRES, J. Síntomas asociados a la deficiencia de boro en la palma aceitera (Elaeis guineensis jacq.) en Costa Rica. **Agronomía Mesoamericana**. v. 24, p. 441-449.

Instituto Nacional de Estadística y Censos (INEC). **VI Censo Nacional Agropecuario. Atlas Estadístico Agropecuario. INEC.** San José. C. R. Disponible en: http://www.inec.go.cr/sites/default/files/documetos-biblioteca-virtual/01._atlas_estadistico_agropecuario_2014.pdf. Consultado el: 16 abril 2017.

KALACSKA, M. **Final report Carta 2005 Spectral Data Collection.** 2005, San José, Costa Rica.

MEXZÓN, R.; CHINCHILLA, C. **El gusano túnel, Stenoma cecropia Meyrick en palma aceitera en América Central**. ASD Oil Palm Papers. v. 27, p. 32-36, 2004.

MINISTERIO DE AGRICULTURA Y GANADERÍA (MAG). **Plan estratégico de la cadena productiva de Palma aceitera**. **Periodo 2008-2010**. Disponible en: http://www.mag.go.cr/bibliotecavirtual/E70-4277.pdf . Consultado el 3mayo 2016.

MOHD, N.; MOHAMAD, A.; SEMAN, A.; BAHROM, E. El uso de sensores remotos para detectar la infección por Ganoderma. **Revista Palmas**, v. 37, n. especial, p. 140-150, 2016. Disponible en: https://publicaciones.fedepalma.org/index.php/palmas/article/view/11898. Consultado el: 16 marzo 2017.

NAVARRO, R. Evaluación de las variables biofísicas mediante teledetección en pinares mediterráneos. **Revista Ambienta**, 2013. Disponible en: http://www.mapama.gob.es/ministerio/pags/Biblioteca/Revistas/pdf_AM/Ambienta_2013_105_78_88.pdf. Consultado en: marzo 2017.

RODRÍGUEZ, G.; SILVA, R.; CASARES, R.; DÍAZ, A.; BARRIOS, R. Fluctuación poblacional de las fases inmaduras de Opsiphanes cassina Felder (Lepidoptera: Nymphalidae) en palma aceitera, estado Monagas, Venezuela. Universidad de Oriente Press. **Revista Científica UDO Agrícola**, v. 12, n. 4, p. 845-854, 2012.

SELVARAJA, S.; BALASUNDRAM, S.; VADAMALAI, G.; HUSNI, M. Use of Spectral Reflectance to Discriminate between Potassium Deficiency and Orange Spotting Symptoms in Oil Palm (Elaeis guineensis). **Life Science Journal**, v. 10, n. 4, 2013. Disponible en: http://www.lifesciencesite.com/lsj/life1004/121_21167life1004_947_951.pdf. Consultado en: marzo 2017.

THENKABAIL, S. P.; LYON, J. G. **Hyperspectral Remote Sensing of Vegetation**. Boca Raton: CRC Press, 2011. DOI: 10.1201/b11222.

VILLEGAS, D. **Evaluación de la fertilización de liberación controlada para el primer año en palma aceitera híbrida (Elaeis oleífera x Elaeis guineensis)**. Tesis Lic. Quito, ECU, Universidad Central del Ecuador, 2015. 98p.