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GIS and Remote Sensing to Support Precision Viticulture for Analysis of Vineyards in the Campanha Wine Region, Brazil

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Abstract: Agricultural products depend upon the geographical area of production and their quality depends on environment and crop management. Grapevine cultivars can be adapted to the environment, resulting in differences in fruit quality, which will produce different wines. The knowledge of the territory gives value to agricultural products and the use of free software has advantages to associate spatial data with Geographical Information System (GIS) functions for Digital Image Processing (DIP), spatial analysis, Digital Elevation Models (DEM) and databases. The objective of this study was analyze spatially vineyards of *Vitis vinifera* in south Brazil, using DEM for zoning landscape and employing RapidEye images at different crop stages, in order to follow the Normalized Difference Vegetation Index (NDVI) and test tools that allow the producer a customized management between vineyards and within each vineyard. The software gvSIG was used to evaluate NDVI for plant vigor in order to infer diseases, water status, and other factors. NDVI, altitude, slope, and exposure average were generated for 64 vineyards. To a Cabernet Sauvignon area, a map was generated, showing the variability of the vineyard by resampling of pixel size image, from five to one-meter spatial resolution and zoning according to critical variables for the vineyard. In conclusion, geotechnology is important for viticulture, as a support to environmental diagnostics and are a strategic application for agricultural management. Analytical tools and sensors can provide fast, easily accessible data to all users, being a technology prone to be of widespread access for the end user.

Keywords: GIS, image processing, spatial analysis, vineyard.
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1 Introduction

Wine quality in Brazil in the last four decades is consistently improving due to sustained investments in professional formation and in viticulture. Positive results of this policy can be verified by the increasing amount of Brazilian wines, which have been exported and now can be found in the international market (Protas and Camargo, 2011). Investments can be made to develop new viticulture regions. Until recently, virtually all production of fine wines originated from the "Serra Gaúcha" wine region in south Brazil, mainly due to settlement of Italian immigrants, even though geo-climatological conditions (high humidity in ripening season is often a problem) were not more favorable than other regions (Evaldo Fensterseifer, 2007; Da Silva and Ducati, 2009).

Vineyards can be highly variable at map scales, and precision viticulture has been employed since the last decade as a set of remote or sensor techniques for monitoring and decision support in viticulture (Bannari et al., 1995; Bramley, 2001; Hall et al., 2002; Lamb et al., 2004; Comba et al., 2015; Matese et al., 2015).

Source: http://www.guiageo-americas.com/mapas/america-do-sul.htm, http://www.mapas-brasil.com/rio-grande-sul.htm

Fig. 1 Location of the study area in Campanha wine region, Rio Grande do Sul State, Brazil.

Satellite images have often been used for monitoring the soil and crops such as Landsat or RADAR (Doraiswamy et al., 2004; Morán et al 2011; Usha and Singh, 2013), both for agricultural production and weed detection by vegetation index (Ferencz et al., 2004; Arno et al., 2009; Thorp and Tian, 2004) assessment of salinity, (Metternicht and Zinck, 2003; Rafiq et al., 2014), desertification (Collado et al., 2002) and water erosion (Vrieling, 2006). High-resolution images are more available today and can be processed by accuracy techniques of remote sensing (Johnson et al., 2003; Dellene et al 2010, Costa et al 2007; Matese and Di Gennaro, 2015). Furthermore, geophysical techniques such as GPR (ground penetration radar) and soil electro resistivity can clarify soil features that confuse the spectral behavior of the plant (Vereecken et al., 2012; Matese and Di Gennaro, 2015). . Application of microwave remote sensing for detection of water stress in vine is also available in the literature (Vereecken et al., 2012). In terroir case, Global Positioning Systems (GPS) and Geographical Information Systems (GIS) were used for investigate wine sensory attributes among other aspects (Reynolds et al 2007).

Therefore, studies in Brazil have been focused in characterizing more promising regions for grape growing. Three approaches have been adopted: tropical wines (Pereira, 2011), inverted ripening cycle (Flores, 2009), and conventional viticulture in new regions in south Brazil. This paper addresses the third, approaches the Campanha region, located in the southern part of Rio Grande do Sul State. This region coincides with the far south of the country, near to the border with Uruguay. In this region, the climate is warm and temperate. There is significant rainfall throughout the year. Even the driest month still has substantial rainfall. According to Köppen-Geiger, the climate classification is Cfa, in which average temperature is 17.6 °C and average annual rainfall is 1262 mm (Peel et al., 2007).

The Campanha region contrasts with the traditional "Serra Gaúcha" region, which is highly rugged, originally covered by humid forests and now relatively densely populated, leading to a patched land occupation where vineyards have, on average, less than five hectares. It is part of the "Pampa" biome, which extends over international borders to Uruguay and Argentina (Embrapa, 2007), where vineyard of *Vitis vinifera* are planted in Uruguay for winemakers, that presenting same physiographic characteristics of the terrain and natural vegetation.

Being less humid and sparsely populated, the Campanha's historical economical drive was extensive cattle grazing, and only recently, its adequacy to viticulture. The first modern vineyards were established around 1976 by the California-based firm Almadén, following field studies (Giovannini, 2014). Presently, as new (mostly Brazilian) investors are planning to start or increase wine production, more comprehensive studies are necessary, with the aggregation of new techniques as Remote Sensing (RS) and GIS.

This paper reports the methodologies to decision-making support, using RS and GIS, which quickly produce useful knowledge of the territory, allowing systematic surveys on land use, biomass, relief and other information. The Seival vineyard, from Miolo Wine Group, was chosen for this project. Fig 1 shows the study area and its geographical context.

Presently there is an effort to characterize several viticultural regions in Brazil, especially in the south, aiming to the establishment of a system of appellations, similar to those already existent in several countries. As in France, Italy or Chile, it is leading to the attribution of DO ("Denominação de Origem") or IP ("Indicação de Procedência") seals to wines originating from geographical defined regions. This study is part of projects coordinated by Brazilian Agriculture Research Corporation from 2012 to 2015. Tonietto and Zanus (2007) used spatial data in a GIS, fundamental to the creation of the first Brazilian D.O., the "Vale dos Vinhedos" D.O. in the Serra Gaúcha wine region.

Following what was made in the Serra Gaúcha wine region by Falcade and Mandelli (1999) and by Tonietto et al. (2008), who used methods based in RS and GIS to characterize relief aspects of geographical indications, a similar approach was adopted in more regions. In the "Serra do Sudeste" wine region, Hoff et al. (2009) and Hoff et al., (2010) investigated relief aspects for suitability for viticulture; Cemin and Ducati (2008) studied the spectral response of grapes in this region (at "Encruzilhada do Sul"), and Ducati et al. (2009) analyzed the relief of vineyards from satellite images in "Pinheiro Machado". In the Campanha wine region, specifically in this "Seival" study area, Hoff et al. (2013) performed spectroradiometric measurements to Normalized Difference Vegetation Index (NDVI) monitoring in 2012 and 2013.

Fig. 2 "Seival" farm, vineyards in Campanha wine region, Brazil. Source: Google Earth, Miolo Wine Group.

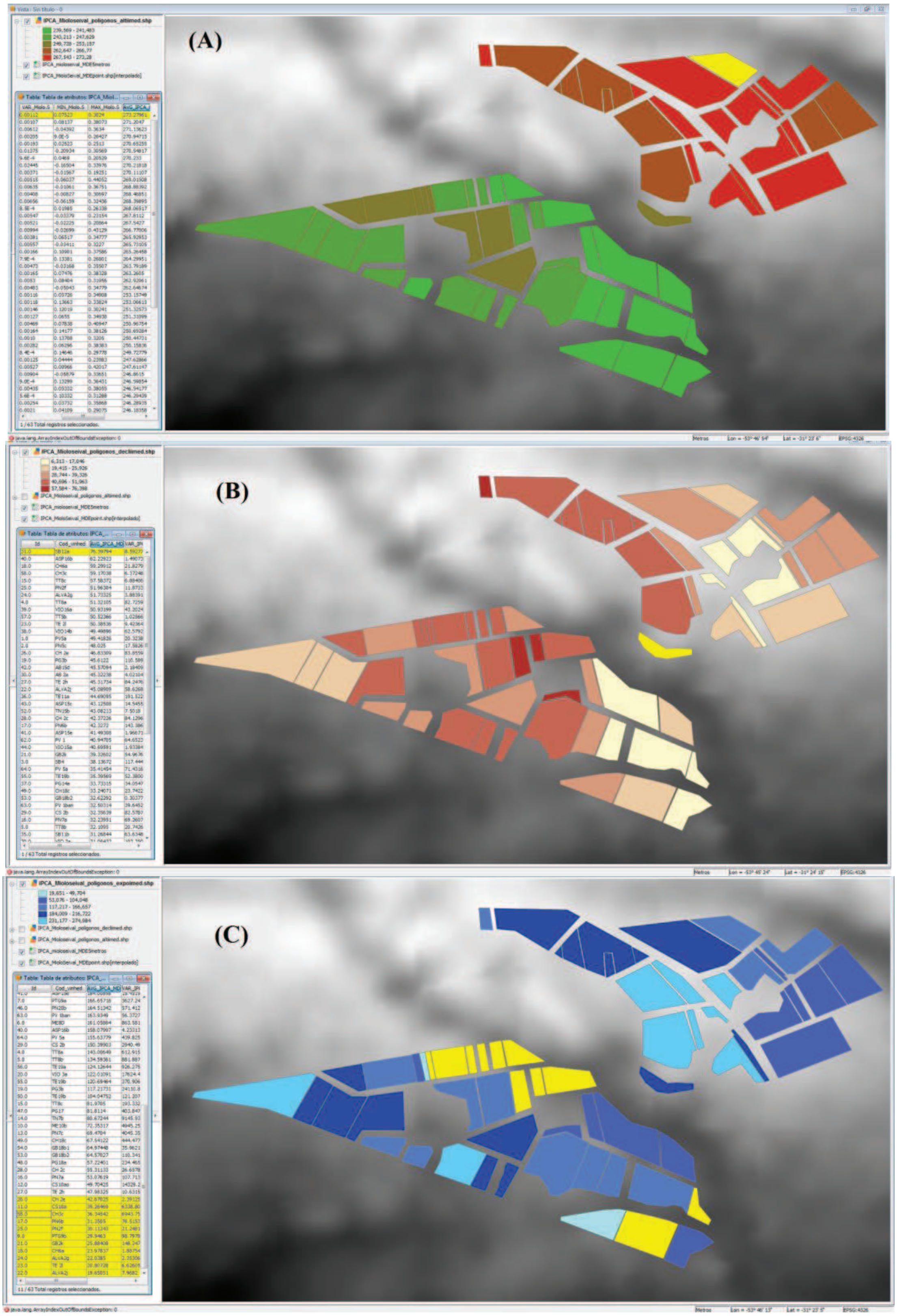

Fig. 3 Inter portion analysis from the DEM. A: average elevation of the vineyards, reclassified in five intervals of altitude; B: average slope of vineyards, reclassified in five slope ranges; C: average exposure, classified into five intervals of sun exposure. “Seival” farm in Campanha wine region, Brazil (environment gvSIG, GVA 2014).

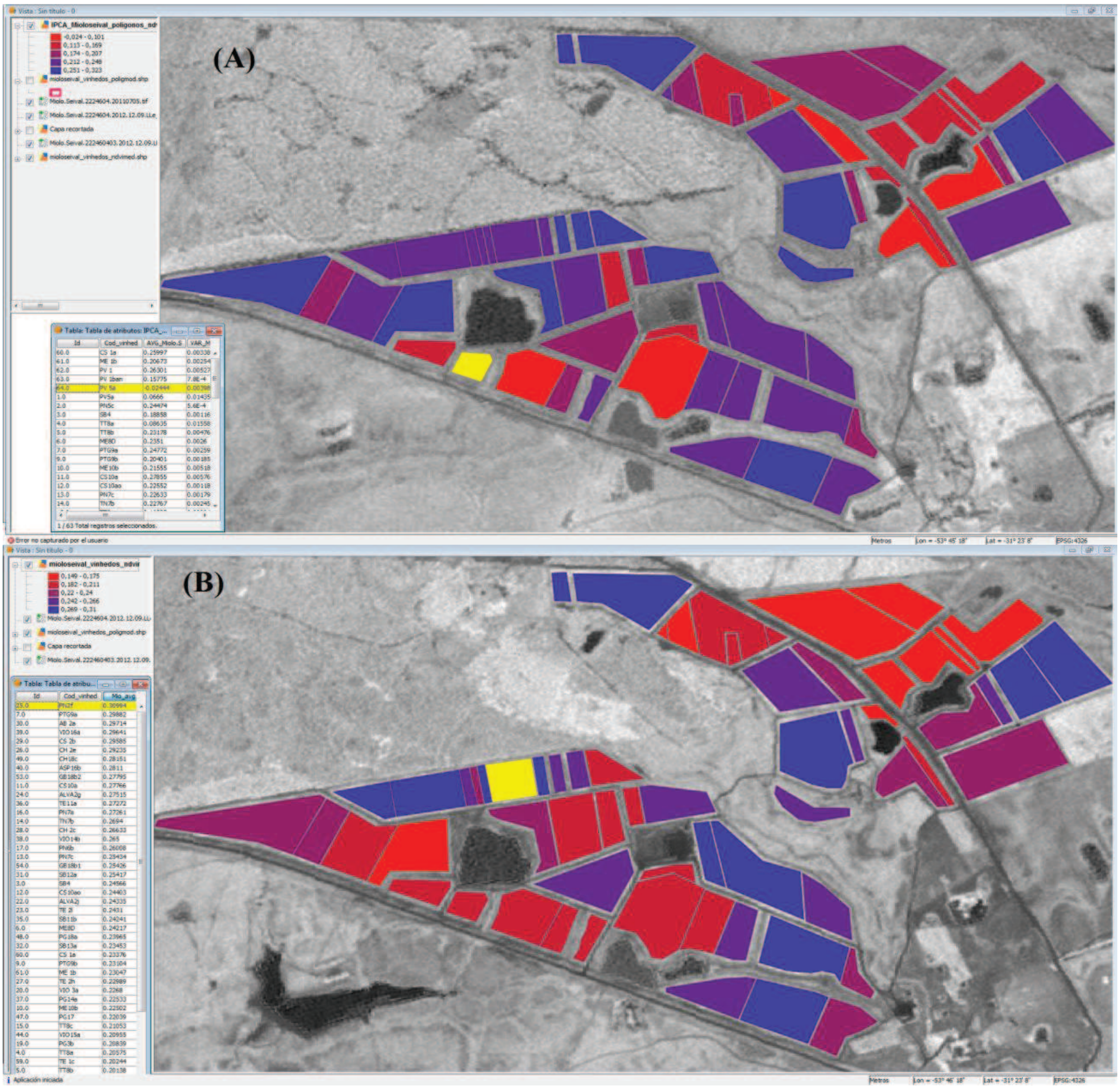

Fig. 4 Analysis inter portion on image RapidEye, A: NDVI average in July 2011, B: NDVI average in December 2012. Both results reclassified in five-plant vigor intervals. "Seival" vineyards in Campanha wine region, Brazil (environment gvSIG, GVA 2014).

The objective of this study was to analyze vineyards of *Vitis vinifera* in Campanha wine region Brazil, using Digital Elevation Models (DEM) for zoning landscape and employing RapidEye images at different crop stages, in order to follow the vegetation index and test tools that allow the producer a customized management between vineyards and within each vineyard. Fig 1 shows the location of this area.

2. Materials and Methods

A map of "Seival" vineyard (Fig 2) was available by Miolo Wine Group, showing 64 vine plots with accompanying information on surface and grape varieties. The study area is in Candiota County, Rio Grande do Sul State, located between 31°23'3.96"S - 31°24'17.27"S (Latitude) and 53°44'59.58"W - 53°47'11.42" W (Longitude). A DEM with spatial resolution of 30 meters was obtained from Hasenack and Weber (2010) to generate maps of altitude, slope and sun exposure.

RapidEye images (Planetlabs, 2015) made available by the Brazilian's Ministry for the Environment were used to monitoring vineyards. These orthorectified images are in the 3A processing level (with radiometric and geometric corrections) with spatial resolution of five meters and five spectral bands (three bands in visible wavelengths, plus the red edge and near infrared). Images were taken during winter (July 5, 2011), when the plant was dormant, without leaves. Moreover, an image was captured in late spring (December 9, 2012). This choice is because at this stage it is still possible to alert to diseases, growing status and soil moisture in order to correct until harvest.

To perform an analysis of vineyard spectral behavior in crop stage and off-season, NDVI was calculated, defined by Tucker (1979) as

$$NDVI = (R_{IR} - R_{VIS})/(R_{IR} + R_{VIS}) \quad [1]$$

Where R_{IR} and R_{VIS} stand for the reflectance acquired in the near infrared (0.760–0.850µm) and red (0.630–0.670µm) regions respectively.

Using management maps provided by the owners, polygons of parcels of interest were traced to be overlapped on images, being also used as masks for further analysis. Resampling operations towards higher spatial resolution were performed on both satellite images, from 5 meters to 1 meter; likewise, the DEM was resampled to 1-meter vertical resolution. Techniques of RS and GIS were used to analyze data of the "Seival" farm for inter-parcel analysis, to compare vineyards in different parts of the property, and for intra-parcel analysis. These operations tested tools intended to allow the producer customized management for each portion.

In fieldwork in March 2013, botritis and mildew were observed in a few plants, frequent diseases in the south of Brazil (Garrido et al, 2015), some already treated at the time. However, the satellite images were available after this date. Therefore, this work is a proposal of methodology to be applied in future crops.

3. Results and Discussion

3.1 Inter-parcel Analysis

As a result, was obtained quickly and remotely an average value of the NDVI and average aspects such as slope, altitude and exposition for 64 portions of vineyard in the farm, so that it was possible to obtain visual and intuitive information distribution of the vigor of entire vineyard at a particular time by period. The inter portion analysis resulted in average values for the analysis of micro relief, separated into five sample classes.

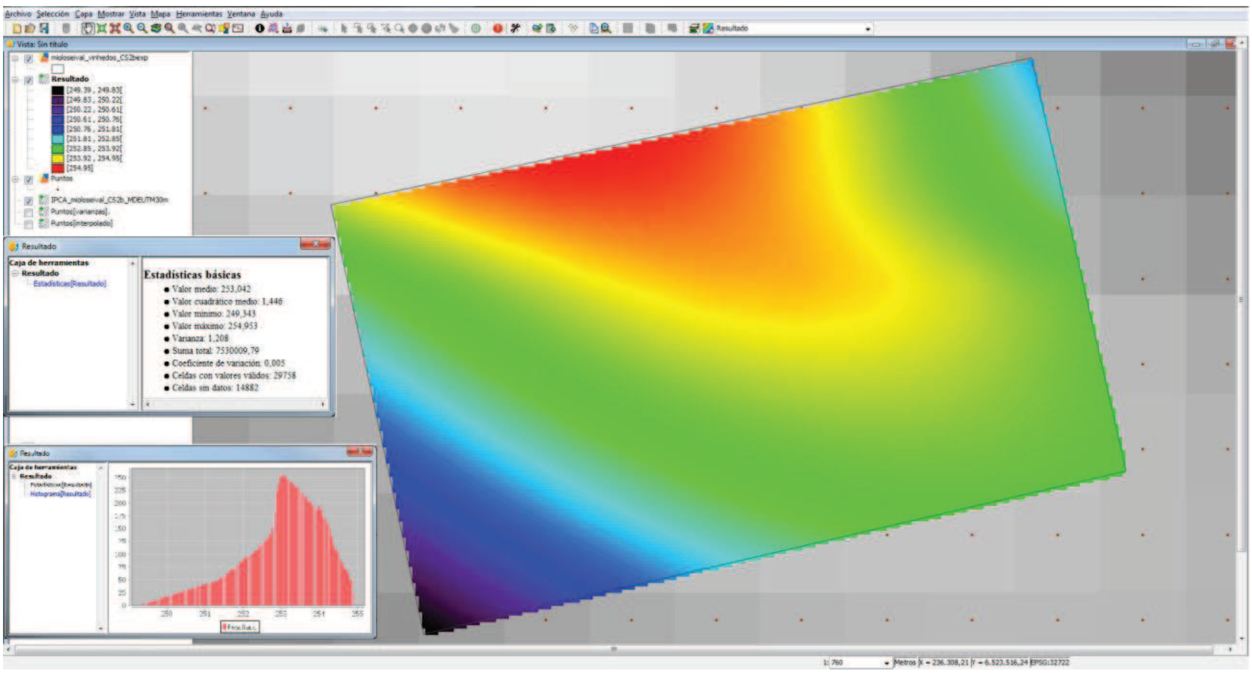

Fig. 5 Intra portion analysis, CS2b Vineyard (Cabernet sauvignon), allowing zoning within the vineyard. From DEM with 30 m resampled to 1-meter resolution, elevation reclassified (m). "Seival" farm in Campanha wine region, Brazil (environment gvSIG, GVA 2014).

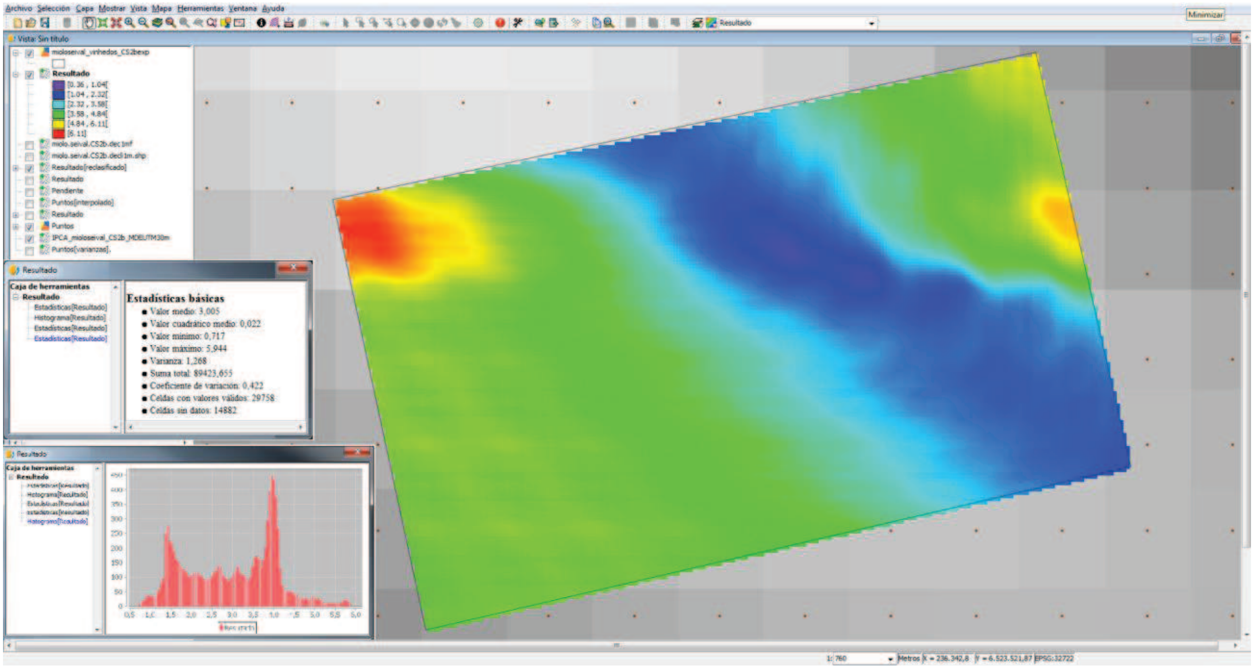

Fig. 6 Intra portion analysis, CS2b Vineyard (Cabernet sauvignon), allowing zoning within the vineyard. From DEM with 30 m resampled to 1-meter resolution, slope reclassified (percent). "Seival" farm in Campanha wine region, Brazil (environment gvSIG, GVA 2014).

The elevation in "Seival" farm varied between 239-273 meters. It is known that the altitude affects a lot during the grape harvest. Therefore, the grapes located in the south and southwest of the area could be harvested earlier than the grapes located north and northeast of the area (Fig 3A).

The slope ranged from 0.6 to 7.6%. Smooth slopes suggest plans terrains that may cause water retention in the soil, considering there are clay soils in this area. Thus, it is necessary to observe the areas south of the basin, where there is a tendency to water retention in a small valley and northeast where the flat top of the hill accumulate water (Fig 3B). In addition, at the time of harvest, the heat and humidity can induce diseases on the vine.

The sun exposure showed average values between 20° and 275° in azimuth Northern, concentrated in north azimuth. The sunlight can favor development of the grapes. Therefore, vineyards with good lighting could have quality for a type of wine, by varying the fruit soluble solids and will be harvested in different ways to produce different wines. Thus, the northeast areas are better lit and there are isolated areas south of the farm with good lighting (Fig 3C).

For NDVI calculated for each vineyard, the average value was done in two passes with a RapidEye image scene. Fig 4A shows the values obtained by the image of July 2011, ranging between -0.024 and 0.323. These values characterize the vine in the winter season (when vines are dormant). However, negative values may also indicate areas with exposed or flooded soil.

Fig 4B shows the average values obtained by the December 2012 image, ranging from 0.149 to 0.31. Low values can be caused by exposed soil and / or moist and it can cause vine diseases. Maximum values are compatible with vines values in December, whose grasses between rows were frequently cut, or the plant has not yet reached full vigor.

3.2. Intra portion analysis

The generation of an individual plan improved the variability of a vineyard with respect to the same aspects as showed in the section before. So, these aspects were better visualize in presentation of processed images by the redefining the image pixel size. The new image was generated, but with a one meter spatial resolution. The intra portion analysis was performed in a Cabernet Sauvignon vineyard - CS2b. The DEM with 30 meter was resampled to 1 meter, providing smoothed terrain to the farmer by information for vineyard management through the knowledge of the variability of micro-relief.

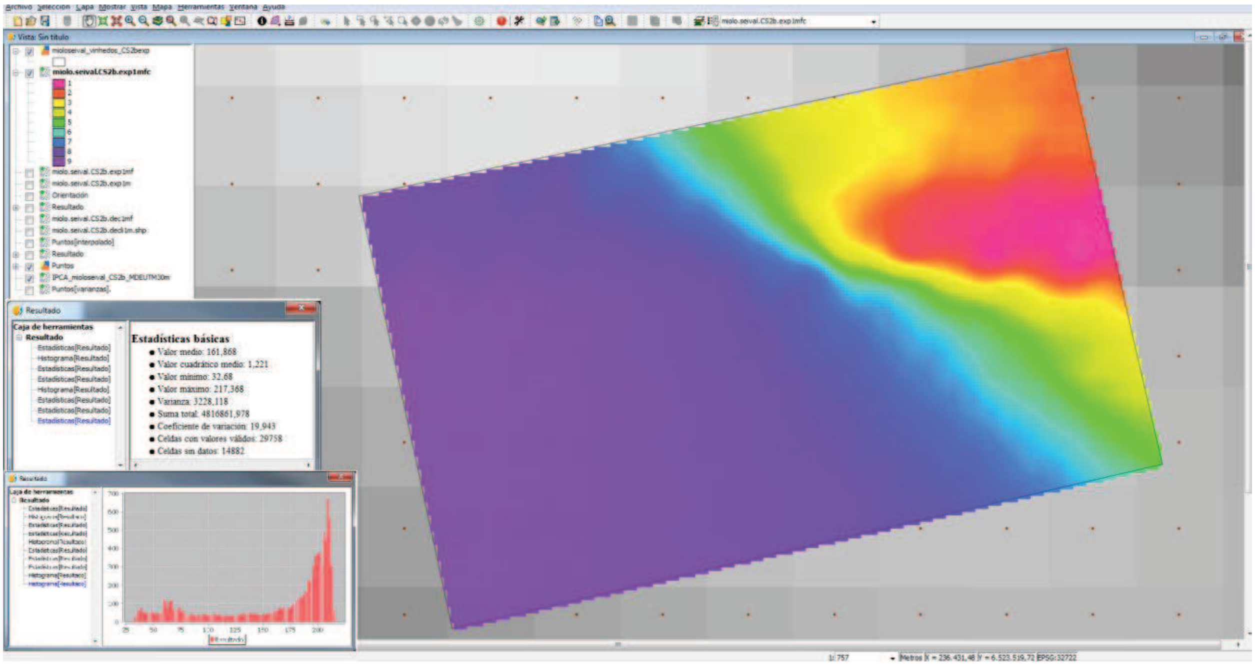

Fig. 7 Intra portion analysis, CS2b Vineyard (Cabernet sauvignon), allowing zoning within the vineyard. From DEM with 30 m resampled to 1-meter resolution, exposure reclassified (degrees N azimuth). "Seival" farm in Campanha wine region, Brazil (environment gvSIG, GVA 2014).

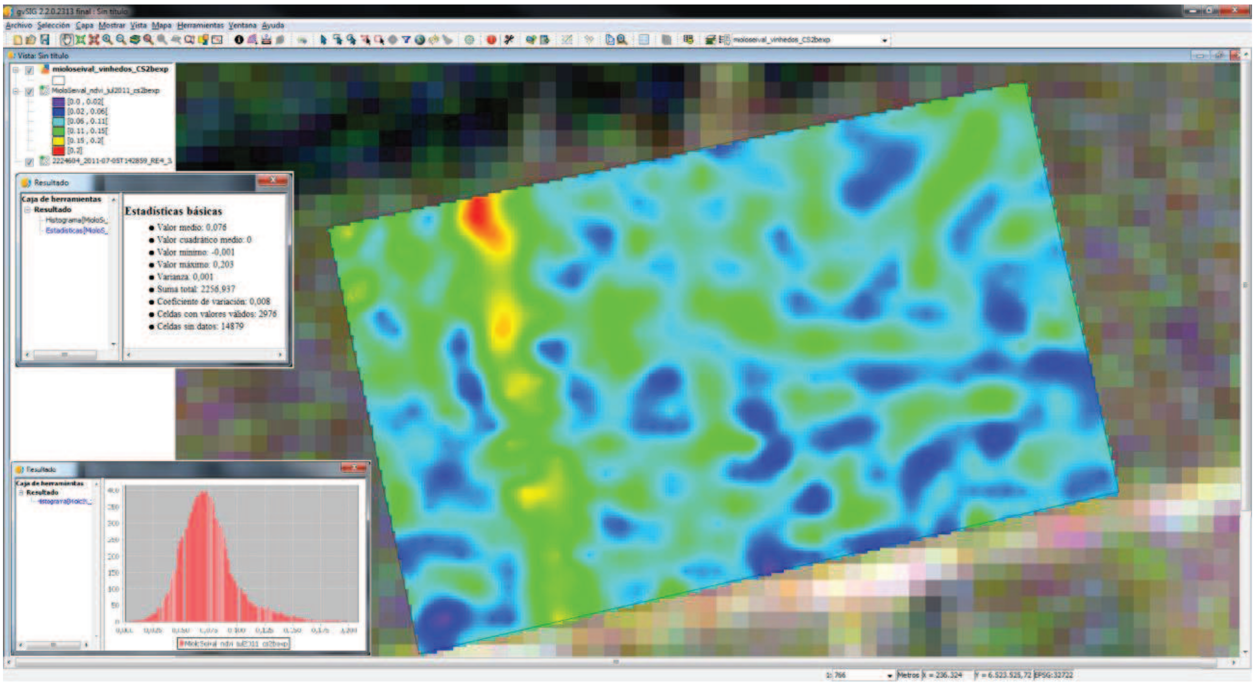

Fig. 8 Cabernet sauvignon - vineyard CS2b, intra portion zoning, NDVI from RapidEye image on July 2011, resampled to 1 meter. "Seival" farm in Campanha wine region, Brazil (environment gvSIG, GVA 2014).

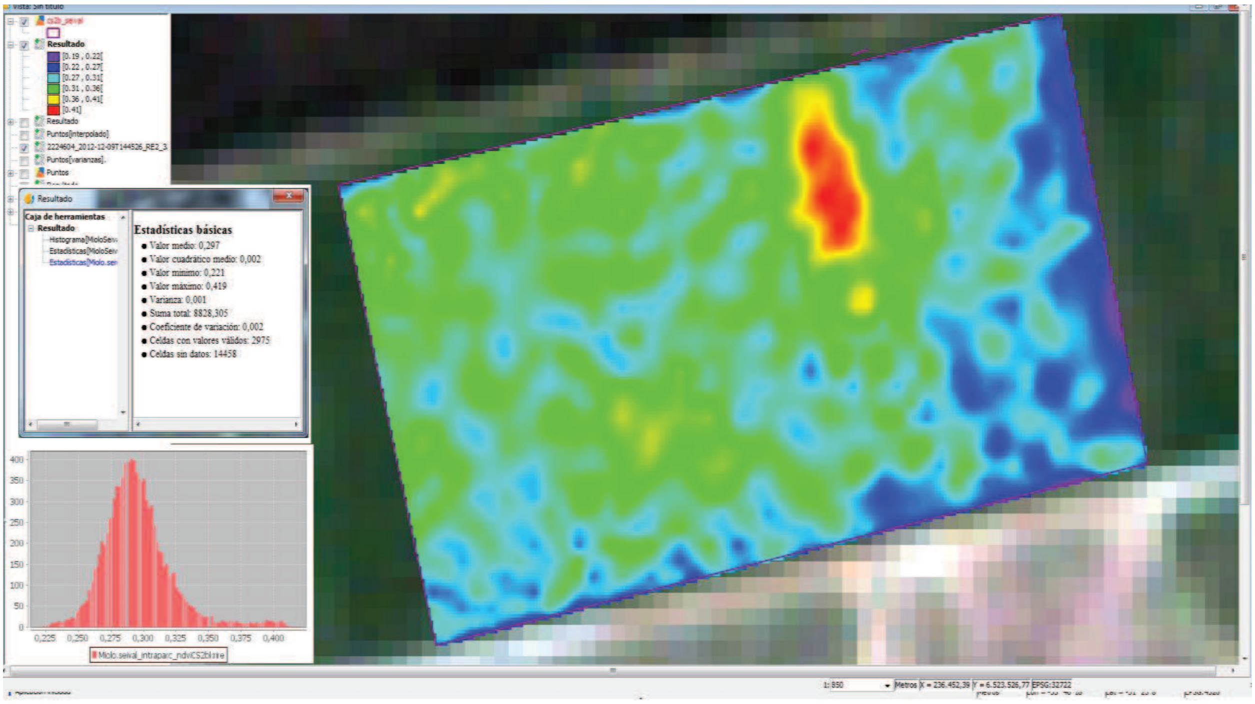

Fig. 9 Cabernet sauvignon, vineyard CS2b, intra portion zoning, NDVI from RapidEye image on December 2012, resampled to 1 meter. "Seival" farm in Campanha wine region, Brazil (environment gvSIG, GVA 2014).

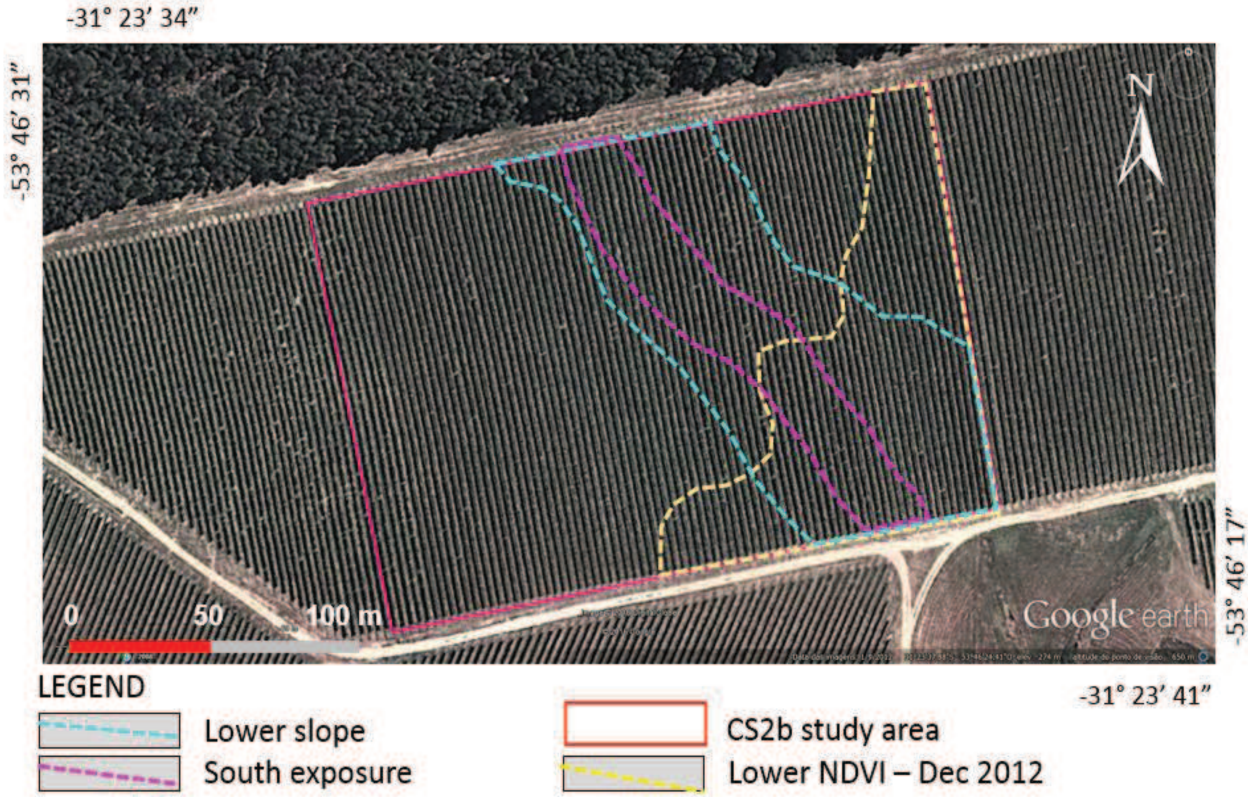

Fig. 10 Cabernet sauvignon, vineyard CS2. Recommended areas for monitoring, due to the lower slope and South exposure (always) and area with lower NDVI (December 2012). "Seival" farm in Campanha wine region, Brazil.

The elevation was segmented in classes between 249 and 255 m (Fig 5). The slope was also classified into six ranges between 2.6 and 4.8 % (Fig 6). Sun exposure of this vineyard varies between 172° and 211° north azimuth (Fig 7). The results showed that some portions of the vineyard have western and partly southern exposure with reasonable slope levels to allow terrain drainage.

The NDVI produced from image RapidEye, was resampled to five for one meter, as shown in Fig 8. Then they compared July 2011 pictures - at dormancy - and December 2012 - when there is significant canopy development. There was a vineyard zoning in two dates, showing that in winter, NDVI was < 0.2, with a mean of 0.076 (Fig 8), while in summer NDVI reached 0.419, with a mean of 0.297 (Fig 9). These values were consistent with the period of crop since, for *Vitis vinifera*, the height of the phenological cycle would be from February to March.

In the NDVI winter image (Fig 8), areas with low NVDI may be associated with water retention in the soil, as these have high clay content by geological origin (CPRM, 2008). It is suggested to design drainage channels within the vineyard, to decrease water accumulation, based on the elevation image (Fig 5). Based on the results of the relief analysis, in this study was observed areas to be monitored continuously, such as those with lower slope, which may accumulate moisture and not be good for the plant, as it may affect the roots. In addition, areas with less sun exposure may delay maturation and harvesting should be monitored. By the NDVI analysis of the December 2012 image, it serves only as an example for future management, recommending monitoring of areas with low rates, since it would suggest diseases or perhaps soil moisture that could lead to diseases. Fig 10 shows the recommended areas for monitoring of Cabernet Sauvignon (CS2b) vineyard at the Seival Farm.

Furthermore, other techniques can be used to detail the monitoring of the vine as to the amount of water and vegetation index of the plant, such as sensors carried by UAV (Baluja et al., 2012; Santesteban et al., 2017). Future research in Campanha wine region needs more imagery scene in high-resolution to monitoring grow vineyard along phenological cycle.

In the effort of developing precision agriculture tools, remote sensing is an effective technique for monitoring vine, even with variations in the plant canopy spectral response, soil background on the canopy spectral response, yet are important low cost tools for producers. In the case of GIS analysis for vineyard as done in this study, there is still no comparison in Brazil. However, it can be compared with cases studied in Spain, as the example, the study was successfully done by Torres et al (2009) using gvSIG free software.

4. Conclusion

The inter portion analysis provided quickly an average value of vegetation index and the relevant aspects of a large number of vineyard, being possible to have a visual and intuitive information of the distribution of attributes throughout the vineyard a given time the harvest. The intra portion analysis of the vineyard CS2b – Cabernet Sauvignon - was provided the spatial variability values within a vineyard, showing relief features and NDVI in two distinct scenes. The results of image processing were continuous values within the vineyard obtained quickly, using two types of data: raster files (DEM and NDVI) and vector file containing polygons of vineyards. The values of aspects such as elevation, slope, exposure, are fixed in any crop, but the producer can decide the handling of the crop according to the variability of the results found. For example, make a crop differently grapes that receive more sunlight or are at lower altitudes. In addition, the producer can deploy differentiated management of drainage and irrigation as the terrain slope. It is concluded that the geospatial technologies are important in the development of viticulture, by supporting environmental diagnostics associated with the vineyard and strategic applications in agricultural management. The analytical tools and the various sensors can quickly provide accessible data to technicians and farmers, which can be viewed by customers of the production system and these technologies, can be transferred to the end user. The technology transfer can be made through free GIS software and the results may be available, either in the form of digital products or graphics through web mapping, digital download and database accessible.

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