Assessment of vegetational indices applied to sugarcane monitoring using Rapideye images

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Abstract. Rapideye sensor have been operating since 2009 and was one of the first multispectral (5 bands) sensors to operate as part of a satellite constellation (5 satellites), able to provide a massive stock of images with singular synoptic (~5 days) and spatial capabilities (5m). However, so far the Rapideye unique characteristic is still underused, precisely, its Red Edge band (690-730) and possible applications to agricultural mapping considering crop biophysical compounds. The Red Edge band is spectrally located between the Red band, where chlorophyll presence causes strong absorption of light, and the Near Infrared (NIR) band, which has a strong reflection associated with the leaf cell structure. In order to explore the spectral characteristics of the Rapideye images we evaluated the sensor performance at the sugarcane crop over five different crop management (i.e. irrigated, non-irrigated, meiosi, conventional management and Coopercitrus management), by comparison between two band ratios: NDVI (Normalized Difference Vegetation Index), that uses Red and NIR bands; and NDRE (Normalized Difference Red Edge Index), which uses the Red and Red Edge bands. Through the use of NDRE index was possible to map discreet and important spatial variations of chlorophyll content in the intra experimental fields.

Keywords: sensoriamento remoto, Rapideye, cana-de-açúcar, indíces espectrais, clorofila, remote sensing, Rapideye, sugarcane, spectral indices, chlorophyll.

1. Introduction

Due to the lack of availability of sensors providing both high spatial and high temporal resolution imagery, traditionally the mapping/monitoring by Remote Sensing approach for large scale agriculture, such as in Brazilian crop areas uses sensors of spatial moderate resolution and high temporal resolution, for example, MODIS (Moderate Resolution Imaging Spectroradiometer – operational in Terra/Acqua satellite) (Victoria et al., 2012) or Vegetation (operational in SPOT - System Pour l'Observation de la Terre - Vegetation satellite - discontinued) (Vicente et al., 2012). That occurs due the demand to map large areas in a short period of time (daily time resolution), fully covering all vegetational growth stages of crops, even short-cycle crops (~2-3 months) as soybean or corn. However, nowadays satellite constellations are able to provide high spatial resolution imagery with a high repetition rate, allowing for capturing high spatial resolution imagery with a high cadence. Those imagery has become a viable option for crop type mapping and agricultural analytics at low cost.

In this way, the Rapideye Earth Imaging System (REIS - called in this paper simply Rapideye), operating since 2009, was one of the first commercially operational sensors through a satellite constellation (5 satellites). The Rapideye system is equipped with a multi-spectral push-broom sensor that generates images with 5 m spatial resolution. The sensors capture 12-bit images at the following spectral bands: Blue (440 – 510 nm), Green (520 – 590 nm), Red (630 – 685 nm), Red Edge (690-730), Near Infrared (760 – 850 nm). The satisfactory performance of Rapideye constellation has enabled the coverage of the entire Brazilian territory yearly, since 2011 (Brazilian Ministry of the Environment – available to public institutions on Geocatálogo (http://geocatalogo.mma.gov.br/).

The most current Rapideye based applications in Brazil are taking advantage of the high spatial resolution characteristics (e.g. urban mapping, Rural Environmental Registry, do português - Cadastro Ambiental Rural/CAR). However, the main differentiator of Rapideye is its Red Edge band, which is spectrally located between the Visible (Red band) where chlorophyll presence causes strong absorption of light, and the NIR band that is representing a strong reflection associated with the leaf cell structure (Weicheldt et al, 2016; Filella & Peñuelas, 1994). The Red Edge band improves the information about chlorophyll spectral feature, filling the gap between Visible (Red band) and NIR band, reducing saturation effects and increasing the sensitivity regarding to moderate and high chlorophyll content. Despite the benefits of the Red Edge band have been proven in several studies (Souza et al., 2015; Zillmann et al. 2015; Kooistra & Clevers, 2016), Brazilian studies about tropical agricultural targets such as sugarcane considering chlorophyll field measurements for validation/calibration purposes are still unusual.

In order to explore the spectral characteristics of the Rapideye images applied to agricultural mapping, we evaluated the sensor performance at the sugarcane crop over five different crop management regimes, by comparison between two band ratios: NDVI (Normalized Difference Vegetation Index) (Rouse et al., 1973), that uses Visible and Near Infrared bands; and NDRE (Normalized Difference Red Edge Index) (Barnes et al., 2000; Eitel et al., 2011), which uses the Visible and Red Edge bands. Through chlorophyll field measurements obtained almost simultaneously with the satellite images, we are able to evaluated/validate the results of both indices.

2. Study area

The study area consists of five experimental sugarcane crop fields located at Bebedouro Citriculture Experimental Station, maintained by Coopercitrus Cooperative Farmers, in Bebedouro municipality, Sao Paulo State, Brazil (Fig. 1). Each crop field has a particular sugarcane crop management system in terms of irrigation, fertilization and integration with other productive systems (Table 1) (Meira, 2016; Coopercitrus, 2016).

Table 1. Experimental fields management description.

Field Number	Field name	Management
1	Irrigated	Drip irrigated sugarcane, planted in 2013 Jun-Jul, harvested in Jun-Jul period of 2014, 2015 and 2016.

ISBN: 978-85-17-00088-1
Anais do XVIII Simpósio Brasileiro de Sensoriamento Remoto - SBSR

		Northern half of the field was only irrigated, the southern half was fertigated. Pre-budded sugarcane shoots.
2	Non-Irrigated	This field was not irrigated. Same planting and harvest schedule of Field 1. Application of a traditional fertilization system. Pre-budded sugarcane shoots.
3	MEIOSI	Portuguese acronym for Inter-rotational Method of Simultaneous Occurrence. Sugarcane and soybeans simultaneous inter-rotational system. Two repetitions of 8 soybeans lines and 2 sugarcane lines. Soybeans planted in Oct 2015, harvested in Mar 2016. Soybeans lines were already harvested since our first fieldwork. Sugarcane lines planted in Jul 2015. Lines will be harvested in Jun 2016 and their stalks will be used to be planted in the field replacing the soybeans harvested in Mar 2016. Pre-budded sugarcane shoots.
4	Conventional Management	Sugarcane planted in Aug 2015, to be harvested in Jun 2016. Sugarcane buds planted from pre-budded shoots extracted from the Experimental Station's pivot.
5	Coopercitrus Management	Sugarcane planted in Aug 2015, to be harvested in Jun 2016. Sugarcane buds planted from pre-budded shoots extracted from the Experimental Station's pivot.
6	Not Monitored	This field was not monitored in this work.

The geological unit at the Experimental Station is the Vale do Rio do Peixe Formation (Bauru Group), with predominance of sandstones and sandy mudstones that present low resistance to physical weathering and moderate to high resistance to chemical weathering (CPRM, 2016). The soils of the area can be predominantly classified as distrofic red ferralsols, which consist in generally deep soils resulted from intense weathering processes, presenting low base saturation (IBGE & Embrapa, 1999), located in a nearly level to gently sloping terrain. Crop systems adopted in the municipality of Bebedouro and surrounding areas are basically sugarcane (greater extension) and citric fruits (lesser extension) plantations. Pasture and other land covers are also present in little extensions.

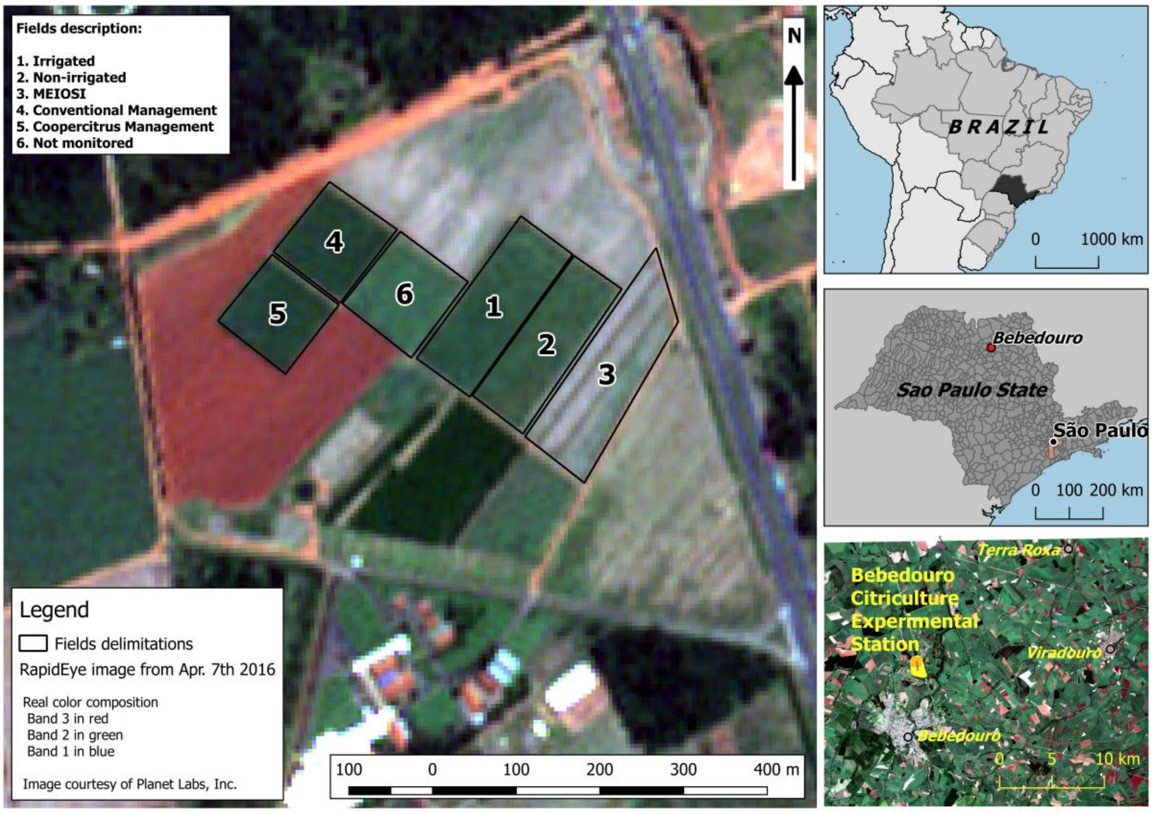

Figure 1. Map of the study area.

3. Material and methods

We used Rapideye images of the area, acquired on April 7th, 2016, over the last phenological stage before harvest on June 17th, 2016. The atmospheric correction of the image was perform using MODIS-based parameters as input of atmospheric local data for the Moderate-Resolution Atmospheric Radiative Transfer Model (MODTRAN) code, afterwards converting at sensor radiance into surface reflectance (Gomes et al, 2015). The following vegetation indices were evaluated in order to compare the performance between bands from Red, Red Edge and Near Infrared spectral region:

- Normalized Difference Vegetation Index (NDVI) (Rouse et al., 1973; Tucker et al, 1979) shows differences in plant vigor, a combination of leaf area and greenness. It is highly sensitive to different disturbing effects like soil background, crop residues background, and atmospheric conditions, and tends to saturate in high valued pixels within the image (Zillmann et al., 2014). It is based on the difference between the reflectance values of vegetation in red and infrared bands:

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

where, NIR and R are respectively near infrared and red band reflectances.

- Normalized Difference Red Edge Index (NDRE) (Gitelson et al., 1996; Barnes et al., 2000; Eitel et al., 2011) is similar to the well-known NDVI, but it uses the Red-Edge spectrum in place of the Red band. The main advantage of using the Red-Edge is the reduced saturation effect due to a lower absorption by the chlorophyll in the red-edge spectral region compared to the red spectrum (Gitelson and Merzlyak 1996). Thus, the NDRE saturates later than the NDVI and is still sensitive to chlorophyll absorption at higher crop canopy densities (Vina et al. 2005). It shows a higher sensitivity to plant foliar stress (Barnes et al. 2000) and to the fraction of absorbed photosynthetically active radiation (fAPAR) than non-red-edge reflectance employing indices (Vina et al. 2005). :

$$NDRE = \frac{NIR - RE}{NIR + RE} \quad (3)$$

where, NIR and RE are respectively Near Infrared and Red Edge band reflectances.

3.1 Fieldwork description: validation process

In order to provide a chlorophyll ground truth values to validate the Rapideye indices we used a SPAD Handheld Device[1]. In our fieldwork (April 28th 2016), for each sampling point (26 points proportionally spread over the five experimental field), we collected five +1 leaves[2] from different stalks. For each leaf, we collected 3 SPAD measurements.

4. Results and Discussions

The both indices (NDVI, NDRE) are quite similar (equation 1 and 2), except for the change from Red band to Red Edge band. In this paper we do not consider effects of the sensor acquisition geometry or canopy, assuming that relationship between sampling points (SPAD measurements) and Rapideye indices is not quantitative, but shows the relative and proportional presence and abundance of chlorophyll in both sensors. The NDRE (Fig. 2 ‘b’) index was able to map much more details, including the border effect (red pixels without chlorophyll), absent in NDVI map (Fig. 2 ‘a’).

The NDRE map provides more details regarding to variations in chlorophyll content over all experimental fields. The NDVI map of the experimental field 1 (Fig. 2 ‘a’) shows mostly homogeneous pixel values (green), even though the experiment is half drip-irrigated, half fertigated (table 1). This different management characteristic is quite obvious in the NDRE map (b), where the pixel values of the northern half portion represent the less chlorophyll values (~yellow) . In this way the NDRE was able to capture variations regarding to fertilization process on the field 1 better than the NDVI. Moreover, the NDRE is obviously more sensitive to in-field spatial variations which are most likely caused by different chlorophyl conetnt.

The boxplots show a similar data behavior for NDRE (d) map vs SPAD (Fig. ‘e’) measurements, mainly over the experiments 1 and 2 (Fig. 2 ‘a,b’). These results are probably due to the well-known influence of hydric stress and fertilization process on the amount of chlorophyll. That influence is not so remarkable in the different crops management at the fields 4 (Conventional Management), and 5 (Coopercitrus Management), showing smaller statistical differences among NDRE, NDVI and SPAD (Fig. 2 ‘c, d, e’). The minor presence of vegetation at the field 3 (MEIOSI) was mapped in detail by the NDRE which highlighted bare soils line (prepared for the plantation) in red pixels and remains of the latest harvest mixed with weed, in green pixels.

[1] SPAD Handheld Device operates using an illuminating system containing two LEDs. One of these LEDs emits a light beam in the red band (650 nm) and the other LED emits a light beam in the infrared band (940 nm). The measurement is based on optical density difference at two wavelengths and it’s possible to convert SPAD values in chlorophyll measurements.

[2] In sugarcane biometry, the +1 leaf corresponds to the first leaf, counting from the top to the bottom of the stalk, that has a clearly visible dewlap.

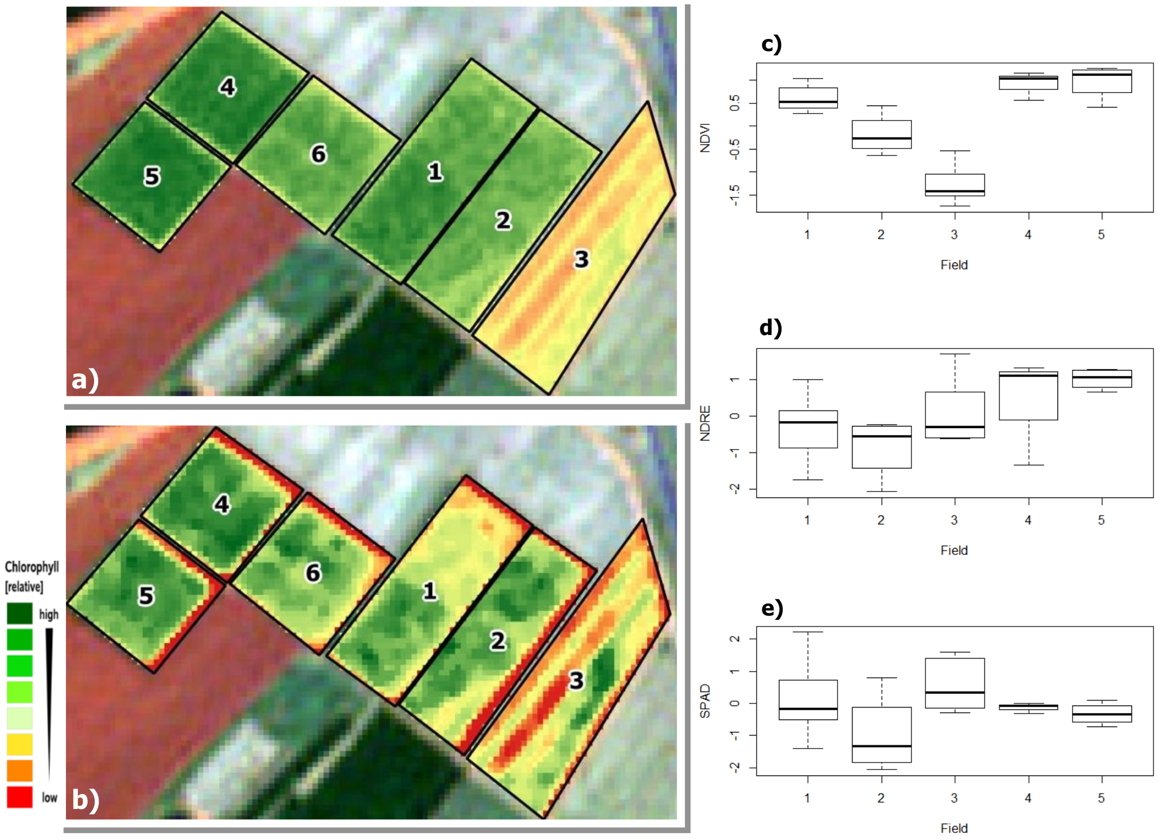

Figura 2. Map of NDVI values (a) and map of NDRE values (b) with Rapideye real color composite bands (r3g2b1) in background. Green pixels represent higher chlorophyll content, in opposite, red pixels means lower presence of chlorophyll. The box plots (c,d,e) show the chlorophyll content per experimental field from: NDVI, NDRE and SPAD field measurements.

5. Conclusions

The Rapideye Red Edge band incorporated in the NDRE (chlorophyll index) was beneficial to map discreet and important spatial variations of chlorophyll content in sugarcane in the intra experimental fields. The spatial resolution of this sensor combined whith its unique spectral characteristics, as we demonstrated here, becomes an important remote sensing device to agricultural mapping.

Image analytics provide valuable information on nutrient deficiency, pest anomalies and productivity estimation. Such kind of maps build a solid foundation for the derivation of site-specific N-fertilizer recommendations. Furthermore, in conjunction with soil fertility and yield maps, chlorophyll level maps can aid in the delineation of site-specific management zones

Acknowledgements

We thank you to Planet Labs and Santigo e Cintra Consulting team, particularly Maurício Meira and Maurício Schiavollini, for logistic support. We also gratefull to Luiz Gustavo (Guru) and Paulo Sérgio both members of Bebedouro Citriculture Experimental Station team, for field and crop management informations. Finally, thank you to Low Carbon Agriculture Plataform team/Embrapa.

ISBN: 978-85-17-00088-1
Anais do XVIII Simpósio Brasileiro de Sensoriamento Remoto - SBSR

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