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ORBITAL IMAGES FOR SPATIAL AND TEMPORAL CHARACTERIZATION OF VINEYARD BY VEGETATION INDEX IN THE "CAMPANHA GAÚCHA" WINE REGION, BRAZIL

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ABSTRACT

Remote sensing has become an important technique for spatial characterization and agricultural monitoring, in order to improve wine development and reduce production costs. The wine region of the “Campanha Gaúcha”, Brazil, was recognized in 2020 as an Indication of Origin for quality wines. This study analyzed orbital data in a “Cabernet sauvignon” vineyard in the municipality of Santana do Livramento. From the images of the Planet and Sentinel-2 satellites, the Normalized Difference Vegetation Index (NDVI) was evaluated, as well as its viability in viticulture in the region. Twelve images from each satellite were analyzed using digital image processing techniques, average NDVI temporal profiles were generated and analyzed by statistical methods. The generated maps produced zoning for each scene over the period studied, for both satellite images. The results showed that the two satellites were suitable for use in monitoring vineyards, due to their excellent temporal, spatial and radiometric resolution.

Keywords: NDVI, precision viticulture, remote sensing, Sentinel 2, Planet

IMAGENS ORBITAIS PARA CARACTERIZAÇÃO ESPACIAL E TEMPORAL DA VINHA POR ÍNDICE VEGETATIVO NA REGIÃO VITIVINÍCOLA CAMPANHA GAÚCHA, BRASIL

RESUMO

O sensoriamento remoto tem se tornado importante técnica de caracterização espacial e monitoramento agrícola, a fim de melhorar o desenvolvimento do vinho e reduzir os custos de produção. A região vitivinícola da “Campanha Gaúcha”, Brasil, foi reconhecida em 2020 como

Indicação de Origem para vinhos de qualidade. Este estudo analisou dados orbitais em um vinhedo de “Cabernet sauvignon” no município de Santana do Livramento. A partir das imagens dos satélites Planet e Sentinel-2, avaliou-se o Índice de Vegetação por Diferença Normalizada (NDVI), bem como sua viabilidade em viticultura na região. Doze imagens de cada satélite foram analisadas usando técnicas de processamento digital de imagens, perfis temporais médios de NDVI foram gerados e analisados por métodos estatísticos. Os mapas gerados produziram zoneamentos para cada cena ao longo do período estudado, para ambas as imagens de satélite. Os resultados mostraram que os dois satélites são adequados para utilização na monitorização de vinhas, devido à sua excelente resolução temporal, espacial e radiométrica.

Palavras-chave: NDVI, viticultura de precisão; sensoriamento remoto, Sentinel 2, Planet

INTRODUCTION

Brazil is the fifth largest wine producer in the Southern Hemisphere, with approximately 80,000 hectares of cultivated vineyards. In the “Campanha Gaúcha” Geographical Indication (CGGI), more than 1,500 hectares are cultivated (MELLO & MACHADO, 2017). CGGI was recognized in Brazil in May, 2020 as a geographical indication for quality wines (REVISTA RURAL, 2020). This region bordering Uruguay and Argentina, is the second largest wine producer in the country, vineyards are cultivated in the Pampa biome, where livestock is predominant (EMBRAPA, 2006; PROTAS & CAMARGO, 2011). The region presents conditions that are different from other Brazilian regions, due to the favorability of the cultivation of vineyards, either due to the long period of annual lighting, as well as the variations in temperature and well-drained soils, important aspects for the vineyards, which can influence the typicality of the wines (VINHOS DA CAMPANHA, 2018).

At the CGGI, most vineyards are grown in the espalier conduction system, which vegetative canopy is positioned vertically and arranged in rows with spacing ranging from 2 to 2.5 meters between the cultivation lines. The upper part of the vine has the branches and the lower part has the fruit, allowing better mechanized management (spraying, mowing, pruning and harvesting). This system is one of the most used in the world for the cultivation of Vitis vinífera for fine and sparkling wines of high quality (MIELE & MANDELLI, 2003; VINHOS DA CAMPANHA, 2018).

The use of remote sensing (RS) in Precision Agriculture (PA) contributed to a better and faster identification of the variability of cultivated areas; such as relief, vegetation, soil, fertility, as well as the management history of the monitored areas (BERNARDI et al., 2014). Studies on soil materials, chlorophyll, soil electrical conductivity, NDVI time profiles have been developed in Brazil (HOFF et al., 2011; MIELE et al., 2011), the use of orbital RS for temporal and spatial characterization of vineyards in the Serra Gaúcha wine region can be highlighted, as well as in the CGGI (JUNGES et al., 2017a; 2017b; PITHAN et al., 2015).

Vegetation indexes such as NDVI, for studying vineyards, have been efficient in defining spatial patterns of the Leaf Area Index (LAI), crop forecasting, water availability and disease detection (DRISSI et al., 2009; JOHNSON et al., 2003). Studies have defined the temporal characteristics of NDVI of vineyards cultivated in the trellising conduction system at CGGI, using Landsat-8 orbital images (JUNGES et al. 2017a). The temporal variability of NDVI showed the accumulation of green biomass during the vegetative cycle, as well as the spatial variability between vineyards in different places, which may be associated with differences in soil, weather conditions and agricultural management (JUNGES et al. 2017b).

In the espalier conduction system, the vegetative canopy is not continuous, so that the vegetation of the line (grapevine) and between the lines (grass or other) can mixing reflectance values, mainly in low spatial resolution satellite images. Due this, Landsat 8 images used in vineyards in these conditions, there is a possibility that the vegetation or exposed soil between the vineyard lines may contribute to the NDVI average values. These values may also be associated with climatic effects on the day of the scene were taken and the high green biomass, which can cause NDVI saturation, masking the variability of the vine (JUNGES et al. 2017a; MIELE & MANDELLI, 2003; SCHAPARINI et al. 2017). Studies about the same area analyzing the NDVI with RapidEye and Landsat 8 images, with spatial resolution of 5 and 30 meters respectively, showed that the higher resolution image produced better NDVI zoning. However, the two images showed similar results of temporal evolution of the vegetation index, with significant differences in the average statistical data between images of the same date (PAULETTO et al. 2018).

Examples of indexes used in precision agriculture are NDVI, EVI, SAVI and NDWI. The leaf area index (LAI) can infer biophysical parameters related to vegetation, such as health, water quantity, productivity, chlorophyll content, percentage of vegetation cover, green biomass and photosynthetically active radiation (JENSEN, 2010). According to Ponzoni et al. (2012) from the LAI, it is possible to express in a dimensionless way the amount of leaves present in the vegetative canopy per area. The denser the vegetation, the reflectance values in the visible range (VIS) and near infrared (NIR), tend to reach minimum and maximum values, this is defined as saturation points. In this way, the vegetation with less vigor will be imperceptible. These saturation tend to occurs first in the VIS, with twice the leaf area per area of land, there may be no more variations in the reflectance values. Whereas, in NIR, saturation points can start when there are between 6 and 8 times more leaves per area. Thus, for the monitoring of cultures, it becomes more appropriate to use the NIR band (PONZONI et al. 2012).

This study aimed to employ images with greater spatial resolution in the space-time monitoring of NDVI in vineyards, in order to quantitatively and qualitatively assess this variability of that index. It also related to the development cycle of the vine and the management adopted in the vineyard in order to verify the potential of zoning of the vineyard, in the context of precision agriculture.

Part of this study was used for a graduate work by the first author, by the University of Vale do Rio dos Sinos - UNISINOS, in the Cartographic and Surveying Engineering Course (PAULETTO, 2019; PAULETTO et al. 2019).

MATERIAL AND METHODS

A Cabernet Sauvignon vineyard with 6.5 hectares was chosen, cultivated in the espalier conduction system (Figure 1). The vineyard belongs to Almadén Winery (Miolo Wine Group), being the first winery installed in the region since 1973 (MIOLO, 2018).

The choice of this vineyard was due to its area being compatible for monitoring vineyards from orbital images, due to the sufficient number of pixels within the study area, in addition to studies already carried out and the management control record by the company.

The area was cut out in order to reduce the edge effects and the influence of the reflectance of the neighboring areas, such as forests, roads, flooded areas surrounding the vineyard.

Images were choice from the Planet and Sentinel-2 satellites missions. Planet Scope images (PLANET Labs, 2018) were provided from the Planet education and research program (PLANET, 2019b), free of charge for university students. Sentinel-2 images are part of the European Space Agency program (ESA, 2015).

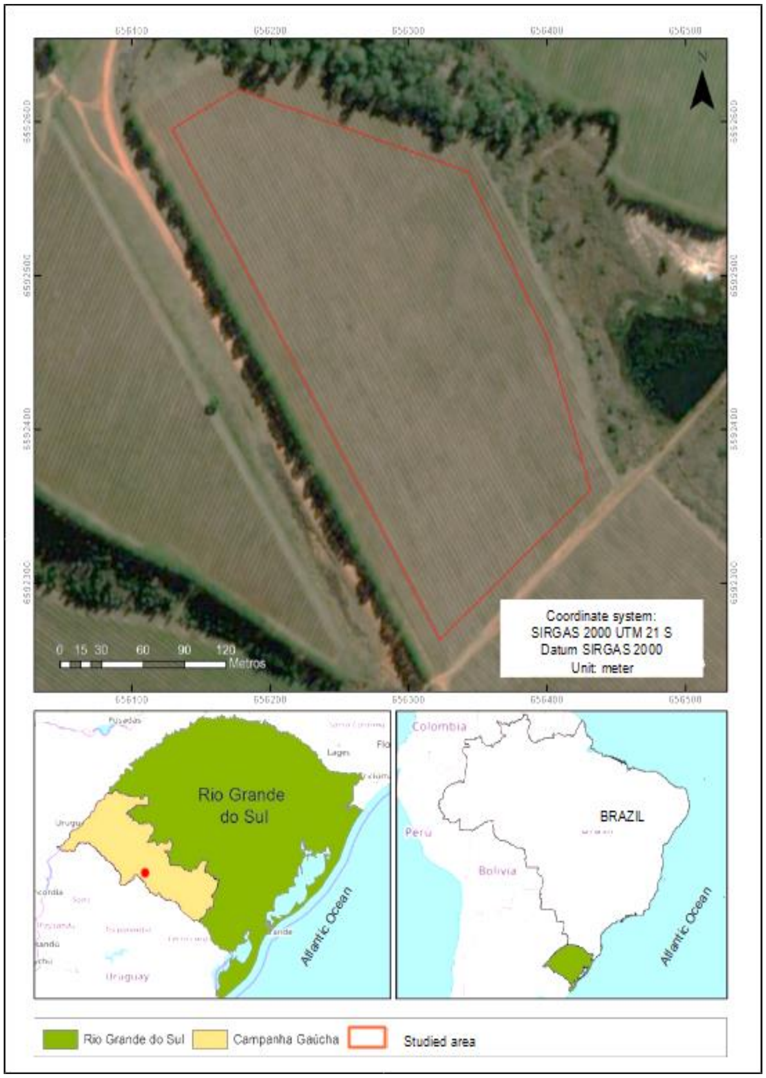

Figure 1. Location of the studied area, "Santana do Livramento", Brazil.

Images with the same acquisition date were searched for both satellites and, due to the difference in temporal resolution between them, a survey of all Sentinel-2 images was made between October 2017 and July 2018 without clouds. This period allowed the complete monitoring of the vegetative cycle of the vine and coinciding with the vineyard management practices made by the winery.

According to the dates of Sentinel-2 images, Planet images with the same date were selected, to comparing of NDVI images generated from the two satellites. Even having a daily frequency, on some dates, it was not possible to obtain Planet images, which caused some failures throughout the study period. However, this was compensated for using the two satellites. Even this, the investigation enabled the monitoring of the vegetative cycle from the development of leaves, flowering and fruits to the dormancy period, that is, the stage of the cycle in which the vine no longer has leaves. Twelve images were selected for the study (Table 1).

Table 1. Scenes of the images selected for the study and their respective seasons and phases of the vine vegetative cycle, at South Brazil (PAULETTO, 2019).

Scene	Season	vegetative cycle phase
2017-11-12	Spring	Vegetative development (leaves and flowering)
2017-11-22	Spring	Vegetative development (leaves and end of flowering)
2017-12-07	Spring	Vegetative development (leaves)
2017-12-12	Spring	Vegetative development (leaves)
2017-12-27	Summer	Vegetative development (leaves and beginning of fruit ripening)
2018-01-31	Summer	Vegetative development (leaves)
2018-02-15	Summer	Vegetative development (leaves)
2018-02-25	Summer	Veg. Develop. (leaves, final ripening of the bunch, pre-harvest)
2018-03-22	Autumn	Post Harvest (leaves)
2018-04-11	Autumn	Senescence and leaf fall
2018-05-26	Autumn	Senescence and leaf fall
2018-06-15	Autumn	Dormancy (without leaves)

The NDVI was developed by Rouse et al. (1974), being calculated from the reflectance of red and near infrared reflected by vegetation, shown by the following expression:

$$NDVI = (NIR - Red)/(NIR + Red)$$

Where: NIR = near infrared band; Red = red band

NDVI values vary between -1 and 1, when close to 1 indicate a higher density of leaves or can also be considered as healthy vegetation, while those close to and less than zero indicate that there is no vegetation present or non healthy. Moreover, it presents a linear response in proportion to green biomass (WEIER & HERRING, 2000). According to that authors, when healthy, vegetation absorbs a large part of VIS radiation, unlike NIR, vegetation reflects most of the radiation incident on the target. For unhealthy vegetation, the amount of VIS radiation is higher, while NIR radiation, the reflected amount is less.

According Jensen (2005), NDVI has advantages in monitoring seasonal and annual changes

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in vegetation, physiological changes and periods of senescence. Even though it is a vegetation index widely used in different cultures, NDVI presents some factors that interfere its interpretation, such as saturation points. In addition, showing variations between images of different sensors, due to the width of the spectral range of red and near infrared and atmospheric interference (JENSEN, 2005; PONZONI et al., 2012).

Image pre-processing

Radiometric, geometric and atmospheric corrections were applied to the images, in order improve the manipulation of the images in the processing stage, such as procedures for information extraction (MENESES & ALMEIDA, 2012). The images of both sensors have differences in spatial, spectral and radiometric resolutions, as shown in Table 2.

Table 2. Central wavelength in the visible and near infrared bands from the satellites selected for the study (PAULETTO, 2019).

Spectral resolution		
Spectral band	Central wavelength (nm)	
	Planet	Sentinel - 2
Blue	485	490
Green	545	560
Red	630	665
NIR	820	842
Radiometric resolution (bit)		
Planet		16
Sentinel - 2		12

The Planet images were corrected by Ortho Scene Product - Analytic tool, an atmospheric correction and the Second Simulation of a Satellite Signal in the Solar Spectrum (6S) - Surface Reflectance. For Sentinel image, the Dark Object Subtraction - DOS 1 method was used (Chavez Jr, 1988). This correction considered only the values of digital numbers (ND), not needing the values of the atmospheric effects on the date of the scene (Congedo, 2016; Weiss et al., 2015). The Semi Automatic Classification Plugin (SCP), module of the QGIS software was used for atmospheric correction of Sentinel images.

This SCP was used by Osco et al. (2017) for atmospheric correction DOS 1, in Landsat 8 satellite images, in order to compare NDVI, SAVI and Simple Ratio (SR), by atmospheric corrections 6S and DOS1. According to Osco et al. (2017), the DOS 1 method proved to be simple and satisfactory, and can be applied to images from other orbital sensors. A comparative study between the same atmospheric correction methods was also studied by Almeida et al. (2015).

Digital Image Processing

The NDVI was generated by QGIS 3.4 software, after clipping and re-projection for the UTM Sirgas 2000 - 21S coordinate system. The NDVI Sentinel images were resampled, from 10 to 3 m resolution by interpolation (ESRI, 2018), in order to equalize with the Planet image, to facilitate the comparison of the two images.

The analysis of NDVI descriptive statistics was done, obtaining measures of central tendency (average, median and mode), dispersion, standard deviation, coefficient of variation and variance. Each pixel became a point, having z-value (NDVI), East (E) and North (N) coordinates from the image. The data were processed using the statistical SPSS software.

According Junges et al. (2017a, 2017b, 2019a, 2019b), Pauletto et al. (2017, 2018), Pithan et al. (2015) and Schaparini et al. (2017), the NDVI was evaluated by average values at temporal profile for the studied period, aiming to investigate similarities in the spatio-temporal behavior of the target.

Histograms and boxplots were done in order to interpretation of data behavior (ANDRIOTTI, 2013; CAMPOS, 2003). Normal distribution curves were generated in the SPSS software. A more detailed analysis was carried out by applying statistical tests to evaluate difference between images, about NDVI average value on each date.

Difference and zoning images

Comparing the NDVI generated for identify the spatial variability, images of difference and NDVI zones were generated for each date. Subtraction calculation of the NDVI Planet image by the NDVI Sentinel-2 image was applied. This resulted in real numerical values of NDVI difference, enabling the identification and zoning, showing what values of each image were most prominent in the study area. The classification of the resulting images, generated the classes: 1) NDVI Equal Planet and Sentinel 2; 2) NDVI largest Planet; 3) NDVI largest Sentinel-2.

The NDVI zoning maps were within the limit defined as ± 1 Standard Deviation (SD) from the NDVI average of each scene. According Molin et al. (2015), definition of limits could to

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identify anomalous values in a data set. To define these limits, in addition to the average, medians were also used, considering one (extreme cut) or more (conservative cut), standard deviations (MOLIN et al. 2015). To generate maps, limits were defined for each date and each class, a map provided a visual analysis of the vineyard: 1) values less than the NDVI average - 1SD (class 1); 2) values within the NDVI average (class 2); 3) values above the NDVI average + 1SD (class 3).

RESULTS AND DISCUSSION

The NDVI Sentinel-2 images were resampled from 10 to 3 meters, using the nearest neighbor interpolation method, which causes less distortion in the image, as there is no change in the digital number (DN) values of each pixel. Crósta (2002) pointed it can be advantageous, but it generates images with little aesthetics due to the values of the pixels that are repeated. Evaluating the statistical data together graphic products, it was observed that resampling did not show significant distortions in the values of NDVI average, median, standard deviation and variance (Figure 2 and Table 3).

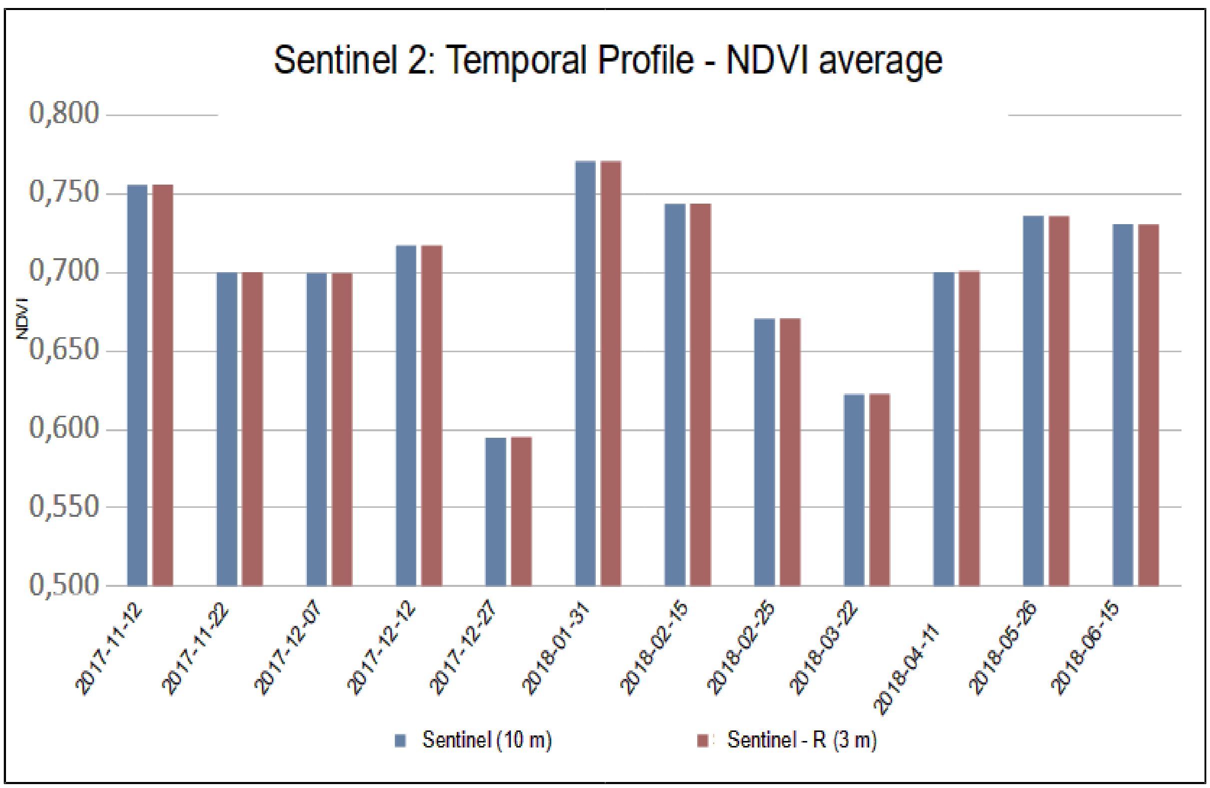

Figure 2. Temporal profile of NDVI average of original and resampled Sentinel-2 images, showing that there were no differences in the values of NDVI average from a Cabernet sauvignon vineyard, Santana do Livramento, Brazil (PAULETTO, 2019).

These variations may caused due the boundaries of the vineyard, where there is different land use. Since that arithmetic average can vary according to the extreme values (minimum and maximum), the median does not vary (ANDRIOTTI, 2013). Thus, the results obtained showed that, even though there were differences in the minimum and maximum values, the central values of the set had no differences.

Table 3. Differences (DIF) between the average and median NDVI values in the original and resampled Sentinel-2 images for each date from a Cabernet sauvignon vineyard, Santana do Livramento, Brazil (PAULETTO, 2019).

Date	NDVI average			NDVI median		
	10 m	3 m	DIF	10 m	3 m	DIF
2017-11-12	0.755	0.755	0.000	0.760	0.760	0.000
2017-11-22	0.699	0.700	0.000	0.707	0.707	0.000
2017-12-07	0.699	0.699	0.000	0.706	0.706	0.000
2017-12-12	0.716	0.716	0.000	0.723	0.723	-0.001
2017-12-27	0.594	0.594	0.000	0.597	0.598	-0.001
2018-01-31	0.770	0.770	0.000	0.776	0.776	0.000
2018-02-15	0.743	0.743	0.000	0.723	0.723	0.000
2018-02-25	0.670	0.670	0.000	0.655	0.655	0.000
2018-03-22	0.622	0.622	0.000	0.622	0.622	0.000
2018-04-11	0.700	0.700	0.000	0.702	0.702	0.000
2018-05-26	0.735	0.735	0.000	0.743	0.743	0.000
2018-06-15	0.730	0.730	0.000	0.733	0.733	0.000

The minimum and maximum values showed greater distortions between the NDVI images with an original resolution of ten and three meters (Table 4).

Table 4. Differences between the minimum and maximum NDVI values in the original and resampled Sentinel-2 images for each date from a Cabernet sauvignon vineyard, Santana do Livramento, Brazil (PAULETTO, 2019).

Date	NDVI minimum			NDVI maximum		
	10 m	3 m	DIF	10 m	3 m	DIF
2017-11-12	0.490	0.415	0.075	0.813	0.813	0.000
2017-11-22	0.480	0.459	0.021	0.755	0.755	0.000
2017-12-07	0.472	0.395	0.077	0.769	0.769	0.000
2017-12-12	0.445	0.432	0.013	0.809	0.809	0.000
2017-12-27	0.463	0.413	0.050	0.649	0.682	0.033
2018-01-31	0.528	0.459	0.069	0.828	0.828	0.000
2018-02-15	0.587	0.492	0.095	0.863	0.863	0.000
2018-02-25	0.472	0.371	0.101	0.790	0.790	0.000
2018-03-22	0.483	0.467	0.016	0.713	0.752	0.039
2018-04-11	0.565	0.559	0.006	0.774	0.774	0.000
2018-05-26	0.576	0.558	0.018	0.782	0.782	0.000
2018-06-15	0.576	0.558	0.018	0.782	0.782	0.000

Bombassaro (2011) used the same resampling method for studies in vineyards and found that the average values did not show significant differences. In this study, the images resampled to 3 m and the generation of NDVI average profiles of vineyards were also adequate. Equalization of the population set allowed for greater detail of the study area.

Descriptive statistic

The points extracted from the NDVI images of vineyard compound a set of the study (n = 7330). Each image for each date represented a variable, 12 for Planet images and 12 for Sentinel-2 images. For each image, descriptive statistics of central tendency and the minimum and maximum NDVI values were also calculated. Positive NDVI values would indicate the green biomass at the vineyard (JUNGES et al. 2017a). Sentinel-2 NDVI average values ranged between 0.594 on December 27. 2017 and 0.770 on January 31. 2018. For Planet images, the NDVI average values ranged between 0.563 on March 22. 2018 and 0.741 on 31 January 2018. Figure 3 shows the variation of NDVI average over the analyzed period.

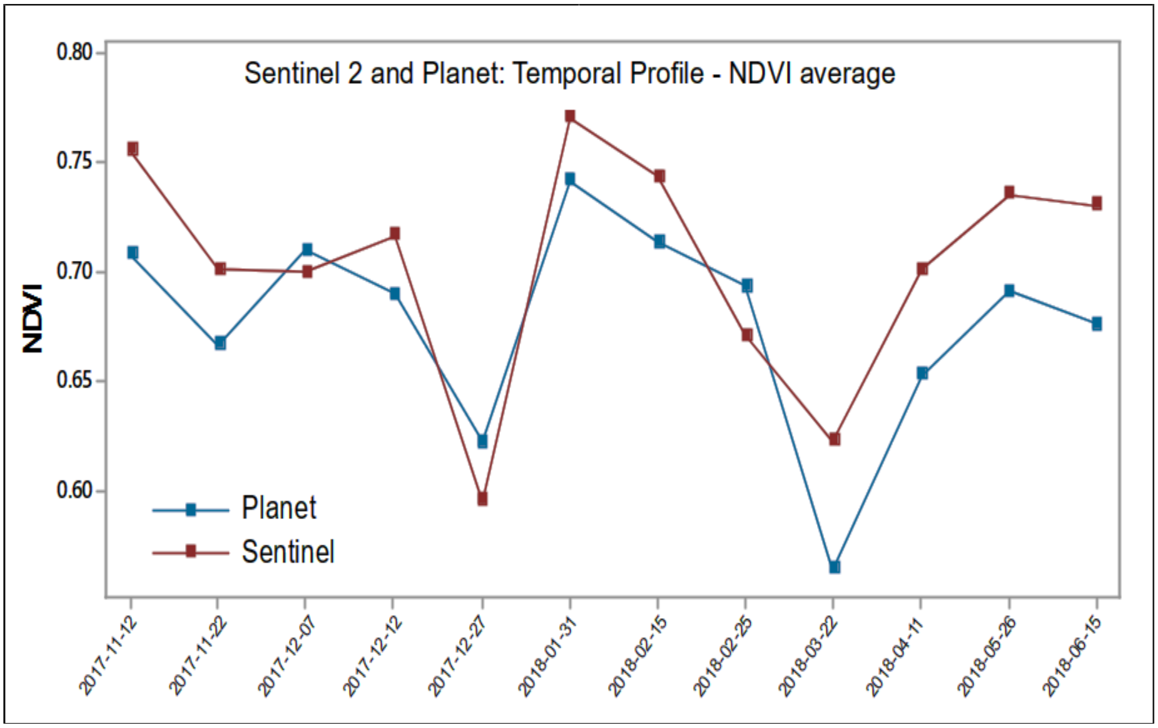

Figure 3. Temporal Profile of the NDVI average of Sentinel and Planet images from a Cabernet sauvignon vineyard, Santana do Livramento, Brazil (PAULETTO, 2019).

The highest NDVI average values was same at 2018-01-31, for both satellites. The lowest value do not match, but the average values are similar. The lowest value of scene 2017-12-27 of the Sentinel was 0.594 and the Planet image, 0.621. The date when the lowest value from Planet NDVI was 0.563, the Sentinel NDVI value was 0.622. Even with qualitative differences in the NDVI average values between Planet and Sentinel images on the date of the lowest value, it is understood that there was no discrepancy in terms of absolute values between the images (differences less than 0.10).

In 12 images, only on 2017-12-07, the NDVI average values were considered equal from the analysis of the average in absolute value. To be equal, the difference was considered to be less than or equal to ± 0.01. On the other dates, the NDVI average values showed greater difference, ranging from -0.03 to 0.06. Differences less than 0.10 were considered no discrepant, but existing. Therefore, these differences were analyzed in the form of Temporal Profiles of NDVI average and Difference Images. The differences between the NDVI average values for each date can be seen in Table 5.The NDVI variation between the images occurred in the vegetative development phase, from 2017-11-12, period of growth and development of the leaves, expansion of the leaf area at vegetative canopy and a growth of vegetation covering the lines between the vines in the average

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pixel value. From 2018-03-22, end stage of the vegetative cycle, senescence and leaf fall occurred and management activities in the vineyard decreased.

Table 5. Differences between the NDVI average of the vineyard of the Planet and Sentinel images from a Cabernet sauvignon vineyard, Santana do Livramento, Brazil (PAULETTO, 2019).

Date	NDVI average Sentinel 2	NDVI average Planet	Diference
2017-11-12	0.755	0.707	0.05
2017-11-22	0.700	0.666	0.03
2017-12-07	0.699	0.709	-0.01
2017-12-12	0.716	0.689	0.03
2017-12-27	0.594	0.621	-0.03
2018-01-31	0.770	0.741	0.03
2018-02-15	0.743	0.713	0.03
2018-02-25	0.670	0.693	-0.02
2018-03-22	0.622	0.563	0.06
2018-04-11	0.700	0.652	0.05
2018-05-26	0.735	0.690	0.05
2018-06-15	0.730	0.675	0.06

The NDVI variation could be associated with a spectral mixture in vineyards cultivated in the espalier conduction system, where there is growth of the vegetation covering between the lines and loss of leaves. So, there are a greater mixture between reflectance of cover vegetation and vine plant than other periods Junges et al (2017a).

On two dates, the NDVI average values of Planet images were higher than those of Sentinel images (2018-12-27 and 2018-02-25). On the other dates, the NDVI average values of the Sentinel-2 images were higher. For these dates when Planet's NDVI average was higher, days before the quoted scenes, mowing was carried out in the vineyard, with the cleaning of the vegetation between the lines of vines. This supposed that Planet images, due to their higher spatial resolution, showed greater ability to define targets and more detailed response of NDVI average. This allowed for better identification of changes in the vineyard over the cycle, with the highest values could be from the vine vegetation.

According to Matese et al (2015), vineyards in espalier system are highly heterogeneous, with the highest NDVI values refer to the vegetative canopy of the vineyard and the lowest, from vegetation between the lines, thus confirming the result described. However, it is also understood that these higher NDVI changes among the images can also be associated with radiometric and geometric distortions present in the images, which can affect the NDVI value. The 2018-01-31 image was the peak of the NDVI average of the analyzed period (0.770 for Sentinel-2 and 0.741 for Planet), 35 days after the last NDVI value obtained if there was only one mechanized mowing, between the line of vines. Thus, the high NDVI value could be due the mixture of the values of all vegetation present in the area (grapevine, line and leading).

From an analysis of the results by the coefficient of variation (CV), according to Andriotti (2013), considering CV values below 40% would represent the homogeneity of the sample set, it is suggested that all data observed were homogeneous. The highest CV found was 8.85% in the Sentinel-2 image of 2018-02-25. However, vineyards in espalier conduction are heterogeneous, diverging from the VC analysis. Spiegel (1994) and Andriotti (2013), wich pointed that the CV could be few useful when the average values are close to zero, as in the case studied, which limits the assessment of heterogeneity. According to Pringle et al. (2003), although descriptive analyzes allow the explanation of the spatial structure, or irregularities, cannot describe the spatial heterogeneity present in a map.

Histogram analysis

The histograms of Figure 4 represent spring, from 2017-11-12 to 2017-12-12, showing similar behavior between different images of the same date throughout that period. The averages are to the left of the median, being smaller and for all scenes, the histogram has a negative asymmetry, tilted to the left (Spiegel, 1994). The histograms of Planet images showed that the NDVI values along the vineyard have a more standardized distribution in relation to Sentinel-2 images. However, the two images showed a leptokurtic distribution, shown that in addition to asymmetric differences, they have a high degree of kurtosis (FIELD, 2009; SPIEGEL, 1994).

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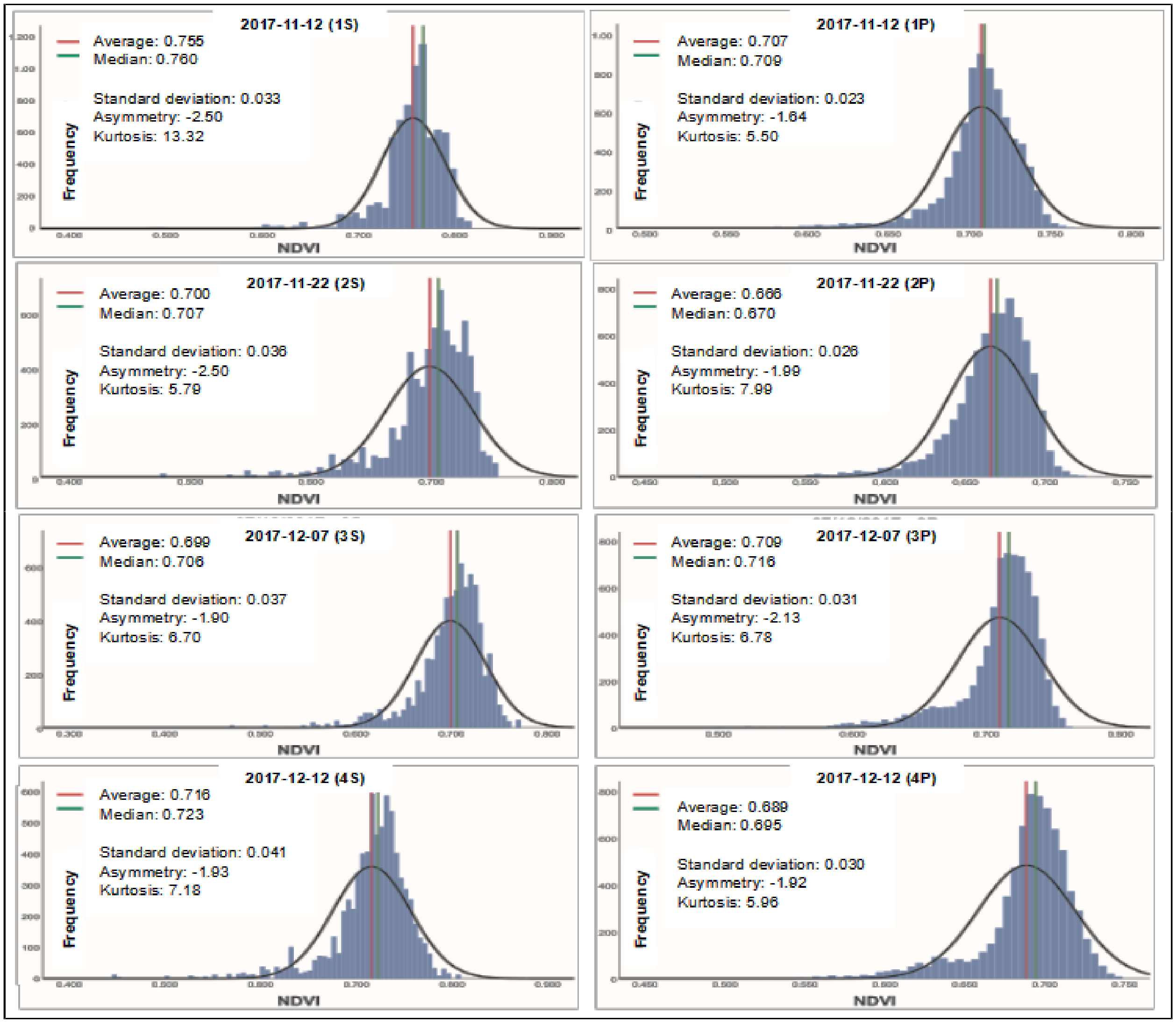

Figure 4. Histogram of the Sentinel-2 and Planet images during the spring season, from November and early December, from a Cabernet sauvignon vineyard, Santana do Livramento, Brazil (PAULETTO, 2019).

The histograms of summer season (Figure 5), when the vegetative development stage of the vine, differences in NDVI variability were observed within the vineyard. On 2017-12-27 and 2018-01-31, the histograms showed uni-modal distribution with negative asymmetry, while on 2018-02-15 and 2018-02-25, the histograms become bimodal, with a greater degree of flattening, throughout its distribution (negative kurtosis or less than 3) (SPIEGEL, 1994). This suggests that variations have occurred within the vineyard.

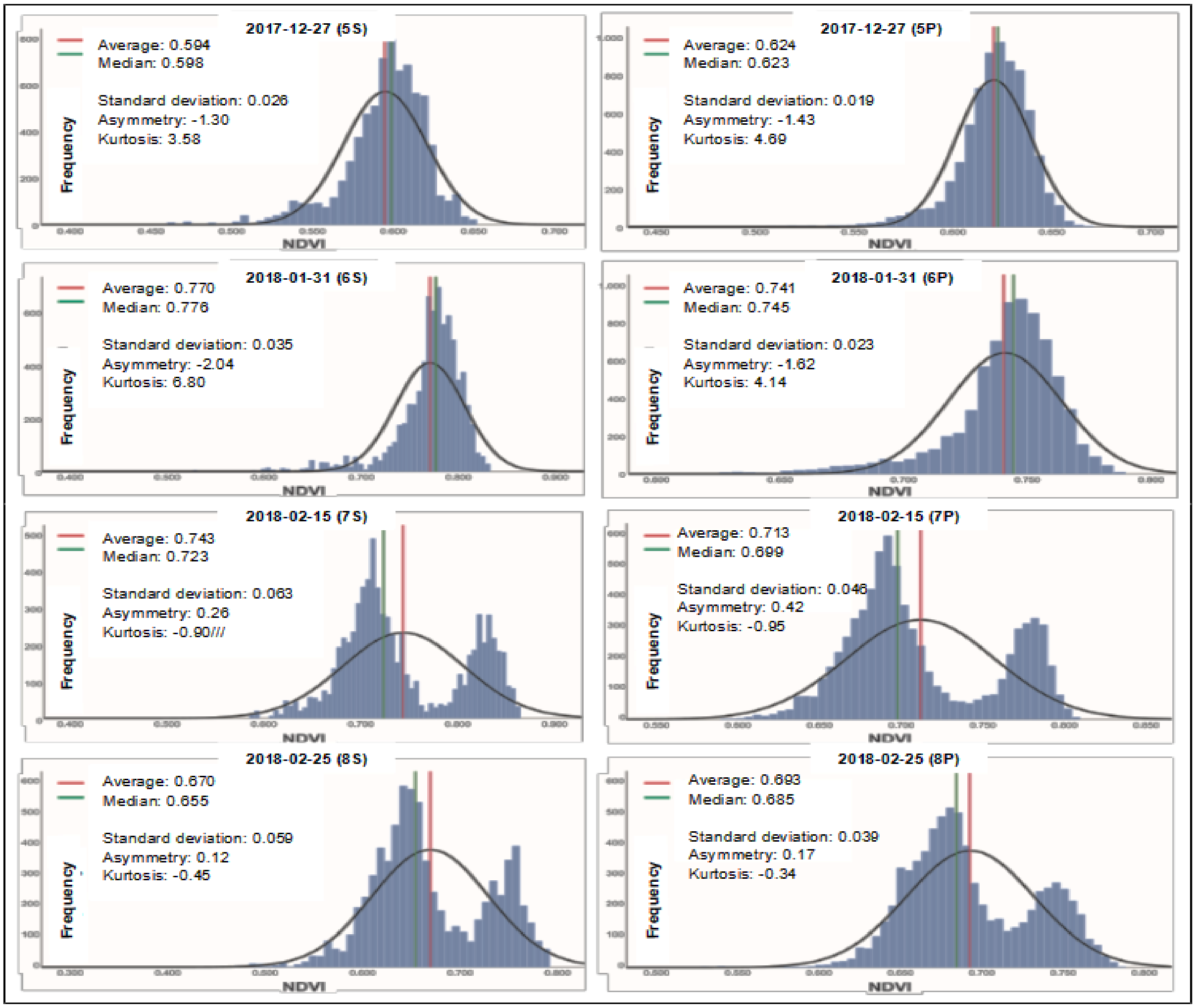

Figure 5. Histogram of the Sentinel-2 and Planet images during the summer season, from late late December to February, from a Cabernet sauvignon vineyard, Santana do Livramento, Brazil (PAULETTO, 2019).

The autumn histograms (Figure 6), in the first two dates, also showed a more flattened shape. However, when approaching winter, the histograms showed a similar behavior to those of the other dates. In the season, there was greater variability in the images from 2018-03-22 and 2018-04-18 scenes. Except the scenes 2018-02-15, 2018-02-25 and 2018-03-22 (Planet image only), most of the images showed asymmetric histograms, tilted to the left. Then was applied the Kolmogorov-Smirnov normality test, with a significance level of $p < 0.05$. Therefore, the results presented in Table 6 showed the abnormality of the set, since the significance values are all lower than the defined limit. Thus, the null hypothesis is rejected, meaning that the data did not present a normal distribution, confirming the results of the histograms and the asymmetry and kurtosis values calculated in the descriptive statistics.

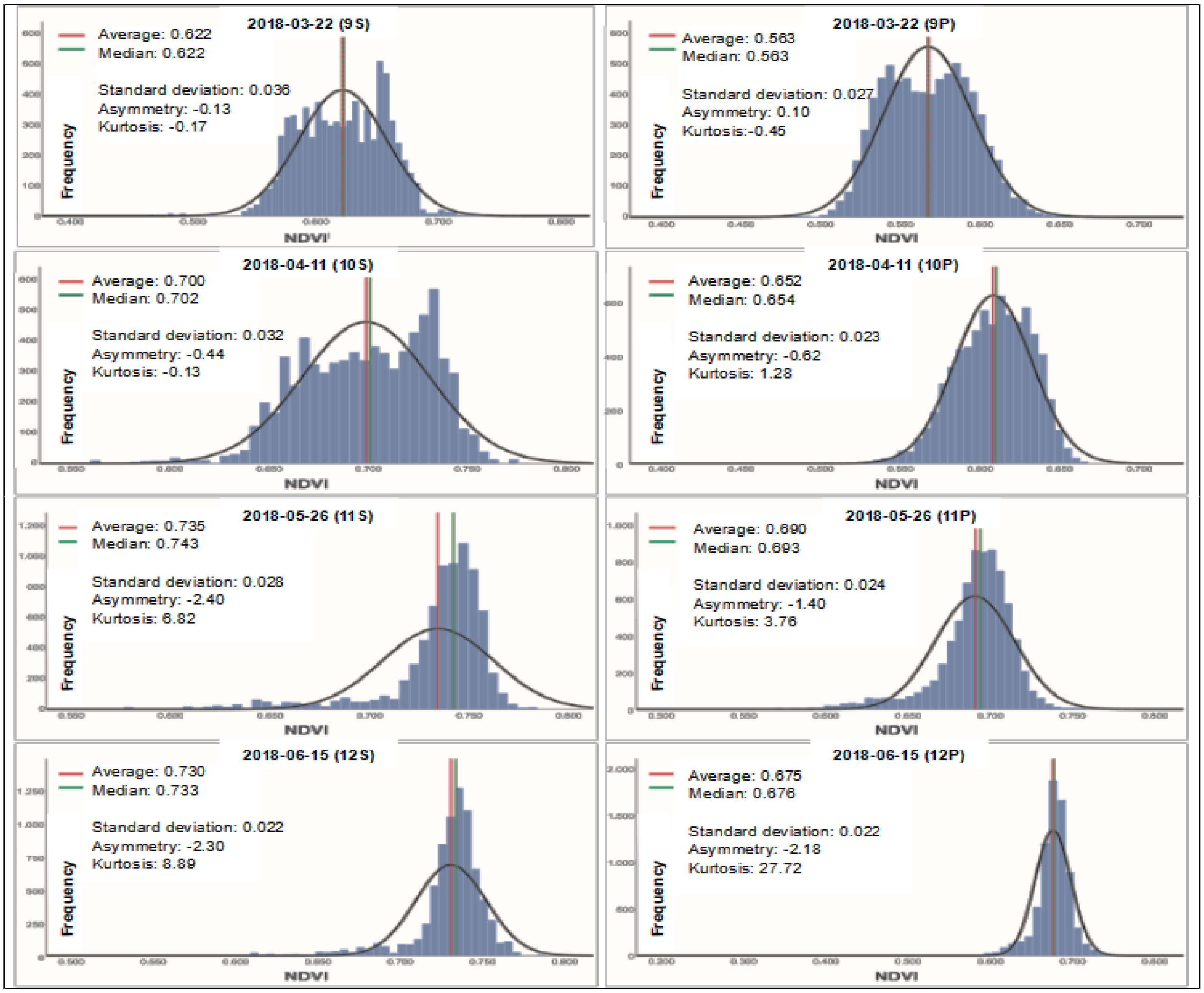

Figure 6. Histograms of the Sentinel-2 and Planet images during the autumn, from late March to early June, from a Cabernet sauvignon vineyard, Santana do Livramento, Brazil (PAULETTO, 2019).

Table 6. Results of the Kolmogorov-Smirnov normality test of Sentinel-2 and Planet data, from a Cabernet sauvignon vineyard, Santana do Livramento, Brazil (PAULETTO, 2019).

Date	n	Planet		Sentinel	
		Stat	P	Stat	P
2017-11-12	7330	0.108	0.000	0.131	0.000
2017-11-22	7330	0.104	0.000	0.124	0.000
2017-12-07	7330	0.160	0.000	0.117	0.000
2017-12-12	7330	0.151	0.000	0.124	0.000
2017-12-27	7330	0.088	0.000	0.096	0.000
2018-01-31	7330	0.122	0.000	0.144	0.000
2018-02-15	7330	0.145	0.000	0.138	0.000
2018-02-25	7330	0.100	0.000	0.115	0.000
2018-03-22	7330	0.053	0.000	0.065	0.000
2018-04-11	7330	0.046	0.000	0.080	0.000
2018-05-26	7330	0.120	0.000	0.199	0.000
2018-06-15	7330	0.101	0.000	0.167	0.000

Temporal profiles from average NDVI

The maximum NDVI average values occurred during the vegetative development period, which reflect the accumulation of green biomass at vegetative canopy, a result also found by Junges et. al (2017a, 2019b) in the same vineyard, as well as in vineyards in the Serra Gaúcha region, using Landsat-8 images (PITHAN et al 2015, SCHAPARINI et al. 2016), using orbital and proximal data (JUNGES et al. 2019b). According Junges et al. (2017a), due the espalier conduction system, predominantly vertical, the values of NDVI average are also related to the vegetation between the line of vines. Thus, the temporal variability can be influenced by this vegetation, whether spontaneous or from cultivated species. However, the dates when the NDVI average values decreased significantly, correspond to the period of vegetative development, between 2017-12-27 and 2018-03-22.

According Junges et al. (2019a) in the same vineyard, comparing with the results found on the same dates, the NDVI values also showed decrease along the temporal profile of the 2017/2018 crop, approaching the average profile in December, but remaining lower in the second half of

March. The reductions in NDVI values also occurred in profiles from other periods, but showing that decrease at the profile of NDVI vineyard are expected due the management of the canopy of the vine and the cover vegetation between the line of vines.

A decrease in NDVI values was observed in December, possibly due to agricultural management in the days preceding the image of 2017-12-27, when leaves were removed, mowing the vegetation between the lines of vines. The green mass was reduced, more intensely management of cover vegetation in the days before the harvest of the grapes (2018, March, 13 and 14). During the senescence period, with leaf fall, the NDVI average values showed an increase, due to the development of cover vegetation and NDVI values increased. For both images, Sentinel-2 and Planet, the average profile proved to be adequate, showing characteristic behavior of the vineyard (Figure 7), consistent with the time profiles of NDVI average obtained by Junges et al. (2017a; 2019a), Pithan et al. (2015) e Schaparini et al. (2017).

The NDVI average values from Planet and Sentinel-2 images were different, result verified from the application of Mann-Whitney test, being a non-parametric statistical test that is equivalent to the student's t test, used for the comparison between two sets of data that do not follow a normal distribution. The results obtained from the Mann-Whitney application (Table 7) showed that the average values are not equal, due to the significance values (Asymp. Sig. (2-tailed) column) being less than 0.05 (FIELD, 2009).

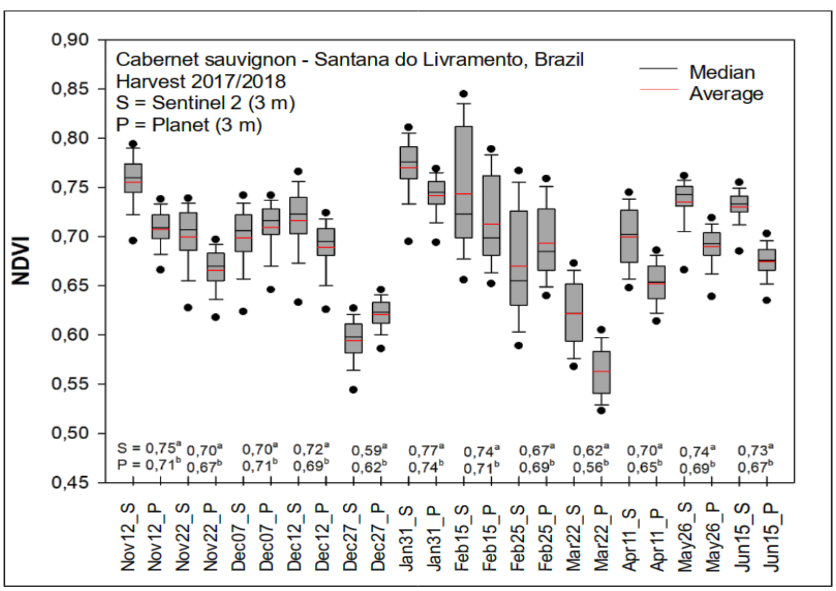

Figure 7. Box Plots representing the average profile of NDVI, median, quartiles, standard deviations from the average and outliers of the Planet and Sentinel-2 images, from a Cabernet sauvignon vineyard, Santana do Livramento, Brazil (PAULETTO, 2019).

Table 7. Results from the Mann-Whitney test of Sentinel-2 and Planet images, from a Cabernet sauvignon vineyard, Santana do Livramento, Brazil (PAULETTO, 2019).

DATA	nn	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)
2017-11-12	7330	4.40E+06	3.13E+07	-87.668	0.000
2017-11-22	7330	8.84E+06	3.57E+07	-70.371	0.000
2017-12-07	7330	2.09E+07	4.78E+07	-23.190	0.000
2017-12-12	7330	1.22E+07	3.91E+07	-57.120	0.000
2017-12-27	7330	9.10E+06	3.60E+07	-69.340	0.000
2018-01-31	7330	9.39E+06	3.63E+07	-68.226	0.000
2018-02-15	7330	1.83E+07	4.51E+07	-33.561	0.000
2018-02-25	7330	1.88E+07	4.56E+07	-31.629	0.000
2018-03-22	7330	5.25E+06	3.21E+07	-84.380	0.000
2018-04-11	7330	6.56E+06	3.34E+07	-79.247	0.000
2018-05-26	7330	4.60E+06	3.15E+07	-86.894	0.000
2018-06-15	7330	2.37E+06	2.92E+07	-95.629	0.000

Difference images

The difference classification of NDVI for Sentinel 2 and Planet images, the negative values (-1; - 0.01) indicated that Planet values are greater than the Sentinel-2 (Class 1). Positive values (0.01; 1) indicated Sentinel 2 values are greater than Planet (class 3). Values between -0.0100 and 0.0100 refer to an equal NDVI from the two images (Class 2).

At 2017-11-12 date, 97. 41 % of the total area (6.42 hectares) were represented by original values of Sentinel-2, 0.82 % equal to the images and 1.77% to the Planet image. In the image of 2017-11-22, 91. 7 % of the values came from the Sentinel-2 image and only 2.88 % came from the Planet image, while 5.42 % are coincident of the two images. At 2017-12-07 date, the values of the Sentinel-2 images are the ones with the lowest proportion, only 10.79 %, while 50.98 % of the NDVI values of the scene are of the Planet images and 38.23 % equal.

The analysis of the NDVI difference images (Figure 8) showed greater homogeneity at spring, in the areas where the NDVI value is higher in the Sentinel-2 image. While, for the image

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of the first half of December, the values of NDVI Planet are more heterogeneous. This may be associated with the management in the vineyard from 2017-11-24 to 2017-12-07, when management practices were made, together with mechanized topping in the study area, suggesting that, with reduced vegetation, the variations in biomass become more noticeable in the image.

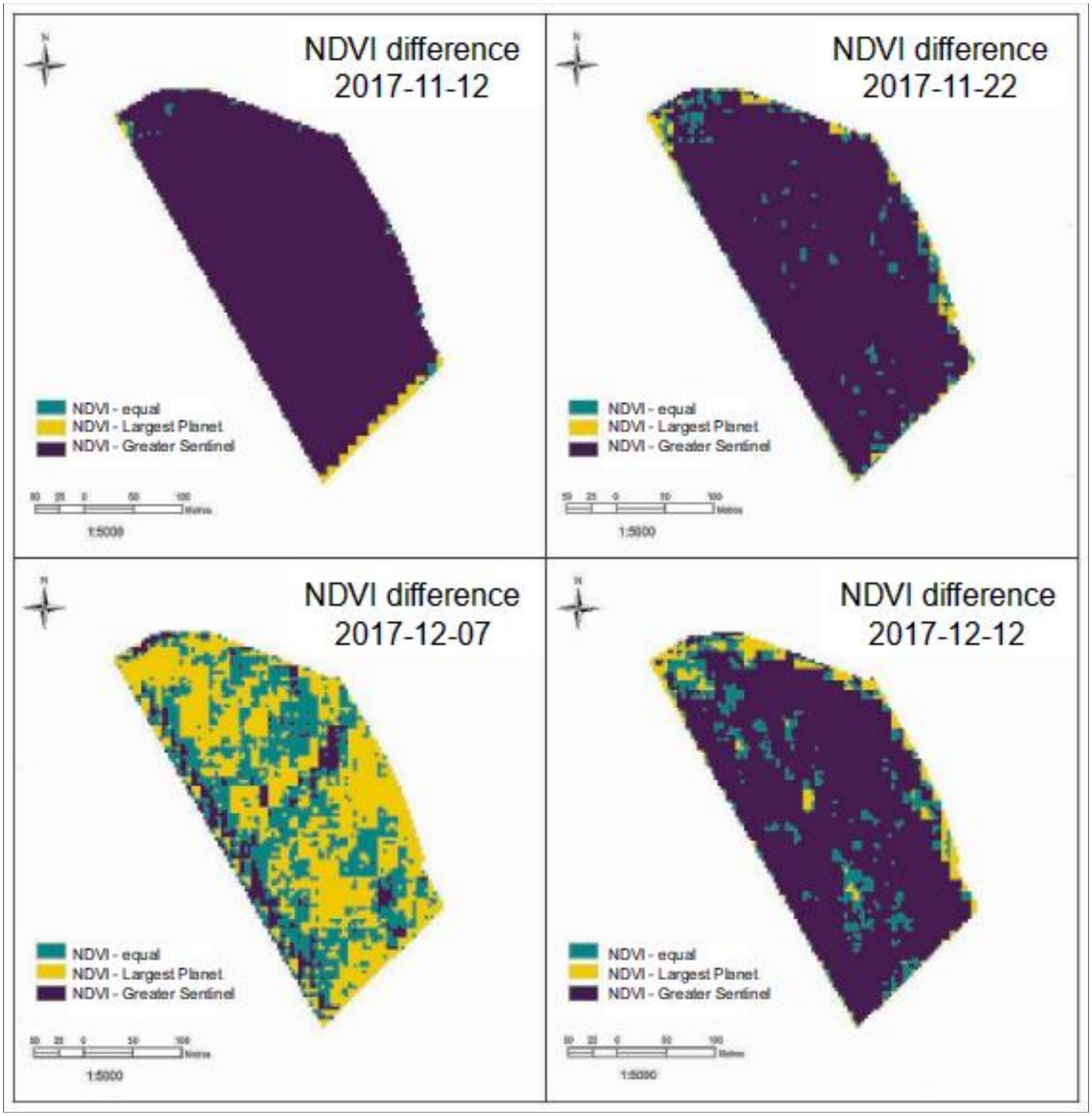

Figure 8. Difference images for the spring season, from a Cabernet sauvignon vineyard, Santana do Livramento, Brazil (PAULETTO, 2019).

During the vegetative development in the summer (Figure 9), on two dates, the NDVI Sentinel-2 values represent more than 80 % of the vineyard (2018-01-31 and 2018-02-15). On date 2018-12-27, 84.46 % of the vineyard is represented by the Planet image, 13.72 % of the values are equal and only 1.82 % of the vineyard is represented by the Sentinel-2 image. Higher NDVI values from the Planet image may be associated with the agricultural management practices. For date the 2018-02-25, the highest NDVI values in the vineyard refer to the Planet image and the smallest area for the Sentinel-2 images, highlighting the homogeneity of these values to the west of the vineyard.

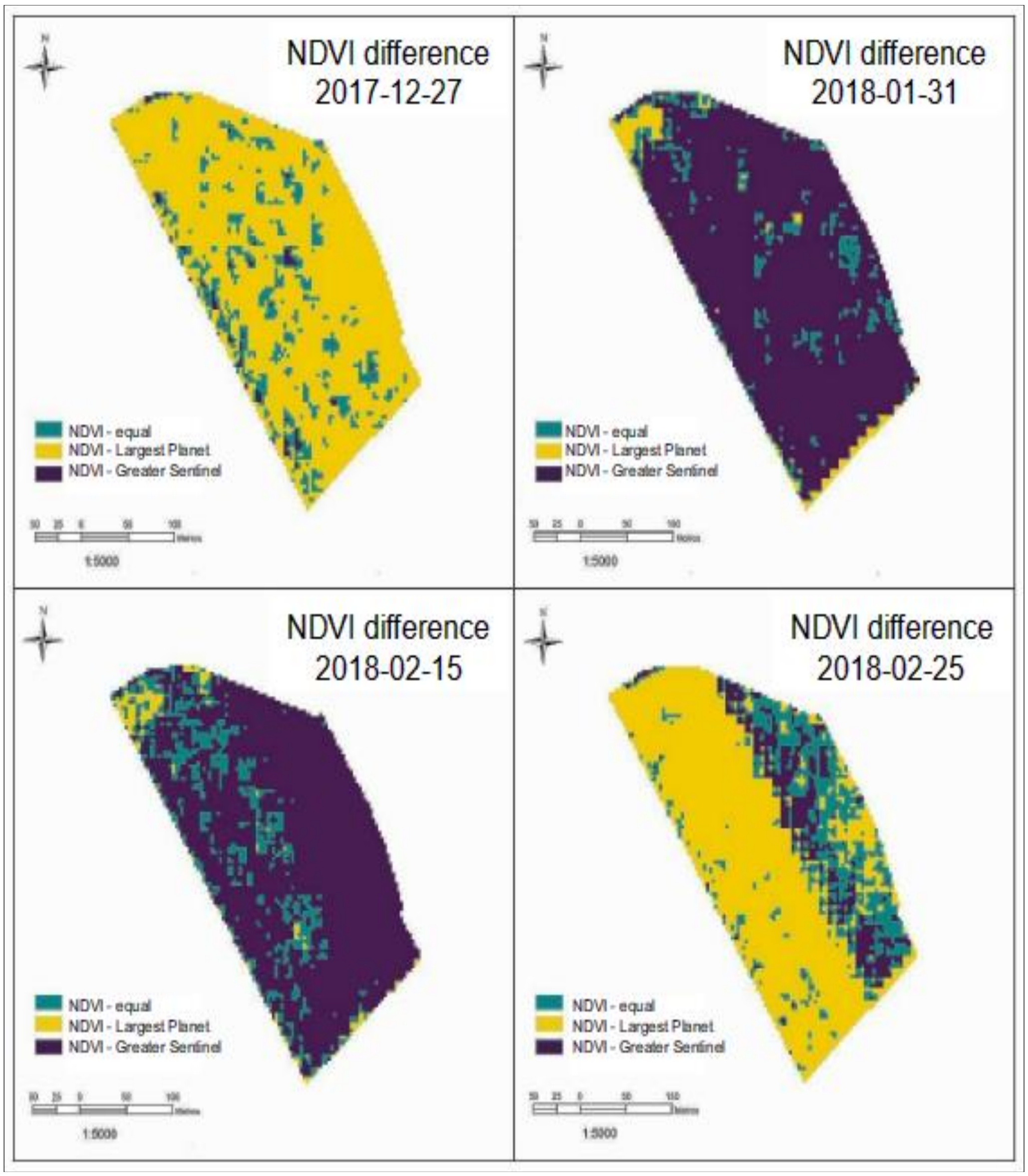

Figure 9. Difference images for the summer season, from a Cabernet sauvignon vineyard, Santana do Livramento, Brazil (PAULETTO, 2019).

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The autumn images did not show differences between dates, as occurred in other seasons (Figure 10). The NDVI values of the Sentinel-2 images comprised more than 95 % of the vineyard area, with great similarity, which may be related to the post-harvest period, senescence, loss of leaves and the development of the vegetation between the lines of vines. Thus, the vegetation had a more homogeneous distribution, which was proved by the difference images, due to the Sentinel-2 image having lower spatial resolution and the pixels covering larger areas in the vineyard. This reflected a mixture of the values of the different types of cover vegetation, showing less variability in the image.

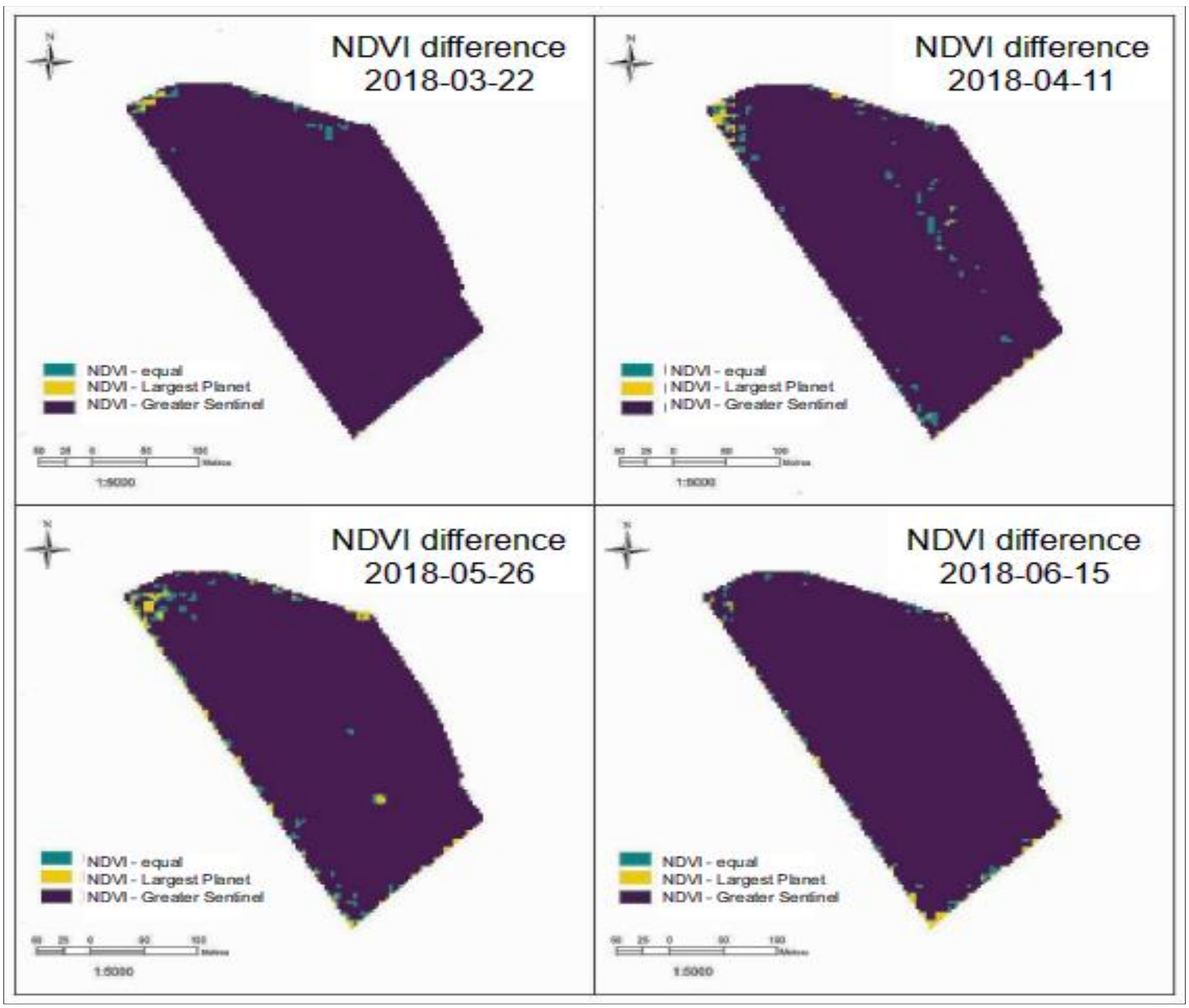

Figure 10. Difference images for the autumn season, from a Cabernet sauvignon vineyard, Santana do Livramento, BRAZIL (PAULETTO, 2019).

Table 8. Class areas, absolute and relative, resulting in difference images over the analyzed seasons, for Sentinel-2 and Planet images, from a Cabernet sauvignon vineyard, Santana do Livramento, Brazil (PAULETTO, 2019).

Data	Largest values NDVI Sentinel-2		equal NDVI values		Largest NDVI Planet values	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Spring						
2017-11-12	6.4233	97.41	0.0540	0.82	0.1170	1.77
2017-11-22	6.0469	91.70	0.3574	5.42	0.1900	2.88
2017-12-07	0.7113	10.79	2.5211	38.23	3.3620	50.98
2017-12-12	5.3910	81.73	0.7641	11.58	0.4410	6.69
Summer						
2017-12-27	0.1198	1.82	0.9049	13.72	5.5688	84.46
2018-01-31	5.7588	87.33	0.5582	8.47	0.2773	4.21
2018-02-15	5.3784	81.54	1.0053	15.24	0.2124	3.22
2018-02-25	0.8392	12.73	1.2596	19.10	4.4956	68.17
Autumn						
2018-03-22	6.5214	98.89	0.0531	0.81	0.0198	0.30
2018-04-11	6.4161	97.30	0.1243	1.88	0.0540	0.82
2018-05-26	6.3531	96.34	0.1324	2.01	0.1089	1.65
2018-06-15	6.4737	98.17	0.0630	0.96	0.0576	0.87

Spatial Variability of NDVI in the Vineyard

In order to identify the spatial variability within the vineyard, the NDVI zoning images were defined from the average ± 1 SD, showing a close relationship between both image from the same date. Patterns in both images at were identified, such as in Northeast portion of the vineyard, of NDVI values referring to class 1. However, in the rest of the vineyard, the temporal-space variability of NDVI values showed great variation between classes. Figure 11 shows examples from dates of February to April, 2018, when occurred harvest and post harvest of vineyard.

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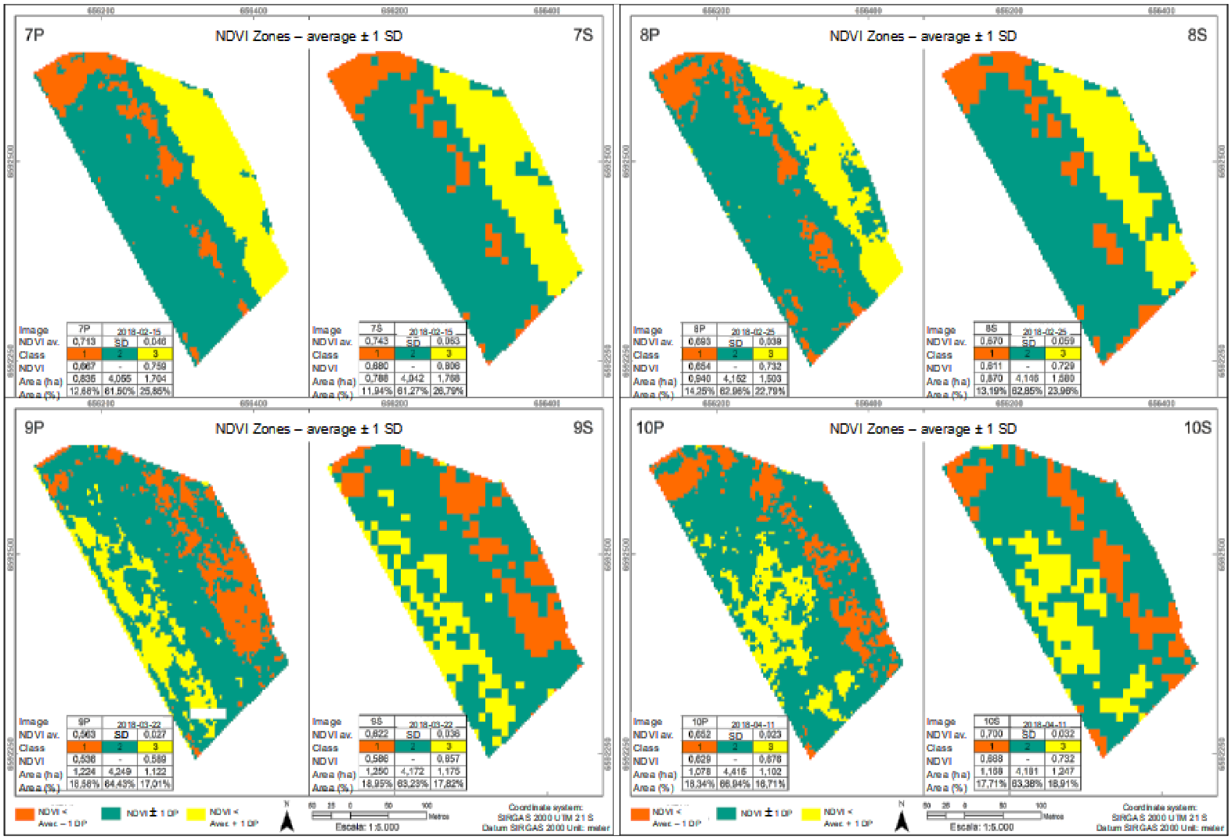

Figure 11. Zoning from the NDVI average values ± 1SD. P = Planet and S = Sentinel-2 images, from a Cabernet sauvignon vineyard, Santana do Livramento, Brazil (PAULETTO, 2019).

Evaluating the area of each class in relative values, seven images registered for class 1 less than 1 % difference between the two images, Sentinel – 2 and Planet. For class 2 and 3, four images represent this same difference. Class 1 presented a smaller difference in area, while classes 2 and 3 the difference was greater. On just one date, there was a difference of more than 5 % of the area between the images. From 2018-02-15, a segmentation of the NDVI values was identified, which was also perceived in the histograms and in the difference images. In the East portion of the vineyard, there is a SE-NW strip, where the NDVI values were included in class 3, the same pattern occurred at 2018-02-25.

From the image of February 15, 2018, there were possibilities of noise from the images, since the differences are noticeable in both images. On the dates of 22-03-2018 and 11-04-2018, there was an inversion of classes 1 and 3 in the eastern and western part of the vineyard, with no other anomalies being noted on the other dates. Except on 12-11-2017, in the western portion of the area, when values included in class 3 are presented. The eastern portion showed values within the defined limits.

The highest NDVI values tended to be located in the western part of the vineyard, with highest elevation. While, the eastern portion, with lower elevation, there were water concentration. Thus, it is understood that in addition to the variability of NDVI being associated with the management of the vineyard, it would also have influence from the relief and soil condition. The ground condition with water retention, could became the NDVI values higher than greater altitude zones, and lower NDVI values at lower altitudes.

The definition of zones larger and smaller than the standard deviation enabled a quantitative and comparative interpretation of the spatial variability of the NDVI of the Sentinel-2 and Planet image. This technique would allow the producer to identify areas with different agricultural management needs, a fact observed by Drissi et al. (2009) and Sun et al. (2017) in vineyards, about the importance of spatial characterization by NDVI.

The difference images showed a predominance of higher NDVI values in Sentinel-2 images, confirmed by the NDVI average profiles, being a simple way to spatialize the differences in NDVI between images, identifying areas where the greatest variations between the images occurred. The identification of these areas, from the average ± 1SD, were important for visualizing areas of greater or lesser development of vegetation. It could support at the correction of problems, decision making and even harvests directed towards the production of different wines from the same vineyard, as previously pointed out by Drissi et al. (2009) and Molin et al. (2015).

CONCLUSIONS

These results correspond to the first studies on the use of Planet and Sentinel-2 images in monitoring vineyards in the Indication of Origin “Campanha Gaúcha”. This application can be increasing the use of Planet images, for a longer period, more than one cycle, or a larger region, more than one vineyard or vineyards of different cultivars. Also a period of greater detail throughout the entire vineyard harvest, or others of the same cultivar. The use of detail images could generate more information about a vineyard or a farm, to verify similarity or difference between the areas, as well as to verify patterns observed in the images for each management applied, performing simultaneous monitoring in the field.

Although the average values showed differences between Sentinel-2 and Planet images, due to the characteristics and processing of the images, both could be used to characterize spatial and temporal characteristics of vineyards. However, the use must be made individually, as the NDVI average values, were not similar between the images, so an association between images is not recommended, such as, for example, a joining of the profiles to cover the lack of images at the same time. over a period. Image failures at some times of the year may be due to the lack of images or cloud cover, which makes it difficult to monitor vineyards from orbital images as mentioned by Junges et al. (2019b).

Even with different atmospheric corrections applied to the Sentinel-2 (original and resampled) and Planet images, these showed many similarities of NDVI average, satisfactorily characterizing the temporal evolution of the accumulation of green biomass in vineyards. The images of the two satellites were suitable for monitoring the variability by NDVI zoning, showing a similar behavior in the spatialization of this index in the vineyard.

Despite the different spatial resolutions, the two images may serve to support the identification of cultivation zones, contributing to obtain information on the variability between plants, in the context of precision agriculture. The choice of the end user for the image for monitoring the vineyard will be according to the farm's financial funds and the desired detail.

The results highlight the need to use orbital images in precision viticulture, which can contribute to the temporal and spatial monitoring of vineyards during the development of the vegetative cycle. The use of these tools can be support this Geographical Indication region, such as monitoring isolated vineyards or set of vineyards of a winery or association of producers geographically close.

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