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Application of remote sensing and geoprocessing of forage palm for the development of agricultural productivity in semi-arid regions

Aplicação de sensoriamento remoto e geoprocessamento da palma forrageira para desenvolvimento da produtividade agropecuária em regiões semiáridas

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Abstract: The semi-arid region has a diversified economy in the agricultural sector, but droughts cause great damage to agricultural activity. For this reason, fodder palm has emerged as an alternative for supplying dairy cattle with food. With this research, the spectral signature of fodder palm at different crop ages was determined through remote sensing and geoprocessing, using satellite images. The multivariate analysis showed that the years with above-average rainfall are in opposition to the grouping containing the lowest reflectance values (in the visible and near-infrared bands), which indicate the periods of greatest coverage of the soil surface by forage palm in relation to native vegetation. However, it was possible to monitor the forage palm at different stages of development, providing support for decision-making regarding the management of areas cultivated with palm to increase milk production in the semi-arid region.

Keywords: Multivariate principal component analysis; Near infrared; Landsat; Reflectance.

Resumo: A região semiárida possui uma economia diversificada no setor agropecuário, no entanto, a seca gera grande prejuízo a atividade agrícola. Assim, a palma forrageira, surge como uma alternativa para o suprimento da alimentação do gado leiteiro. Com essa pesquisa, determinou-se a assinatura espectral da palma forrageira em diferentes idades de cultivos, através do sensoriamento remoto e geoprocessamento, utilizando imagens de satélite. A análise multivariada mostrou que nos anos com precipitação acima da média está em oposição ao agrupamento que contém os menores valores das reflectâncias (nas bandas do visível e do infravermelho próximo), que indicam os períodos de maior cobertura da superfície do solo pela palma forrageira em relação a vegetação nativa. Contudo, foi possível o monitoramento da palma forrageira com diferentes graus de desenvolvimento, subsidiando as tomadas de decisão, no que concerne o manejo das áreas cultivadas com palma para aumento de produção leiteira no semiárido.

Palavras-chave: Análise multivariada de componentes principais; Infravermelho próximo; Landsat; Reflectância.

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1. Introduction

Agreste Pernambuco has a diversified economy in the agricultural sector, with dairy and beef cattle farming, as well as corn, beans, fava beans and cassava (Monteiro et al., 2007). In this region, droughts cause great damage due to the reduction in food, making it very difficult to keep cattle (Reis Filho, 2014). As a result, there is a drastic reduction in milk production in these drought regions (IBGE, 2022).

Given the constant droughts that occur in the Agreste and Sertão regions of the state of Pernambuco, there is a need for an alternative source of food for the animals, since common forage plants have low production potential in regions of extreme drought (Mattos, 2005). Therefore, forage palm is an efficient alternative for supplying dairy cattle with food (Epifânio, 2019).

As a cactaceous plant with morphophysiological characteristics that adapt to semi-arid conditions, forage palm has been cultivated on a large scale by farmers in the dairy basins of the Northeast, mainly in Pernambuco and Alagoas, and recently in the state of Minas Gerais, making it one of the main fodder plants for dairy cattle during the dry season (Lira et al., 2006; Castro et el., 2020). Since the plant has a special physiological mechanism for absorbing, using and losing water, it is well adapted to the adverse conditions of these regions (Teles et al., 2002).

Recent studies show that technologies based on remote sensing make it possible to accurately identify the physiological state of the plant, assessing parameters such as chlorophyll content, hydration and vigor (SANTOS et al., 2023). This information helps to make strategic decisions about the ideal time to harvest and the planning of supplementary pastures (SILVA et al., 2024). Thus, integrating remote sensing with agricultural practices improves productivity and contributes to the sustainability of livestock production.

In this way, remote sensing is the technology capable of keeping up with the technological expansion of the field, helping to delimit areas and, through the data acquired, improving mapping accuracy (Zanotta et al., 2019). Images from the Landsat project can be downloaded from the United States Geological Survey (USGS) website, or even from the QGIS program, using the Structured Conservation Planning (SCP) plugin, where they will also be geoprocessed (Sette, 2018). As a result, these technologies have been working together to help with possible decision-making (Zanotta et al., 2019). The constant evolution of software makes cartographic representation closer to reality possible and optimizes production time by making it more accurate (Teixeira, 2018).

Due to technological advances, there are already some tools that contribute to the emergence of various methodologies whose priority is to recognize the spectral signature, as a type of plant is visualized by satellite image, with the focus of optimizing work in the field remotely (Crusiol et al., 2019; Sette, 2018). The interaction between solar radiation, the plant and the sensor produces biophysical information about the vegetation, which helps to identify the cultivated area (Crusiol et al., 2018).

As water accumulates, chlorophyll increases or any other variation occurs in the plant, the spectral signature in the near infrared is likely to become visible (Formaggio, 2017). The forage palm has an abundance of water; most of the moisture in cacti is present in the cladodes (Bezerra et al., 2015).

In this context, the aim of this research was to determine the spectral signature of fodder palm at six different crop ages, using remote sensing and geoprocessing tools, using images from the Landsat 8 satellite.

2. Methodology

2.1 Area covered by the survey

This research was carried out on a commercial dairy farm in the municipality of Capoeiras-PE, located in the Ipojuca Valley microregion, in the Agreste mesoregion of Pernambuco, under UTM coordinates: North: 9,033,291.83 m, East: 761186.30 m, and altitude of 790 m.

This municipality is part of the dairy basin of the state of Pernambuco, ranking third in the Agreste region of Pernambuco as a milk producer (IBGE, 2022) (Figure 01). According to the Köppen classification, the region's climate is characterized as BSh (hot and dry climate). Annual rainfall ranges from 291 mm to 1043.04 mm, with an average annual rainfall of less than 800 mm and a risk of drought of more than 60%, with rainy periods from March to June (APAC, 2023).

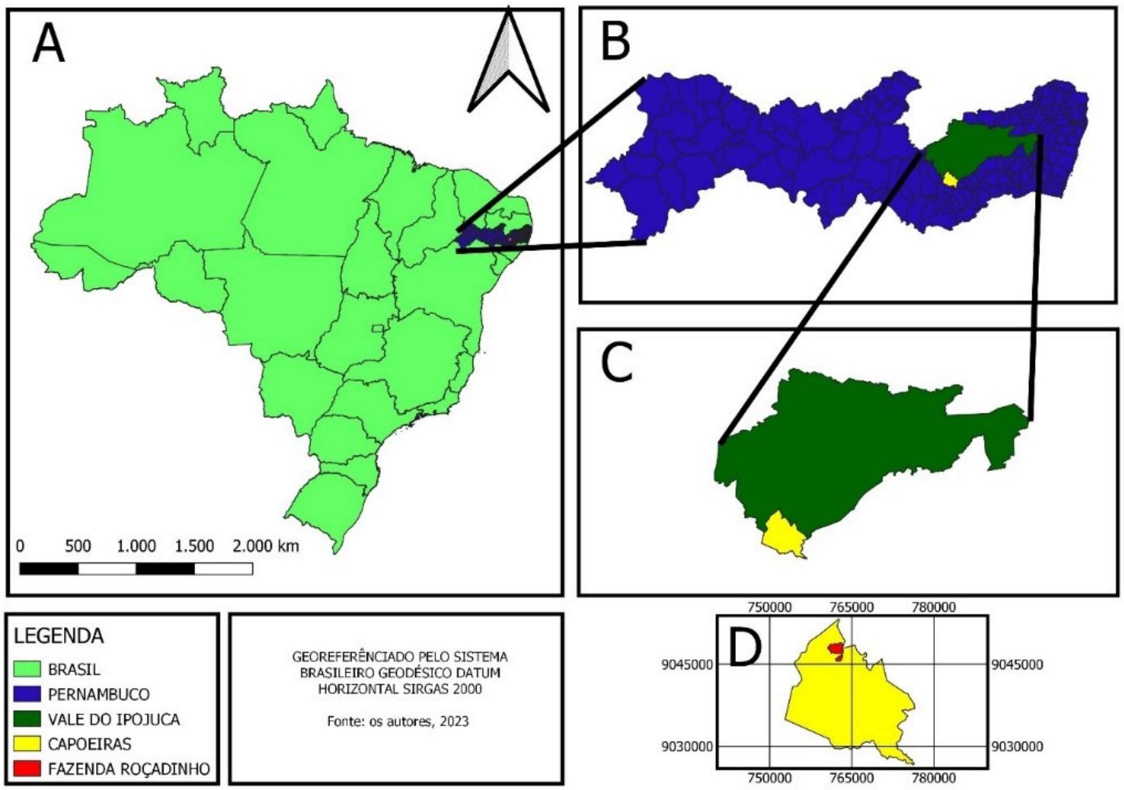

Figure 1 – Location of the municipality of Capoeiras, in the Ipojuca Valley micro-region, PE, Brazil. Legend: (A) Pernambuco in Brazil, (B) Ipojuca Valley Microregion in Pernambuco, (C) Municipality of Capoeiras in the Ipojuca Valley Microregion and (D) Commercial property in the municipality of Capoeiras. Source: Authors (2023).

2.2 Data collection and analysis

A planimetric topographic survey was carried out of six areas: Area 1 (3.8 ha); Area 2 (8.3 ha); Area 3 (3.8 ha); Area 4 (4.8 ha); Area 5 (3.2 ha) and Area 6 (3.5 ha), as they were used as fodder palm study areas, on the commercial property in the municipality of Capoeiras-PE, Figure 02.

The images from October 24, 2019, October 26, 2020, November 9, 2021 and October 8, 2022 were used to determine the spectral signature of the forage palm, knowing that these areas have different ages of the palm, Figure 02.

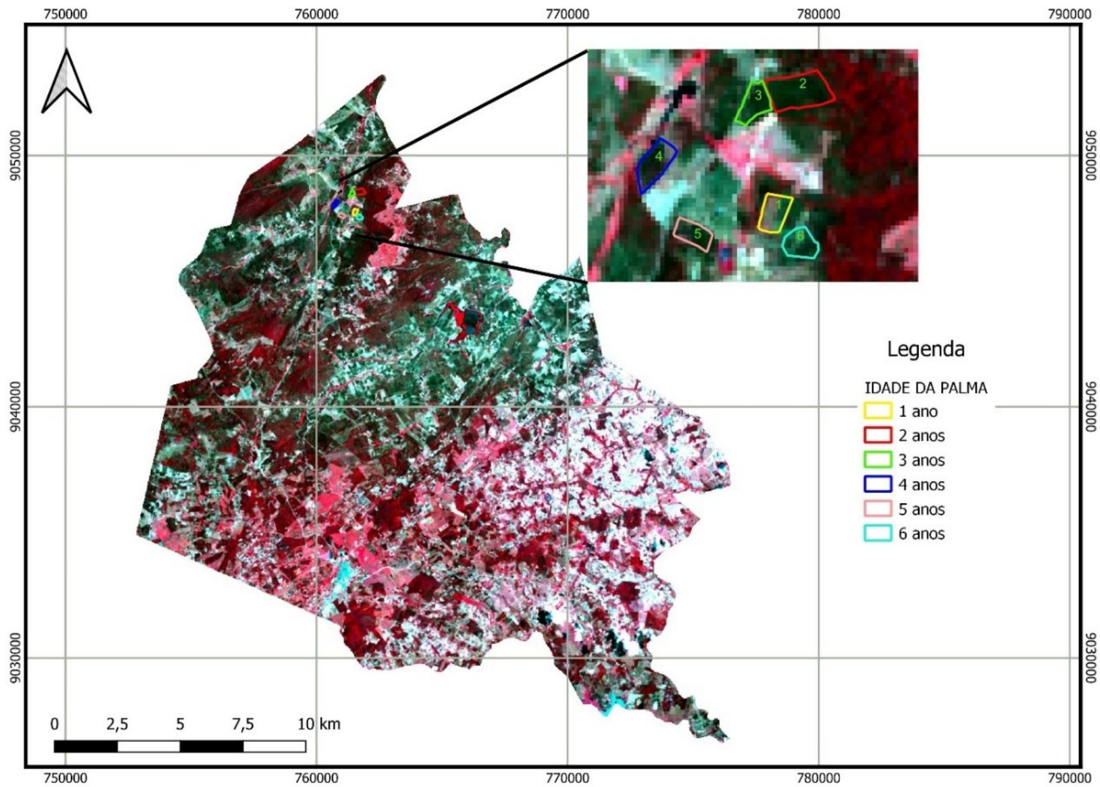

Figure 02 – Areas selected for capturing pixels to determine the spectral signature and respective ages of the oil palm using the Landsat 8 image in October 2022.
Source: Authors (2023).

These areas were used to determine the spectral signature of elephant ear palm (Figure 02). The topographic survey was carried out using the Global Positioning System (GPS). The coordinates were post-processed to identify the palm areas using the post-processing program GTR-processor.

The images from the Landsat 8 satellite using the OLI/TIRS sensor were made available by the United States Geological Survey (USGS) in November 2022 and then processed in the QGIS program version 3.22.5.

When geoprocessing the images, the top-of-atmosphere reflectance (TOA reflectance) was initially corrected using the Semi-Automatic Classification plug-in (SCP), as shown in Equation 01, according to USGS (2022).

$$R = (Add.ref. + Mult.ref. \times IB) / sen(\theta SE) \quad \text{eq. 01}$$

Where:
R - TOA reflectance;
Add.ref - Multiplicative reflectance scaling factor (2.0000*10-5);
Mult.ref - Reflectance additive scaling factor (-0.10);
IB - Image of the band of interest (B02, B03, B04, B05, B06 and B07);
sen (θSE) - Sine of the local solar elevation angle (0.907047055).

The SCP is initially configured to load the desired satellite image in GeoTIFF format, then the reference band (corresponding to the near infrared) is defined. This is followed by atmospheric correction (using the DOS1 method to correct atmospheric distortions). Samples are then trained to draw the Regions of Interest (ROIs) in the areas of vegetation, exposed soil and water. Subsequently, the classification configuration was carried out, choosing the Maximum Likelihood classification method. Finally, the classification was run, checking the confusion matrix and adjusting the ROIs.

Next, the TOA reflectance-corrected images were reprojected, with the following bands: blue, green, red, near infrared and panchromatic, onto the SIRGAS 2000 DATUM, in Zone 24 South. Subsequently, the images were cropped to the polygonal area of the municipality of Capoeiras. In the Landsat 8 sensors, the visible and near-infrared bands are shown in Table 01.

Table 01 – Landsat 8 satellite wavelengths and their corresponding bands.

Band	Range	Wavelength (µm)
02	Blue	0,45 a 0,51
03	Green	0,53 a 0,59
04	Red	0,64 a 0,67
05	Near infrared	0,85 a 0,88

Source: Authors (2023).

In order to identify the spectral signature, several pixels of forage palm, native vegetation, pasture and water were captured by the QGIS plug-in Semi-Automatic Classification (SCP). The palm was identified in the pixels of the six areas that were selected in this study and which are highlighted in Figure 07. Pasture, native vegetation and water were identified in the pixels contained in the polygonal area of the municipality of Capoeiras-PE, which is also shown in Figure 2.

A principal component analysis (PCA) was carried out to reduce the dimensionality of the multivariate data used in this work, such as precipitation, fodder palm, native vegetation and reflectance. Initially, the variables were normalized to remove different scales and ensure comparability, then the principal components were selected based on the variance explained. Interpretation of the results involved analysis of the factor loadings to identify which variables have the greatest influence on each component. In the agricultural context, PCA can reveal patterns of integration between variables, helping to understand how rainfall affects the vegetation and productivity of fodder palm in different spectral conditions.

3. Results and discussion

The variation in rainfall between the years 2019 and 2022 was used as an element of analysis in this research to assess its association with reflectances using the multivariate analysis techniques of principal components and clustering. The average rainfall during this period was 666.42 mm, as shown in Figure 03.

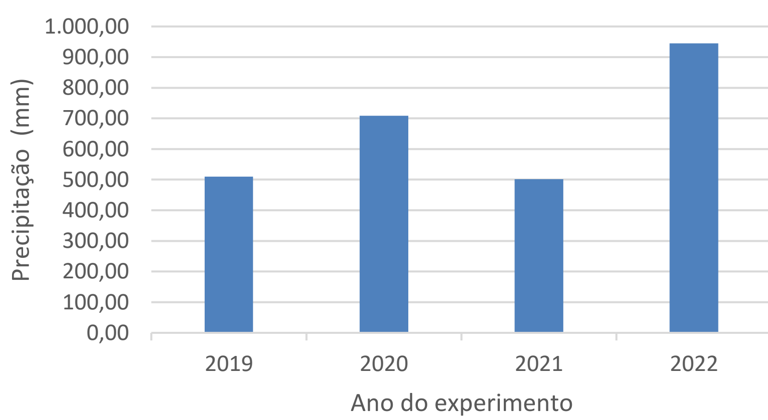

Figure 03 – Annual rainfall for the four years of research.
Source: Authors (2023).

Figure 04 shows the palm's spectral signature, with an upward curve ranging from 0.02 to 0.19 reflectance, comprising the visible and near infrared bands, with wavelengths ranging from 0.48 µm band 02 (blue); 0.56 µm band 03 (green); 0.66 µm band 04 (red) and 0.87 µm band 05 (near infrared).

When comparing the spectral curve of the forage palm with other vegetation such as pasture and native vegetation, it was observed that the palm has lower reflectance than the pasture in the near infrared wavelength, with a variation of 15%, probably because the palm stores water in its cellular structures (Lima et al., 2003). Native vegetation, on the other hand, exhibits spectral behavior that is more similar to forage palm. This similarity can possibly be attributed to the presence of water reserves in the plant cells, as illustrated in Figure 04.

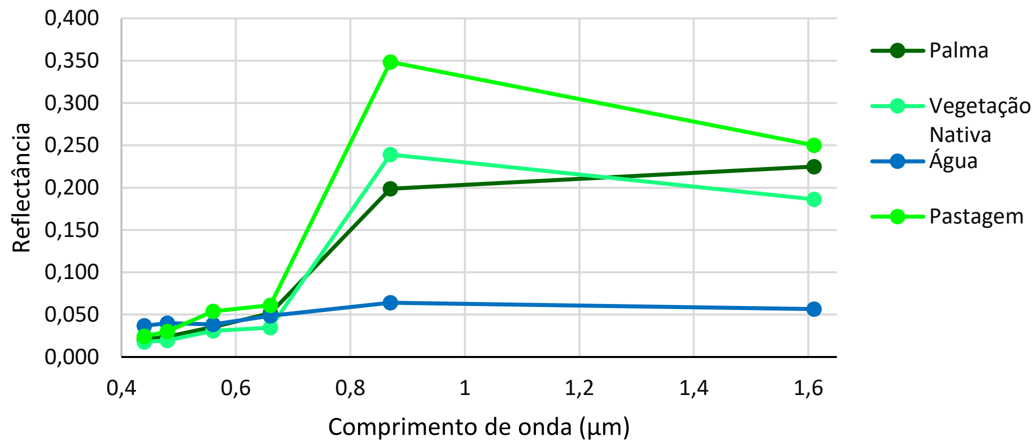

Figure 04 – Graph of the spectral signatures of pasture, native vegetation, palm and water obtained from the Landsat 8 satellite image.
Source: Authors (2023).

In agreement with the same reflectance parameters, Batista et al. (2018) using SENTINEL-2A images, found that Paricá plants (S. Parahyba, var. amazonicum) have low reflectance values in the visible region: blue (Band 02), green (Band 03) and red (Band 04) below 5%; and high values, above 20% in the near infrared region (Band 08). Compared to the satellite in this study (Landsat), the blue, green and red bands are also below 5%, but the near-infrared band showed a value of around 19%, probably due to the higher accumulation of water in the palm cells than in the Paricá crop.

Pedrali et al. (2016) studied the spectral behavior of six tree species found at the Federal University of Santa Maria/RS, using the FieldSpec 3 spectroradiometer. They noted that in the near infrared wavelength, the reflectances of these six species were high, ranging from 47 to 58%, values which were higher than in this research, probably due to a lower amount of water in their cell structures.

The multivariate statistical analysis by principal components (Figure 05) shows the influence of rainfall on reflectance, thus establishing a clear relationship between these variables. In the years 2022 and 2020, when rainfall was higher (945 and 708 mm, respectively) than the average (666.42 mm), there was a positive correlation with forage palm and native vegetation. On the other hand, in the years 2019 and 2021, with lower rainfall (510.36 and 501.89 mm, respectively), the relationship was negative with fodder palm and native vegetation.

The principal component (PC1) on the left shows the parameters: oil palm, native vegetation and the reflectance of the rainiest years (2020 and 2022) together with the precipitation parameter. On the other hand, on the right-hand side of the same axis, there are the parameters of all the bands in this research: reflectance of the blue band (R_B01 and R_B02), reflectance of the green band (R_B03), reflectance of the red band (R_B04), reflectance of the near infrared band (R_B05) and reflectance of the mid-infrared band (R_B06 and R_B07) together with the least rainy years (2019 and 2021). This shows the variation in reflectance as a function of rainfall, showing that in the less rainy years the reflectances are higher (Figure 05B).

Also in Figure 05A, we see that the reflectance measured in 2020 for area 3 with one year of planting (corresponding to 2020.1) which should be grouped with the rainiest years, however, is on the opposite side, and may have received some influence from area 3 (soil type, slope, soil depth, etc.).

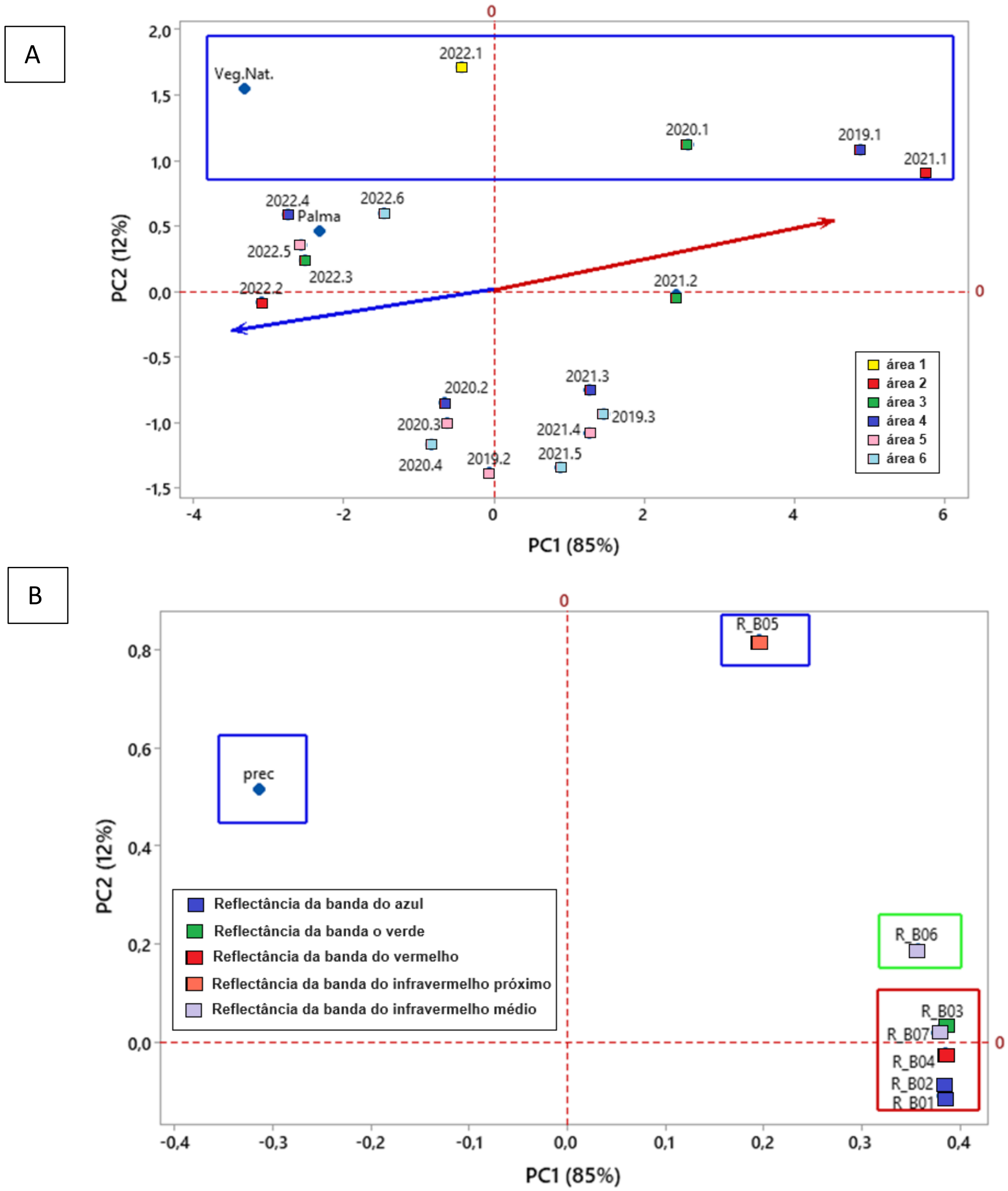

Figure 05 – Graph of the multivariate analysis by principal components.
** Veg. Nat. - Native Vegetation, Prec. - precipitation.*
Source: Authors (2023).

In the principal component (PC2) of the upper or positive portion, there is the grouping of the first year of planting of all the areas (2019.1, 2020.1, 2021.1 and 2022.1), it can also be seen that the reflectance of the native vegetation and the near infrared wavelength (R_B05) are grouped together in this principal component. This suggests that areas with only one year of planting and, consequently, still at an early stage of development, are predominantly influenced by native vegetation and exposed soil in relation to oil palm (Figure 05B).

Ribeiro et al. (2019), when analyzing the influence of the seasons on cerrado vegetation, observed that spectral behavior is best assessed using the wavelengths of the red and near infrared spectral regions, corroborating the present research, in which the authors noted that in the rainy season the vegetation is photosynthetically active, because the vegetation is greener.

Damasceno et al. (2020) analysed the spatio-temporal dynamics of vegetation cover in the municipality of Arcoverde (Pernambuco), concluding that rainfall had a positive influence on the Normalized Difference Vegetation Index (NDVI), where this index is the subtraction of the near infrared band (NIR) and the red band divided by the sum of these two bands, i.e. greater rainfall increases the reflectance of the NIR band.

According to the dendrogram shown in Figure 06, the grouping of the years 2019, 2020 and 2021 is noticeable, covering planted areas 2, 3, 4, 5 and 6. On the other hand, the year 2022, together with fodder palm and native vegetation, forms another distinct grouping.

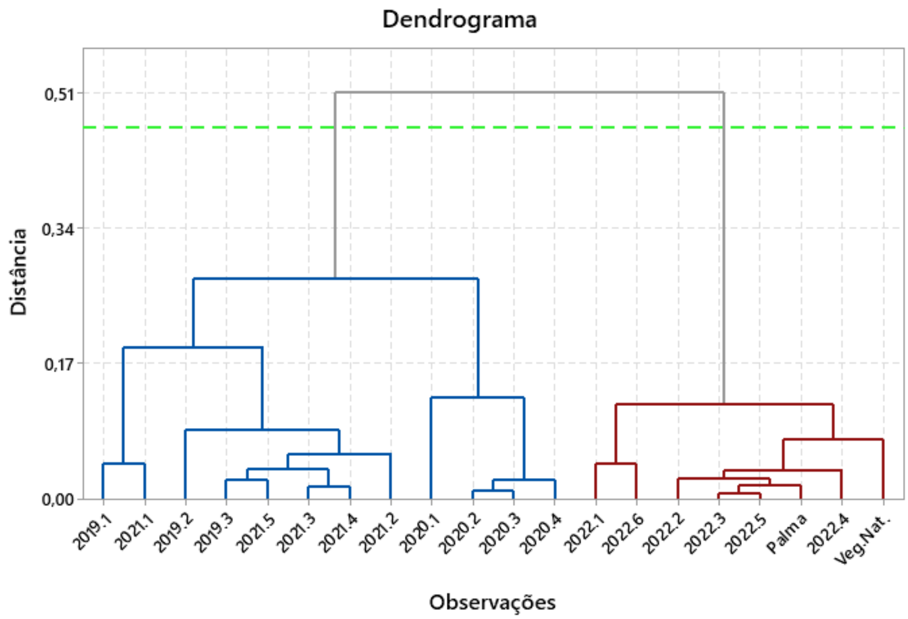

Figure 06 – Graph of the multivariate analysis of the observation grouping of the six areas over the four-year period. Source: Authors (2023).

Looking at the spectral signatures of the four images acquired for the different planting areas (Figures 07, 08, 09 and 10), it can be seen that the reflectance values, in the wavelength that makes up the near infrared band, show practically no difference between them, from the second year of planting onwards. Only in the first year of planting do the areas show a reflectance curve that distances itself from the other years of planting, varying from 2 to 8% of this distance, as this dispersion may be related to rainfall or the characteristics of the area where the planting was carried out.

Research into the spectral signature of agricultural targets (sugarcane) detected in WorldView-2 satellite images showed a small difference between the spectral curves of healthy sugarcane and sugarcane with spots on the crop. This behavior may be the result of minimal structural changes in the plant as a result of the infestation of this disease (Ferreira Sobrinho and Alves, 2013). This result is important when interpreting the spectral signature, since the change in the color of the crop will influence the spectral signature curve.

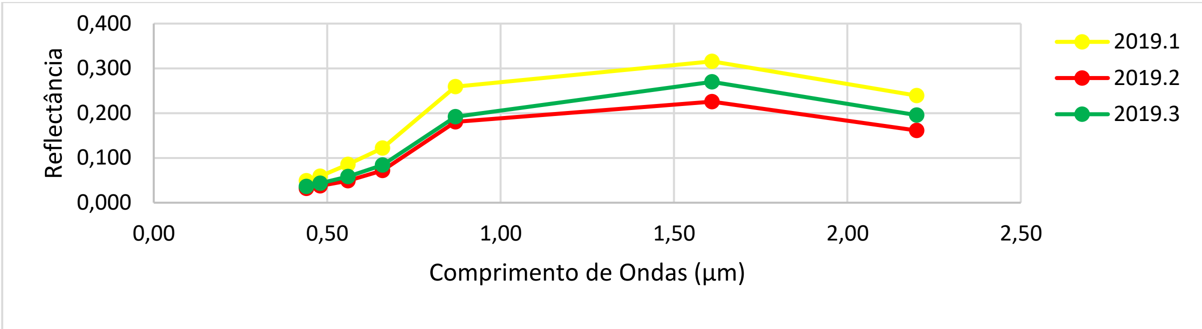

Figure 07 – Spectral signature of oil palm in 2019.
** 2019.1 (area 4, one year of planting), 2019.2 (area 5, two years of planting) and 2019.3 (area 6, three years of planting).*
Source: Authors (2023).

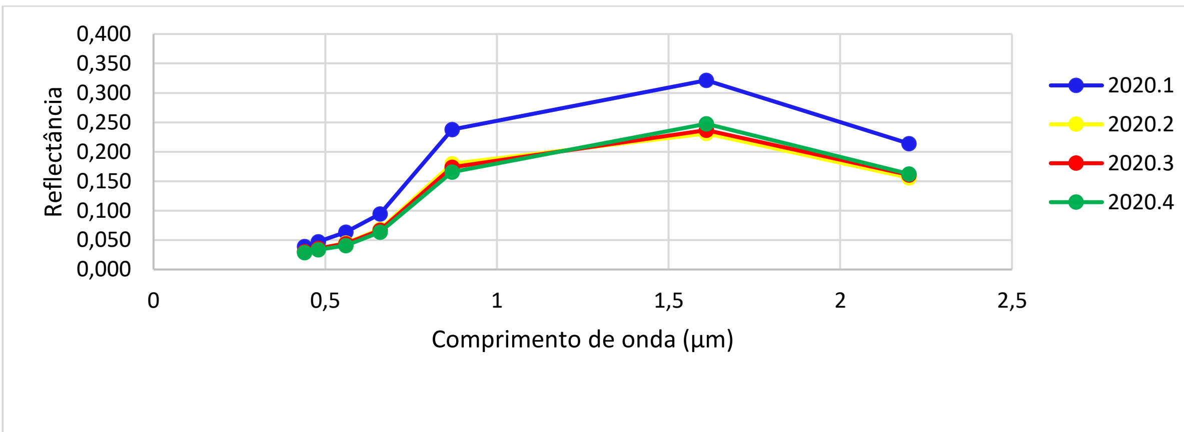

Figure 08 – Spectral signature of oil palm in 2020.
**2020.1 (area 3, one year of planting), 2020.2 (area 4, two years of planting), 2020.3 (area 5, three years of planting) and 2020.4 (area 6, four years of planting).*
Source: Authors (2023).

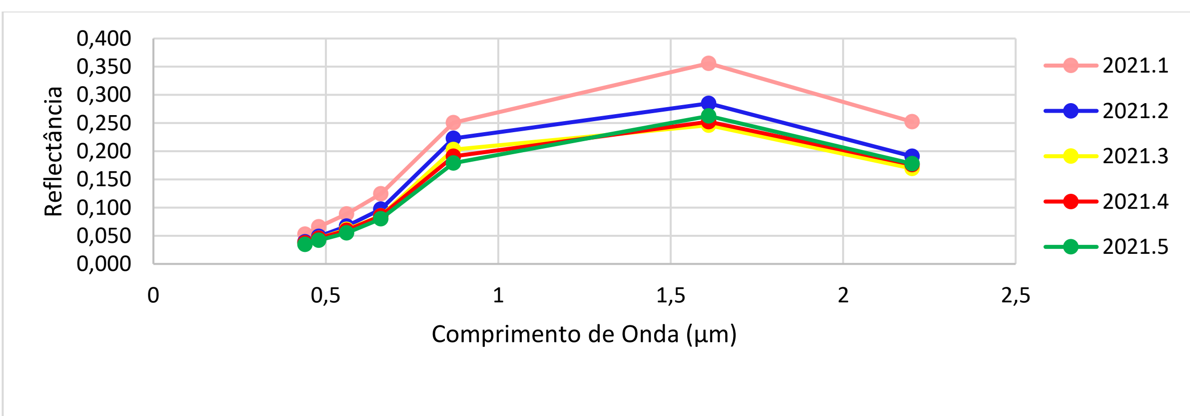

Figure 09 – Spectral signature of oil palm in 2021.
**2021.1 (area 2, one year of planting), 2021.2 (area 3, two years of planting), 2021.3 (area 4, three years of planting), 2021.4 (area 5, four years of planting) and 2021.5 (area 6, five years of planting).*
Source: Authors (2023).

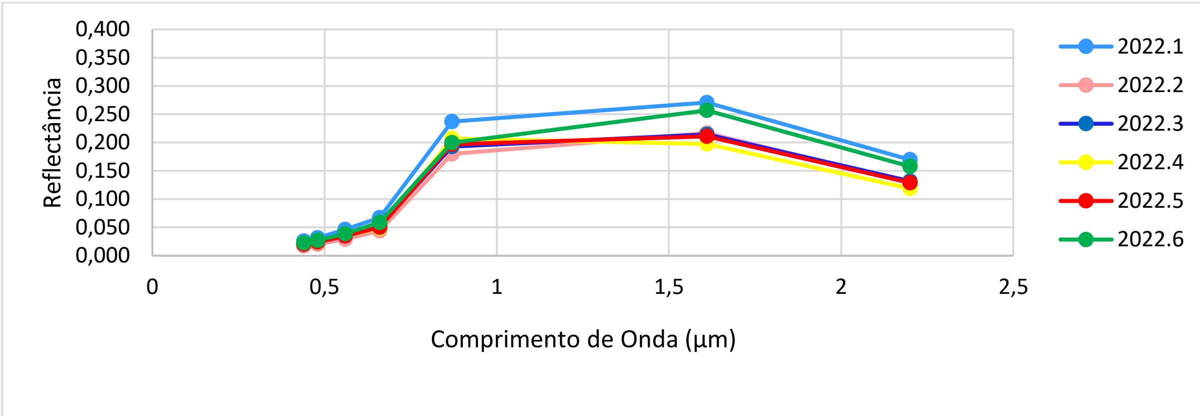

Figure 10 – Spectral signature of oil palm in 2022.
** 2021.1 (area 1, one year of planting), 2021.2 (area 2, two years of planting), 2021.3 (area 3, three years of planting), 2021.4 (area 4, four years of planting), 2021.5 (area 5, five years of planting) and 2021.6 (area 6, six years of planting).*
Source: Authors (2023).

Remote sensing techniques have several limitations that can impact the accuracy and interpretation of the results. In this study, challenges include the spatial resolution of the Landsat 8 sensor, which may not capture variations in smaller crop areas. In addition, the top-of-atmosphere (TOA) reflectance correction depends on atmospheric conditions at the time of acquisition, which can introduce errors if not properly modeled. Another factor is the availability of images with low cloud cover, which can limit the periodicity of the analysis. Determining the spectral signature of fodder palm is also influenced by variations in plant age and agricultural management between areas, making standardization difficult. Finally, the use of multi-temporal data requires careful calibration to ensure comparability between years, taking into account changes in solar illumination and seasonal characteristics that can confuse the results.

Thus, the spectral signature of fodder palm is a promising tool for agricultural management, making it possible to monitor indicators such as chlorophyll content, humidity and plant vigor in real time. And this data obtained by multispectral or hyperspectral sensors helps producers to identify areas with water deficiency and can prioritize irrigation more efficiently, reducing costs and waste.

4. Final considerations

Remote Sensing and Geoprocessing techniques helped to determine the spectral signature of the palm in the six years of planting and to associate this information with the type of crop, the amount of water in the cell and the age of the crop. The spectral signature of the forage palm, due to the large amount of water in the cell structure, showed a reflectance curve below the reflectance curve of the pasture and a reflectance curve very close to the native vegetation. Analyzing the spectral signatures in the six years of planting, it was possible to identify that the first year of planting had a wider range of reflectance compared to the other years.

In the multivariate statistical analysis, there was a difference in the years with the highest rainfall, with lower reflectance values than the years with the lowest rainfall, indicating the periods of lowest palm densification in relation to the native vegetation. These dynamics may suggest to public managers that the use of these geoprocessing and remote sensing tools can support decision-making regarding the areas used to monitor oil palm with different degrees of growth and planting techniques.

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