2019 Brazilian Technology Symposium

SPECTRAL BEHAVIOR OF MAIZE, RICE, SOY AND OAT CROPS USING MULTI-SPECTRAL IMAGES FROM SENTINEL-2

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***Abstract*— Monitoring the status of crops at regional, local and smallholder farming levels is essential in the search for sustainable agricultural management. One of the methodologies applied for this purpose is precision agriculture, which, together with the technological tools and equipment (Global Navigation Satellite Systems, Remote Sensing, Geographic Information Systems and Unmanned Aerial Vehicles), form an integrated agricultural system based on information of crop production and evolution. Remote sensing uses measures of the interaction response from electromagnetic radiation (ER) with soil and vegetation as a basis for the development of agricultural crops yields and harvest index predictors. In this research, spectral signatures (reflectance values related to wavelength units) and the Normalized Differenced Vegetation Index (NDVI) were analyzed for maize, soybean, rice and oat crops in a growing area of 320 hectares, located in the city of Tremembé (São Paulo-Brazil) for the summer harvest period from November to March of the crop cycles of 2017/2018 and 2018/2019, through the use of multi-spectral images of SENTINEL-2 satellite platform (and one image from Landsat-8 to cover the missing image for December 2017). The results showed a higher spectral response (especially in the RedEdge and Near-InfraRed region) for soybean crops, followed by rice and corn around the 60 to 90 days of sowing, and a decrease with the approach to harvest, which is given by nutrient loss and leaf chlorosis. In addition, the NDVI values where higher to the crop cycle 2017/2018 (0.962) given in the image of December of 2017, around the 55 to 80 days of sowing for the soybean and rice crops. However, the development of crop cycle 2018/2019 seem to show more homogeneous spectral results and larger areas with high NDVI values than the first cycle.**

Keywords—NDVI; Precision Agriculture; Spectral signatures; SENTINEL-2.

I. INTRODUCTION

Digital geographic information is now considered a basis for acquiring essential environmental and crop monitoring information, adding the availability of high quality data from different times and places. The increase in the availability of digital geographic information data sources, as well as satellite platforms with free and unrestricted imagery access policy and improvements in spatial, spectral and radiometric resolutions, have made the multi-spectral imagery very useful for detecting crop and vegetation changes [1]. One of the methods for obtaining information from different objects through instruments that are not in physical contact with those objects is remote sensing, broadly known as the science that study the responses of electromagnetic radiation (ER) interactions with terrestrial materials by developing ground surface imaging [2]. To increase Earth monitoring possibilities, space agencies have created initiatives such as the Copernicus Sentinel-2 (S2), and Landsat-8 satellite missions, to guarantee a permanent supply of satellite images of mid-spatial resolution (with 10 and 30 meters respectively) and a great potential for generating vegetation coverage information.

The European's Space Agency (ESA) Copernicus mission Sentinel-2 is a polar-orbiting, multi-spectral mid-resolution imaging (10 m pixel size and 10 to 5 days of temporal resolution) with twin polar-orbiting satellites, Sentinel-2A (launched 23 June 2015) and 2B (launched 7 March 2017) [3]. In addition, other of the satellite programs widely used for Earth observations applications is the joint NASA/U.S. Geological Survey (USGS) Landsat series; this satellite program is the longest running enterprise providing imagery of the Earth from space. The USGS opened the access of the Landsat satellite data since 2008, with the last satellite launched in February 2013 (Landsat-8) [4].

Remote sensing technology applications on satellite platforms, aerial unmanned vehicles and portable radiometers together with the use of Global Navigation Satellite System (GNSS), Geographic Information System (GIS) and farm equipment form an integrated system based on information of crop production and evolution known as *Precision Agriculture*. This system has as principal goal the practice of sustainable agriculture and the seek to improve management of agricultural inputs (fertilizers, herbicides, seeds and fuel) by increasing crop productivity and reducing adverse impacts on the environment. Remote sensors capture the interaction response of ER with soil and vegetation as a measure of the ratio of reflected radiance flux to incident radiance flux at a specific wavelength (spectral reflectance of the surface) [5]. Analyzing the spectral signature response of different crop types and vegetation index values as the Normalized Differenced Vegetation Index (NDVI) during the development of the crop can provide a technical support in farming practices such as fertilizer application, water management and a tool to estimates the crop health and growth status [3].

In this respect, we aim to obtain the spectral signatures (spectral reflectance values) for maize, soybean, rice and oat crops in a growing area of 320 hectares, located in the city of Tremembé (São Paulo-Brazil) for summer sowing cycles (November to March) 2017/2018 and 2018/2019 (oat culture is studied from April to June 2018), with the purpose of analyzing the signature behavior in the different phases of the crops. In addition, we seek to employ the NDVI index to determine the

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This work was supported by the Brazilian agency of National Council for the Improvement of Higher Education (*CAPES*) and the program MackPesquisa of the Presbyterian University of Mackenzie – São Paulo.

behavior of the crops in each cycle, showing the advantage, useful and utility of Sentinel-2 images in precision agriculture.

II. MATERIALS AND METHODS

A. Data

There are some differences in the image characteristics from satellite platforms, given in the spatial, spectral, radiometric and temporal resolutions. The Multi-Spectral Imager (MSI) sensor of Sentinel-2 and the Operational Land Imager (OLI) sensor of Landsat-8 are similar but have different spectral and spatial resolution, and their data have different levels of radiometric and atmospheric correction.

Landsat 8 bands have wavelengths analogous to Sentinel-2 bands [6], as showed in the Table 1.

TABLE I. THE LANDSAT-8 OLI AND SENTINEL-2 MSI EQUIVALENT SPECTRAL BANDS CONSIDERED IN THIS STUDY.

Landsat-8 OLI	Sentinel-2 MSI
[a]B2 (Blue) - 30 - (452–512)	B2 -10 - (458–523)
B3 (Green) - 30 - (533–590)	B3 -10 - (543–578)
B4 (Red) - 30 - (636–673)	B4 -10 - (650–680)
	B5 (RedEdge 1)-20 - (689,1–719,1)
	B6 (RedEdge 2)-20 - (725,5–755,5)
	B7 (RedEdge 3)-20 - (762,8–802,8)
B5 (NIR) - 30 - (851–879)	B8 -10 - (785–900)
	B8A (RedEdge 4) -20 - (843,7–885,7)
	B9 (WaterVapor) -60 - (843,7–885,7)
B6 (SWIR1) - 30 - (1566–1651)	B11 - 20 - (1565–1655)
B7 (SWIR2) – 30 - (2107–2294)	B12 - 20 - (2100–2280)
B8 (PAN) – 15 - (500–680)	
B9 (CIRRUS) – 30 - (1360–1390)	B10 - 60 - (1342,5-1404,5)

[a] Band number (name)- spatial resolution (m)-spectral band range (nm)

The MSI Sentinel-2 sensor covers 13 spectral bands (443-2190 nm), but only 10 are useful for agricultural monitoring, involving the regions of visible (B2-B4), vegetation redEdge (B5-B7 and B8A), NIR (Near infra-red B8) and the SWIR (Short wave infra-red B11 and B12). About the OLI sensor of Landsat-8, it covers 8 spectral bands (443-2200 nm), capturing also image data in the regions of visible (B2-B4), NIR (B5), SWIR 1 (B6) and SWIR 2 (B7), adding the panchromatic region band (B8), being only 6 of this bands useful in vegetation studies.

The revisit time of Landsat-8 satellite and Sentinel-2 platforms are 16 and 5 days respectively, availing observations spread over time; different Sentinel-2 image data were used to this study, involving one image per month to the summer sowing period (November to March) for the crop cycles of 2017/2018 and 2018/2019, which allowed to include 5 images for each of the cycles under study, except for the Sentinel-2 image of December 2017 that showed dense cloud cover over the area of interest, and was replaced for a Landsat-8 image for this research, given the equivalent spectral band characteristics (Fig.1) and the available tools for their corrections.

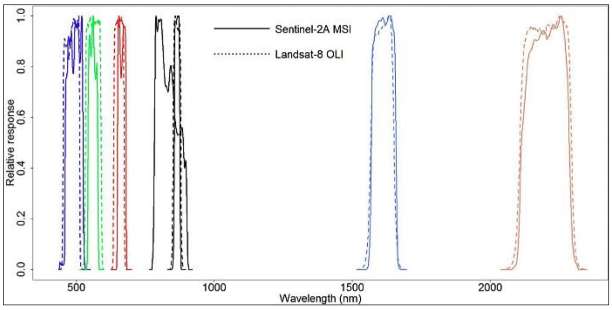

Figure 1. Spectral response for the approximately equivalent Sentinel-2 MSI (solid lines) and Landsat-8 OLI (dashed lines) [6].

B. Study Area

The study area is a plantation (maize, rice, soybean and oat crops) of approximately 320 hectares located about 560 msnm of elevation in the city of Tremembé (São Paulo-Brazil) (Fig.2.) at the Universal Transversal Mercator (UTM) coordinates of 438,814.90 m E, 7,461,118.52 m N for the reference system SIRGAS 2000 zone 23 S. Local measures in the nearest weather station identify as the driest month to July, with precipitation about 21 mm, in contrast to the highest precipitation in January with an average precipitation of 238 mm [7].

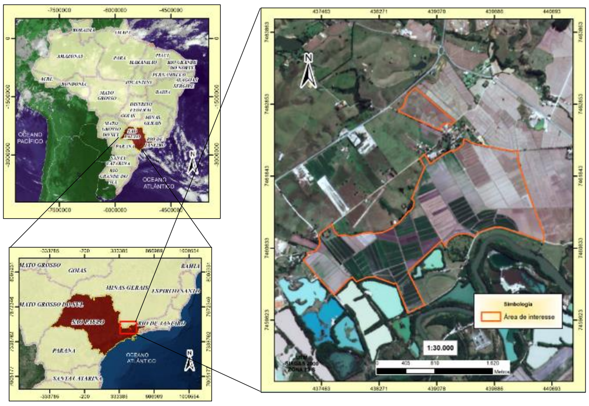

Figure 2. Study area (delimiting boundary in orange right region) in the city of Tremembé (São Paulo).

C. Image processing

Sentinel-2 (Level-1C) products were downloaded from OpenHub, an ESA's web platform for the publicly available download of Copernicus mission products (available at https://scihub.copernicus.eu/), those are delivered directly at Top of Atmosphere reflectance values (feature a TOA - top of atmosphere geometric and radiometric correction), and using Qgis 3.2 version software semiautomatic classification (SCP) plugin for atmospheric correction to obtain the reflectance values at the base of atmosphere (BOA) applying the dark object subtraction (DOS1) correction method. One of the sources of error that can completely alter the image radiometrically is the atmosphere, it affects the radiance measured in the image in two ways: as a reflector, by adding extra radiance to the signal and as an absorber, attenuating the intensity of energy illuminating the target on the surface. DOS1 atmospheric correction method applies (1), (2) and (3) for an image-based technique which uses a metadata file that contains the information required to transfer the digital counts (DC) of the image into physical reflectance values [8].

$$L_{DO1\%} = \frac{0.01[(ESUN\lambda * \cos\theta_S * T_Z) + Edown] * T_v}{\pi * d^2} \tag{1}$$

$$L_p = L_{min} - L_{DO1\%} \tag{2}$$

$$\rho = \frac{[\pi * (L_\lambda - L_p) * d^2]}{E_{SUN\lambda} * \cos\theta_s} \tag{3}$$

Where:

- $L\lambda$ = Spectral radiation in the sensor (Radiance in the satellite)
- Lp = Path radiance
- $Lmin$ = Radiance obtained with the digital count value ($DNmin$)
- $LDO1\%$ = radiance of Dark Object, assumed to have a reflectance value of 0.01
- d = Earth-Sun Distance in Astronomical Units (AU)
- Tv = Transmittance of the atmosphere in the direction of vision
- Tz=Atmospheric transmittance in the lighting direction
- $ESUN\lambda$ = Mean solar exo-atmospheric irradiances (W/(m2 µm))
- θs = Solar zenital angle in degrees
- $Edown$=Diffuse irradiance descending
- ρ = surface reflectance

Several DOS techniques consider different assumption about Tv, Tz, and $Edown$. The DOS1 technique assume for Tv and Tz the value of 1, and for $Edown$ the value of 0 [9]. After applying the atmospheric correction, the digital counts of Sentinel-2 images resulting are measures of land surface reflectance.

In the case of the Landsat-8 image, the EarthExplorer website provides free access to level L2A processed products, which have geometric, radiometric, and atmospheric correction by applying the Landsat Surface Reflectance Code (LaSRC) physical correction method. This method uses OLI sensor information capture values and optical properties of the atmosphere to correct the images and present digital image counts in reflectance values of the surface (BOA) [10].

The physical reflectance values for each of the cultures were obtained after the atmospheric correction of the images, and the graphics of the spectral signatures were made using phyton 3. Considering the date of every image and the records of field books obtained from the farmers (separate zoning areas were considered to identify crop differences), different spectral firms were obtained, corresponding to the development of the crops.

D. Normalized differenced vegetation index (NDVI)

NDVI is the most commonly used vegetation index when analyzing vegetation vigor, it is one of the oldest, best known and most frequently used vegetation index [11]. The NDVI approach is based on the fact that healthy vegetation has low reflectance in the visible portion of the spectrum due to chlorophyll and absorption of other pigments, and has high reflectance in NIR due to internal reflectance by the green leaf tissue, the values of NDVI calculations for a given pixel always result in a number ranging from -1 to +1, where, only positive values correspond to vegetation areas, values close to zero do not mean vegetation, and negative values belong to clouds, snow, water, uncovered soil areas and rocks. In the formula for NDVI (4), NIR is the near infrared range band and R is the red range band [11].

$$NDVI = \frac{NIR - R}{NIR + R} \tag{4}$$

III. RESULTS AND DISCUSSION

A. Spectral signatures analysis

Comparative experimental analysis of the spectral behavior graphs (spectral signatures) of the oat, corn, rice and soybean crops for the 2017/2018 and 2018/2019 sowing cycles present the following observation results:

- In general, there is a similarity to the specific assumptions of all the cultures studied (oat, rice, soybeans and maize), with marked differences in the spectral response by presenting inflection points of values at bands 3 (0.560µm), 4 (0.665µm), 5 (0.705 µm), 7 (0.783 µm), 8 (0.842 µm) and 8A (0.865 µm) of Sentinel-2.
- In crop zone 10b (rice), Fig 3a and 3b., showed a higher reflectance response for the spectral signatures in the 2017/2018 cycle, with a peak value (circled in red) around of 48% (0.865 µm) for 60 days of sowing in equivalent to the 32% peak value (circled in red) for the 2018/2019 cycle for 85 days of sowing.
- Similarly, in crop zone 10d (rice) (Fig 3c and 3d.), the maximum peak of reflectance value is 57% (circle in red), given in band 8A (0.865 µm) at 50 days of sowing, for crop cycle 2018/2019, different from the spectral response in the 2017/2018 of 47% at 45 days of sowing (circled in red), which gives the idea that there is a better development of this culture in the second cycle, being that the common behavior in all cultivation areas.

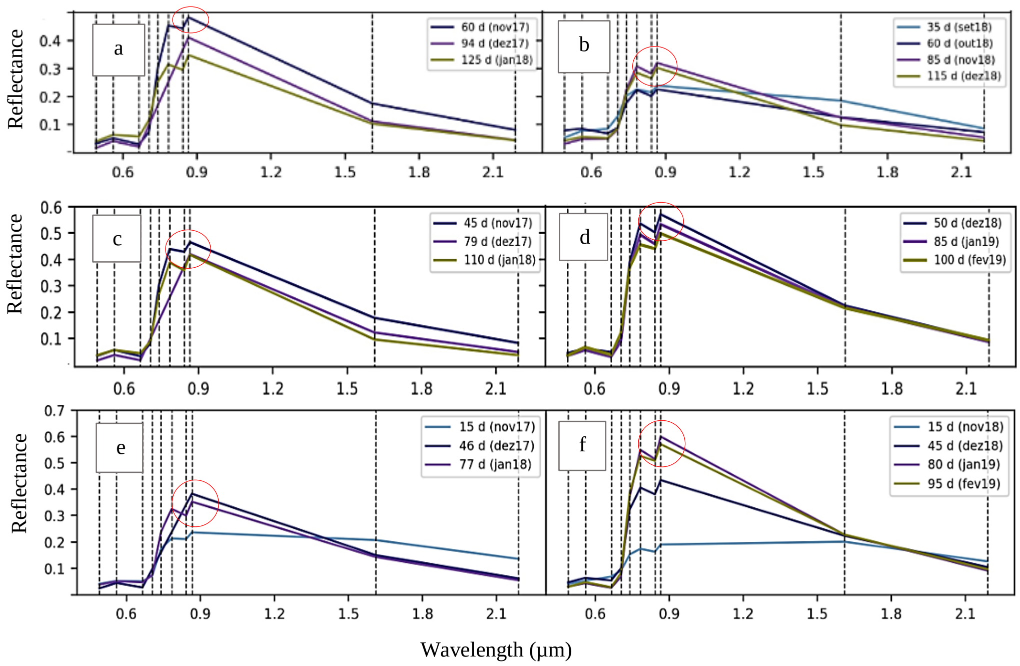

Figure 3. Spectral behavior results of cycles 2017/2018 (left) and 2018/2019 (right) for growing zones 10b-rice (a and b), 10d-rice (c and d), 6-maize (e and f).

- For sowing zone 10a (maize), Figure 3e and 3f shows a spectral response peak in band 8A in the 2017/2018 cycle at 40% with 46 days of sowing and a spectral peak in the same band of 60% for 80 days of sowing in the 2018/2019 cycle. It is also noted that the duration of the first cycle was shorter (77 days) than the 95 days of the second cycle, assuming a problem (nutrient deficiency, for example) in this parcel for the 2017/2018 cycle.
- The soybean crop has higher reflectance values compared to other crops (rice, corn and oats) (Fig.4), with the highest response values in the NIR region and the lowest in the green region, which would be related to the good percentage absorption for the soybean of nitrogen in the visible range (focused on green 0.560µm).

According to [12] and [13] the values of reflectance in visible range (0.490 µm to 0.665 µm) are related to the content of chlorophyll (carotenes and anthocyanins) and nitrogen in crops. Thus, it can be identified, as in [14], that nitrogen content (also associated with better crop yields) is related to lower visible reflectance and higher redEdge reflectance (0.705 µm to 0.783 µm).

As is shown in [1], the spectrum intervals where peaks occur may have the potential to generate information related to some plant characteristics. In the case of nitrogen (N) content in leaves, it presents a highly significant coefficient with reflectance values in the wavelength range of 450 nm and 780 nm. This may be related to the higher reflectance values found in soybean crops, given the increased consumption of nitrogen fertilizers over the period of the sowing.

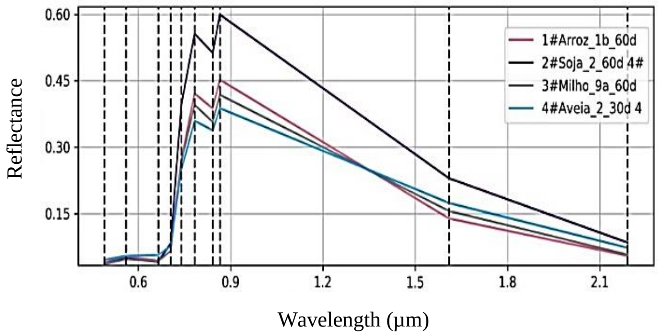

Figure 4. Spectral behavior of corn, rice, soybean and oat crops for around 60 days of sowing.

B. NDVI analysis

The calculation of the NDVI revealed the relationship of the spectral response of the crops with the NDVI values, which being an index that measures the vigor of the crops, begins to decrease with get close to the harvest season, given the variation of the pigment in the leaves that tend to yellow in the crops studied. The maximum value obtained for NDVI as seen in Fig. 5 was in the 2017/2018 cycle (0.962) for the December 2017 image, with sowing zones 10d (rice 79 days) and 2 (soybeans 54 days) showing the largest area with the maximum value.

In the 2018/2019 cycle, the maximum value obtained for NDVI was 0.924 for the January 2019 image, with the sowing zones 2 (soybeans 55 days), 3 (soybeans 65 days) and 11 (Soybeans 80 days) showing the largest area with the maximum value. For the growing zones 6, 8 and 10 a (sown with maize) also showed a better response in the 2018/2019 cycle with larger areas of 0.86 NDVI values.

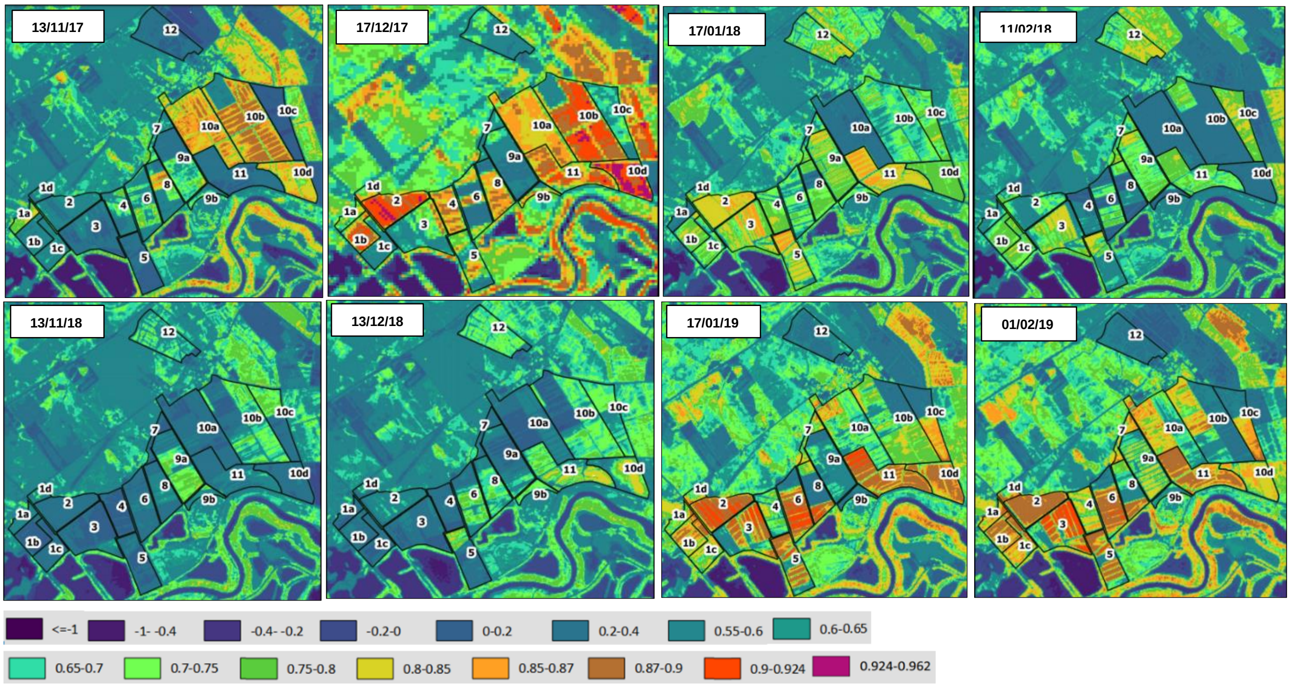

Figure 5. NDVI variations obtained for the 2017/2018 and 2018/2019 sowing cycles (November to March).

IV. CONCLUSION

There is a marked tendency in the curvature of a signature; generally, the reflectance curves showed their highest responses around 60 to 90 days of sowing. The spectral responses decrease with the approach to harvest, which is given by nutrient loss and leaf chlorosis.

Thus it was also found that, according to what was manifested in [12] the spectral responses decrease with the approach to harvest, which is given by the senescent dry vegetation, nutrient loss and leaf chlorosis (yellowing).

In addition, it was observed in most cases that the soybean crop has higher reflectance values compared to other crops (corn, rice and oats), this can be related to the nitrogen content in the sowing and during the development of the crop. It can be seen that apparently there is better crop development in the second cycle (2018/2019).

In general, spectral signatures can be influenced by various external factors, such as: sowing time, nutrient content, soil moisture, leaf density, and others. Therefore, spectral response analysis is considered a baseline for discrimination of points of interest in field campaigns. It is also evidenced that vegetation indices can be used as a tool in the detection of possible affected areas.

Results can only be verified by joining field analyzes of crop nutrient content (nitrogen, potassium, phosphorus, and others), which are usually obtained using spectroradiometers or chemical methods by taking soil and leaf samples.

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