



Correlation between vegetation indexes generated at *Vitis Vinifera* L. and soil, plant and production parameters for emergency application in decision making

Márcio da Silva Santos¹  Luciano Gebler^{2*}  Elódio Sebem³ 

¹Universidade Federal de Santa Maria (UFSM), Santa Maria, RS, Brasil.

²Embrapa Uva & Vinho, 95200-970, Vacaria, RS, Brasil. E-mail: luciano.gebler@embrapa.br. *Corresponding author.

³Instituto Federal de Santa Catarina (IFSC), Florianópolis, SC, Brasil.

ABSTRACT: *Correlation between proximal sensing techniques and laboratory results of qualitative variables plus agronomic attributes was evaluated of a 3,0 ha vineyard in the county of Muitos Capões, Northeast of Rio Grande do Sul State, Brazil, in *Vitis vinifera* L. at 2017/2018 harvest, aiming to evaluate the replacement of conventional laboratory analysis in viticulture by Vegetation Indexes, at situations where laboratory access are unavailable. Based on bibliographic research, looking for vegetative indexes developed or used for canopy reflectance analysis on grapevines and whose working bands were within the spectral range provided by the equipment used, a total of 17 viable candidates were obtained. These chosen vegetation indices were correlated, through Pearson (5%), with agronomic soil attributes (apparent electrical conductivity, clay, pH in H₂O, phosphorus, potassium, organic matter, aluminum, calcium, magnesium, effective CTC, CTC at pH 7.0, zinc, copper, sulfur and boron) for depths 0 -20 cm and 20-40 cm, and plant tissue (Nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, copper, zinc, iron, manganese and boron), in addition to some key oenological and phytotechnical parameters for the quantification of wine production and quality. One hundred and thirty nine significant correlations were obtained from this cross, with 36 moderate coefficients between 19 parameter variables versus 12 of the indexes. We concluded that in cases where access or availability of laboratory analyzes is difficult or impracticable, the use of vegetation indices is possible if the correlation coefficients reach, at least, the moderate magnitude, serving as a support to decision making until the lack analytical structure to be remedied.*

Key words: *vegetation indexes, precision agriculture, remote sensing.*

Correlação entre índices de vegetação gerados em *Vitis Vinifera* L. E parâmetros de solo, planta e produção para aplicação emergencial na tomada de decisão

RESUMO: *Avaliou-se a correlação entre as técnicas de sensoriamento proximal e os resultados laboratoriais de variáveis qualitativas, mais os atributos agrônômicos do solo de um vinhedo de 3,0 ha no município de Muitos Capões, região nordeste do estado do Rio Grande do Sul, Brasil, na safra 2017/2018. Objetivou avaliar a substituição das análises laboratoriais convencionais em viticultura por Índices de Vegetação, em situações de indisponibilidade de acesso ao laboratório. Com base em pesquisa bibliográfica, buscaram-se índices vegetativos desenvolvidos ou utilizados para análise de refletância de dossel em videiras e cujas bandas de trabalho estavam dentro do intervalo espectral fornecido pelo equipamento utilizado, obtendo-se um total de 17 candidatos viáveis. Esses índices de vegetação escolhidos foram correlacionados, por meio de Pearson (5%), com atributos agrônômicos do solo (condutividade elétrica aparente, argila, pH em H₂O, fósforo, potássio, matéria orgânica, alumínio, cálcio, magnésio, CTC efetivo, CTC em pH 7,0, zinco, cobre, enxofre e boro) para profundidades de 0 - 20 cm e 20 - 40 cm, e tecido vegetal (nitrogênio, fósforo, potássio, cálcio, magnésio, enxofre, cobre, zinco, ferro, manganês e boro), além de alguns parâmetros enológicos e fitotécnicos essenciais para a quantificação da produção e qualidade do vinho. Deste cruzamento foram obtidas 139 correlações significativas, resultando 36 coeficientes moderados entre 19 variáveis de parâmetros versus 12 dos índices. Concluímos que nos casos em que o acesso ou disponibilidade de análises laboratoriais é difícil ou impraticável, a utilização de índices de vegetação é possível, desde que os coeficientes de correlação atinjam, pelo menos, a magnitude moderada, servindo como suporte para a tomada de decisão até a falta de estrutura analítica ser remediada.*

Palavras chave: *índices vegetativos, agricultura de precisão, sensoriamento remoto.*

INTRODUCTION

Precision Agriculture (PA) is a relatively new technology in grapevine, where it is specifically called Precision Viticulture (PV), highlighting the pioneering research conducted in the United States (WAMPLE et al., 1998) and in Australia

(BRAMLEY and PROFFITT, 1999; PROFFITT et al., 2006). It was later adopted by winemakers from Europe such as France and Spain and South America (MIELE et al., 2014). Precision viticulture is related to countries with high technological development, where the adoption of these technologies and results obtained have brought success to the activity

(ESSER, 2002). According to Flores et al., (2011) Precision Viticulture (PV) can be understood as the management of temporal and spatial variability of vineyards targeting improve the economic yield of the activity, both by increasing productivity and/or quality, as well as reducing production costs and environmental impacts.

In Brazil, Precision Viticulture is still an incipient technology. Extensive research and testing is required, as well as the development of a variety of equipment, hardware and software (Cass, 2013), looking for improving labor efficiency, irrigation and fertilization, increasing production, quality, profitability, and sustainability of the activity (PROFFIT et al., 2006). Application of proximal or distal hyperspectral remote sensing for studies related to evaluating agricultural vegetation will allow the monitoring of important crop variables, including stresses (as those caused by water, insects, pollution, etc.), agricultural production, productivity, carbon sequestration, phenology, crop maturation, among others.

Associated with remote sensing, there is a vast potential for the application of vegetation indexes for agriculture, that are constituted in mathematical models, based on the spectral analysis of electromagnetic waves (MARCUSI et al., 2010). Due to the ability to quickly assess the amount and condition of plants over large areas repeatedly, with physical foundation and real correspondence of crop in the field, they present correlations between solar radiation and photosynthetically active tissues of plants (XUE et al., 2008). These indexes can be very useful for the estimation of biophysical variables such as productivity, percentage of green cover on the soil, biomass, leaf area index (LAI), content of water and biochemical components, and the fraction of photosynthetically active radiation. This has already been proven by Zwiggelaar, (1998), Lacar et al. (2001), Hall et al. (2003), Herrera et al. (2003), Brown et al. (2004), Bramley and Hamilton (2004), SETHURAMASAMYRAJA et al. (2010), Smit et al. (2010), Cerovic et al. (2012), in several studies involving spectroradiometry on grape culture, including relating vegetative indices to some agronomic parameters in isolation.

It also allows the expansion of the optimized and sustainable management capacity of the vineyards. This study was carried out to identify the best vegetation indexes for *Vitis vinifera* L. at the pre blossom stage (BBCH 75 phenological stage) in literature and correlate them with agronomic attributes of soil, plant, quality of wine and productivity, obtained in the field and analyzed in

laboratory, aiming the replacement of these analysis by Vegetation Indexes in viticulture, at situations where laboratory access would be unavailable

MATERIALS AND METHODS

The study area, located in the Muitos Capões county, Northeast region of Rio Grande do Sul State, Brazil, at Entre Rios Farm and Vineyard (Latitude: -28.387376 °S, Longitude: -51.253558°W), had 3,0 ha of 10 years old vineyard, equally divided (1.0 ha) among Chardonnay, Merlot and Pinot Noir wine cultivars, for the production of fine and sparkling wines. Conduction system of vineyard was by cordon/spur on a trellis, with spacing of 1 m plants x 3 m between lines. The climate of the region, according to Köppen, is a Cfb type (Peel et al., 2007), with average annual rainfall of 1775 mm and average temperatures of 16.2 °C (PEREIRA et al., 2009). The land was a gently slope, between 843 and 850 meters height above sea level.

A semi-directed sampling mesh was established for each plot represented by the planted cultivar, with its baseline located in the first row of plants, from which points were distributed every 20 meters orthogonal and laterally. For marking the orthogonal points to this baseline, when the theoretical grid point was between the lines of the plants, its position was approximated to the plant on the nearest line, increasing or reducing the radius of 20 meters.

This generated a new line of points every 4-6 planting lines, maintaining a representativeness ratio around one point for every 400 m², for each of 74 sample points total in the area. For this, a GPS / GNSS receiver (RTK GR-3 FH915) was used, as well as ArcGIS 10.3 and MS Office software, guiding the spectroradiometric readings and the collections for chemical and physical soil analysis, as well as the phyto technical and oenological parameters.

Soil collection and its subsequent laboratory analysis was performed by simple sampling using Dutch auger at depths of 0-20 and 20-40 cm, according to the methodology and recommendations of the Brazilian Society of Soil Science (2016).

The analysis of the physical variables of the soil were collected using the same process, grid and depths of the chemical variables, following the methodology and recommendations of the Brazilian Soil Science Society (2016).

For the chemical analysis of the plant tissue, 100 whole and healthy leaves were collected during the full flowering period among the 20 plants

(composite sample), closest to the referenced plant, in the 74 sampling points. The selection consisted of collecting the leaf in the opposite position of the first bunch, from the base of the branch. One leaf per branch/cluster, at the phenological stage 81 BBCH according to the phenological classification of Lorenz et al. (1995) and according to the methodology of the Embrapa Chemical Soil, Plant and Fertilizer Manual, (2009).

To assess the spatial variability of each analyzed attribute, geostatistical analysis was used, based on experimental semivariograms adjusted by theoretical models proposed by Robertson, (1998), with the aid of the computer program Geostatistics for the Environmental Sciences (GS+) developed by Gamma Design Software. To define the model and adjust the semivariograms, the smallest sum of squares of residuals (SQR), the smallest nugget effect (C0), the shortest range (ranger) in relation to the maximum distance (lag distance), the analysis of variance and the spatial dependence classification (DE), for data that met these criteria, ordinary kriging interpolation followed by cross-validation was adopted, otherwise, the Inverse Distance Interpolator (IDW) was accepted (RIBEIRO JR and DIGGLE, 2001).

The soil variables analyzed were: Clay; pH in H₂O; Phosphorus (P); Potassium (K); Organic Matter (OM); Aluminum (Al); Calcium (Ca); Magnesium (Mg); Effective CTC; CTC at pH 7.0; Zinc (Zn); Copper (Cu); Sulfur (S) and Boron (B). The soil physics variables analyzed were: Soil moisture (g / g), Fractions of sand (%), Silt (%) and Clay (%). The plant tissue variables analyzed were: Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Sulfur (S), Copper (Cu), Zinc (Zn), Iron (Fe), Manganese (Mn) and Boron (B). All the variables analyzed showed spatial variability in the evaluated area, allowing their evaluation in relation to the vegetation indexes

Using the same sample grid, leaf reflectance readings were performed using the FieldSpec Hand Held 2 portable spectrometer, with a spectral resolution of 325 and 1075 nanometer and a measuring range of 1 nanometer. The plants were between the phenological stages 75 BBCH (pea-sized grains) and 77 BBCH (Beginning of cluster compaction according to the BBCH scale of Lorenz et al., 1995). No separations were made between the spectral readings of the different varieties, since the manuals and protocols dealing with the collection and analysis of soil and plant tissue in Brazil do not present this level of detail. (Brazilian Society of Soil Science, 2016).

Two field spectral readings methods were performed for each vegetation index, with distinct

vegetative targets. The first was by leaf clip, using a probe attached to the FieldSpec (CP) and the source of electromagnetic radiation from the equipment. The second, by proximal sensing of the canopy of the *Vitis vinifera* L., with the optical input of the sensor do FieldSpec at 1 m distance, with a viewing angle (Wd) of approximately $\pm 25^\circ$, using the electromagnetic energy reflectance of solar radiation (SP). Reflectance readings were performed on the 3 plants closest to the sampling point, on the right and left, with a total of 10 spectral readings for each reading method (CP and SP) across all 74 sampling points. All field spectroscopy measurements (both with clipping - CP and over canopy - SP) were performed on the date of November 15, 2017.

The 17 vegetative indexes selected for this study (Table 1) were chosen because of the spectral range limitation available in FieldSpec Hand Held 2, and were intended only for the analysis of correlations between biophysical variables, biomass and biochemical components with recognized application for agricultural production according to Fomaggio and Sanches (2017).

Table 1 - Vegetation indices selected for application in grape plants (*Vitis vinifera* L.) using bands in the range between 325 and 1075 nanometers.

Spectroradiometer calibration was performed with a Spectralon reference plate with approximate reflectance to that of a perfect Lambertian surface (100% reflectance) (Steffen et al., 1996). Spectral field readings were performed from 11:00 am to 12:45 pm, taking advantage of the smaller solar inclination angle, higher radiant energy flow and adequate weather conditions, with little wind and predominantly cloud-free skies, according to LORD et al. (1988).

Measurement of Soil Apparent Electrical Conductivity (ECa) was performed with a soil conductivity measure system developed by Embrapa Instrumentation (Rabello et al., 2010) at each of the 74 sample points in the field, with readings at depths of 20 and 40 cm.

For analysis of the phyto technical parameters, without considering distinction between varieties, in order to follow the recommendations of chemical, physical and vegetal analysis, all the clusters of the 3 plants closest to each sampling point of the basic grid constructed for soil samples were counted. Each sampling point was represented by 7 plants. We also randomly harvested 3 clusters per plant close to the sampling point (composite sampling), were later weighed in a precision scale (SHIMADZU model AUW2220D), and averaged to obtain cluster mass.

Table 1 - Vegetation indexes selected for application in grape plants (*Vitis vinifera* L.) using bands in the range between 325 and 1075 nanometers.

Vegetation index	Author	Equation
Modified normalized Difference vegetation index (mNDVI)	FUENTES et al., (2001)	$mNDVI = \frac{(R750 - R705)}{(R750 + R705)}$
Improved Vegetation Index (EVI)	Huete et al., (1997)	$EVI = \frac{G\{NIR - RED}{NIR + C1(RED - C2(BLUE + L))\}}$
Photochemical Reflectance Index (PRI)	Gamon, Peñuelas e Field (1992)	$PRI = \frac{(R531 - R570)}{(R531 + R570)}$
Simple Ratio (SR)	Jordan, (1969)	$SR = \frac{NIR}{RED}$
Red Green Ratio (RGR)	Fuentes et al., (2001)	$RGR = \frac{(R600 - R699)}{(R500 - R599)}$
Normalized Difference Vegetation Index (NDVI)	Rouse et al., (1974)	$NDVI = \frac{(NIR - RED)}{(NIR + RED)}$
Normalized Pigment Vegetation Index (NPCI)	Peñuelas, Baret e Filela, (1995)	$NPCI = \frac{(R680 - R430)}{(R680 + R430)}$
Simple Pigment Ratio Index (SRPI)	Zarco-Tejada, (2000)	$SRPI = \frac{(R430)}{(R680)}$
Intensive Structure Pigment Index (SIPI)	Zarco-Tejada, (2000)	$SIPI = \frac{(R800 - R445)}{(R800 - R680)}$
Pigment Index 1 (PI1)	Zarco-Tejada, (2000)	$PI1 = \frac{(R695)}{(R422)}$
Pigment Index 2 (PI2)	Zarco-Tejada, (2000)	$PI2 = \frac{(R695)}{(R760)}$
Pigment Index 3 (PI3)	Lichtenthaler et al., (1996)	$PI3 = \frac{(R440)}{(R690)}$
Sum of Reflectances in Green (SGR)	Fuentes et al., (2001)	$SGR = \sum_{n=500}^{599} R_n$
Senescent Plant Reflectance Index (PSRI)	Merzlyak et al., (1999)	$PSRI = \frac{(R680 - R500)}{(R750)}$
Plant Reflectance Index Anthocyanins (ARI)	Gitelson, Merzlyak, Chivkunova, (2001)	$ARI1 = \left(\frac{1}{R550}\right) - \left(\frac{1}{R700}\right)$
Plant Water Index (PWI)	Peñuelas et al., (1997)	$PWI = \frac{(R900)}{(R970)}$
Normalized Phaeophytinization Index (NPQI)	Zarco-Tejada (2000)	$NPQI = \frac{(R415 - R435)}{(R415 + R435)}$

The phytotechnical parameters for this study were: Average yield per sampling point - PM, Productivity per sampling point - Prod., (Grams / point) and Average mass of bunches per sampling point - MMC, (bunches / g). Clusters of all varieties were collected during the 2018 harvest, between 18 and 19 January in the 89 BBCH phenological phase (full maturation), according to the phenological classification of Lorenz et al. (1995).

For the analysis of the oenological parameters, about 222 bunches were collected in 3

hectares of the study area, obeying the sample grid, without considering differences between the varieties.

Chemical analysis of the grape was carried out in the chemistry laboratory of the experimental station of Embrapa Uva e Vinho - Vacaria RS, evaluating: Total Soluble Solids (TSS), using a Portable Digital Refractometer (model Pal-1), and Titratable Acidity in Organic Acid (TA) using the titration technique according to the methodology described by the Adolfo Lutz Institute (1985).

Physicochemical variables and vegetation indexes were tabulated in spreadsheets and the

classical descriptive statistical analysis was performed using the statistical software IBM SPSS (Statistics version 12), and the basic statistics of the variables were calculated. Data frequency distribution normality was tested by the non-parametric Kolmogorov-Smirnov dependence test, given the critical value level of $P > 0.5$, as proposed by Ferreira, (2014). The results of the coefficient of variation (CV) were compared with those suggested by Gomes (1985) for experiments on agricultural crops, considering low CV those below 10%; average when CV is between 10 and 20%; High CV when it is between 20 and 30%; and very high when the CV is over 30%. Analysis of the raw data was performed through histograms and boxplot, identifying anomalous values and eliminating those that did not represent reality, according to Molin et al., (2015). Pearson's linear correlation coefficient (r) at the 5% level was applied to identify possible associations between the searched parameters and correlation coefficient ranges were interpreted based on the magnitude classification proposed by Ferreira, (2014).

RESULTS AND DISCUSSION

Table 2 shows the data of the variables with normal distribution tested by the non-parametric Kolmogorov-Smirnov dependence test, given the critical value level of $P > 0.5$, as proposed by Ferreira, (2014).

Of the 31 variables that achieve normality, 139 significant correlations were obtained, with 68 cases of positive correlation ranging from 0.235 to 0.572 and 71 cases of negative coefficients (inversely proportional) ranging from -0.565 to -0.230.

Pearson's simple linear correlation coefficients obtained from the analysis were interpreted based on 7 categories according to Ferreira's correlation magnitude classification, (2014), with 65 significant correlations with moderate magnitudes, being 29 moderate positive and 36 moderately negative.

The vegetation indexes (VIs) that presented the highest number of correlations by Pearson in relation to the parameter of agronomic variables tested were SR-SP, NPQI-SP and P11-SP, with 14 significant correlations each. Considering the magnitude of the results, the vegetation indexes with the highest number of moderate positive significant correlations were: mNDVI-CP, PRI-CP, mNDVI-SP, P11-SP and ARI-SP, presenting 4 correlations each, while SR-SP obtained the highest number of negative moderate correlations with 5 significant correlations.

The PRI-CP, mNDVI CP and SP indices obtained the highest significant moderate positive

correlations on the same parameters of the soil (Ca, Mg, CTC Efet. And CTC pH 7.0), all related to the soil pH, however they did not obtain responses from well-differentiated bands of the spectrum, green in the case of PRI and red in the case of mNDVI. Since the mNDVI-SP allows the canopy to be monitored proximally, it can be useful as an indication of management zones linked to these parameters in an expeditious manner, but with good efficiency. PI-1 and ARI, in the SP condition, were more related to potassium, both in leaf and soil, allowing the proposition of specific management zones for this element and, since they were also correlated with copper in plant tissue, they can be used as indicators of regions with problems of excess of this micro element during canopy sensing. This relationship probably occurs within the scope of the green band in the spectrum, where both indices use values in common, since the other values end up being at the opposite ends of the light spectrum. The highest Pearson correlation coefficient of the EVI-CP index occurred with the texture variables of soil physical analysis at a depth of 20-40 cm (Table 1). In this case, Clay had a negative correlation coefficient of -0.310 and Silt had a positive correlation of 0.310, so both obtained the coefficient of determination (r^2) of 0.096, ie 99.9% of the total variation remained unexplained showing a weak correlation trend.

EVI-CP index also had a weak positive magnitude correlation with the Mn of plant tissue analysis, with a coefficient of 0.250. According to Justice et al. (1998), the EVI (Enhanced Vegetation Index) index is correlated with biomass, presenting canopy response, making it indicative of the dynamic biophysical properties related to the productivity and the energy balance of the vegetation. Ponzoni et al. (2012) have also demonstrated the ability of the EVI vegetation index for remote sensing to detect biomass in vegetation. Huete; Justice and Liu (1994); Huete; Liu; Batchily and Van Leeuwen (1997) pointed out that the EVI index improves detection sensitivity in regions with higher biomass, reducing the influence of soil and atmosphere signal on canopy response.

The Photochemical Reflectance Index (PRI) Vegetation Index was proposed by Gamon et al., (1999) as an indicator of the deoxidation status of xanthophyll pigments related to photosynthetic processes, having the potential to provide continuous global monitoring of primary plant productivity (FORMAGGIO and SANCHES, 2017). PRI-CP obtained 8 correlations, being 4 moderate positive correlations with Ca, Mg, Effective CEC and CEC pH 7.0 from the soil chemical analysis at the depth

Table 2 - Pearson (r) linear correlation between vegetation indexes and plant tissue variables, soil physics and soil chemistry.

Vegetation Indexes	Plant tissue								
	Nitrogen (%) m/m	Potassium (%) m/m	Zinc (mg/kg)	Manganese (mg/kg)	Boron (mg/kg)				
mNDVI CP	-0.271*	-0.249*	-0.110ns	-0.356ns	-0.363*				
EVI CP	-0.068ns	0.135ns	0.160ns	0.250*	0.220ns				
PRI CP	-0.214ns	-0.379*	-0.204ns	-0.325*	-0.228ns				
ARI CP	-0.374*	0.221ns	-0.123ns	-0.294*	-0.402*				
SR SP	-0.230*	-0.401*	-0.447*	-0.424*	-0.415*				
mNDVI SP	-0.305*	-0.267*	-0.436*	-0.407*	-0.441*				
RGR SP	-0.286*	-0.160ns	-0.402**	-0.405**	-0.424**				
NPQI SP	-0.065ns	-0.412*	-0.223ns	-0.316*	-0.287*				
PI1 SP	0.106ns	0.460*	0.259*	0.295*	0.261*				
PI2 SP	0.260*	0.335*	0.428*	0.376*	0.375*				
PI3 SP	-0.025ns	-0.506**	-0.266*	-0.249*	-0.169ns				
ARI SP	0.007ns	0.566*	0.280*	0.291*	0.197ns				
Vegetation Indexes	Soil physics								
	0 - 20 cm depth		Depth 20 - 40 cm						
	Moisture (g/g)	Silt (%)	Moisture (g/g)	Silt (%)	Clay (%)				
mNDVI CP	-0.193 ^{ns}	0.044 ^{ns}	-0.241*	0.235*	-0.179 ^{ns}				
EVI CP	0.060 ^{ns}	0.199 ^{ns}	0.113 ^{ns}	0.310*	-0.310*				
PRI CP	-0.100 ^{ns}	0.164 ^{ns}	-0.151 ^{ns}	0.165 ^{ns}	-0.137 ^{ns}				
ARI CP	-0.194 ^{ns}	0.252*	-0.220 ^{ns}	0.070 ^{ns}	-0.091 ^{ns}				
SR SP	-0.056 ^{ns}	0.022 ^{ns}	-0.158 ^{ns}	0.110 ^{ns}	-0.104 ^{ns}				
mNDVI SP	-0.025 ^{ns}	0.129 ^{ns}	-0.171 ^{ns}	0.155 ^{ns}	-0.177 ^{ns}				
RGR SP	-0.034 ^{ns}	0.248*	-0.159 ^{ns}	0.198 ^{ns}	-0.218 ^{ns}				
NPQI SP	-0.265*	-0.037 ^{ns}	-0.302*	0.060 ^{ns}	-0.008				
PI1 SP	0.183 ^{ns}	-0.100 ^{ns}	0.285*	-0.173 ^{ns}	0.138 ^{ns}				
PI2 SP	0.022 ^{ns}	-0.100 ^{ns}	0.163 ^{ns}	-0.149 ^{ns}	0.154 ^{ns}				
PI3 SP	-0.155 ^{ns}	0.001 ^{ns}	-0.255*	0.117 ^{ns}	-0.078 ^{ns}				
ARI SP	0.166 ^{ns}	0.114 ^{ns}	0.253*	-0.066 ^{ns}	0.014 ^{ns}				
Vegetation Indexes	Soil chemistry								
	0 - 20 cm depth					Depth 20 - 40 cm			
	Potassium (mg/dm ³)	Calcium (cmol/dm ³)	Magnesium (cmol/dm ³)	CEC Efet. (cmol/dm ³)	CEC pH7 (cmol/dm ³)	Copper (mg/dm ³)	Potassium (mg/dm ³)	CEC pH7 (mg/dm ³)	Copper (mg/dm ³)
mNDVI CP	-0.495*	0.479*	0.501*	0.491*	0.474*	-0.208 ^{ns}	-0.534*	0.246*	-0.165 ^{ns}
EVI CP	-0.015 ^{ns}	0.123 ^{ns}	0.088 ^{ns}	0.120 ^{ns}	0.118 ^{ns}	-0.089 ^{ns}	-0.106 ^{ns}	0.198 ^{ns}	-0.031 ^{ns}
PRI CP	-0.565*	0.521*	0.528*	0.538*	0.572*	-0.554*	-0.520*	0.376*	-0.484*
ARI CP	-0.107 ^{ns}	0.360*	0.273*	0.367*	0.260*	-0.018 ^{ns}	-0.049 ^{ns}	-0.045 ^{ns}	0.030 ^{ns}
SR SP	-0.454*	0.455*	0.432*	0.471*	0.534*	-0.343*	-0.346*	0.306*	-0.252*
mNDVI SP	-0.471*	0.498*	0.440*	0.508*	0.505*	-0.255*	-0.375*	0.280*	-0.138 ^{ns}
RGR SP	-0.447*	0.433*	0.351*	0.435*	0.385*	-0.183 ^{ns}	-0.304*	0.179 ^{ns}	-0.106 ^{ns}
NPQI SP	-0.450*	0.277*	0.255*	0.308*	0.375*	-0.472*	-0.240*	0.342*	-0.389*
PI1 SP	0.546*	-0.409*	-0.352*	-0.425*	-0.494*	0.474*	0.325*	-0.339*	0.420*
PI2 SP	0.446*	-0.484*	-0.446*	-0.500*	-0.545*	0.325*	0.321*	-0.311*	0.217 ^{ns}
PI3 SP	-0.465*	0.329*	0.292*	0.350*	0.454*	-0.491*	-0.268*	0.322*	-0.448*
ARI SP	0.460*	-0.335*	-0.333*	-0.359*	-0.484*	0.502*	0.316*	-0.336*	0.434*

*Significant correlation at 5% probability level; ** significant correlation at the 1% probability level; ns not significant.

of 0-20 cm and 4 moderate negative correlations with K and Cu of the chemical soil analysis at two depths (0-20 and 40-20 cm). The highest significant correlation coefficient correlated with the PRI – CP index occurred with the CEC pH 7.0 at a depth of 0-20 cm (Table 1), with a value of 0.572 positive moderate correlation and coefficient of determination (r^2) equal 0.327, ie 68% of the total variation remains unexplained, showing a moderate trend of correlation. In this experiment, the highest negative value of the isolated correlation coefficient occurred with PRI – CP correlated with K for a depth of 0-20 cm, reaching a moderate negative correlation of -0.565, with a r^2 value of 0.320, ie, 68% of the total variation remains unexplained.

The vegetation index ARI-CP showed 8 correlations, with only a moderate magnitude in relation to Boron of chemical analysis of plant tissue, reaching a negative moderate correlation of -0.402, and the coefficient of determination (r^2) equal to 0.162, or ie 84% of the total variation remains unexplained. The vegetation index ARI (Anthocyanin Reflectance Index) has been used to detect higher concentrations of anthocyanin in vegetation, allowing to specialize the concentrations of this chemical parameter, according to the authors Gitelson; MerzLyak; Chivkunova (2001).

The vegetation index SR-SP obtained 9 simple linear correlations, being 4 correlations with moderate positive magnitude with the variables Ca, Mg, Effective CTC and CTC pH 7.0 from soil chemical analysis at 0-20 cm depth and 5 correlations. moderate negative results with K, Zn, Mg and B of the chemical analysis of the plant tissue and K of the chemical analysis of the soil at a depth of 0-20 cm.

The highest significant correlation of the SR-SP index occurred with the soil CEC at pH 7.0 at a depth of 0-20 cm (Table 1), presenting a moderate positive correlation coefficient (0.534), and the coefficient of determination (r^2) equal to 0.285, ie 72% of the total variation remains unexplained. According to Jordan (1969), the SR index (simple ration) correlates with the vegetation cover, based on the principle that the leaves absorb relatively more the red light range than the infrared light; and therefore, the more leaves are present in the canopy, the greater the proportion.

The vegetation index mNDVI-SP obtained 13 correlations, with 4 moderately positive correlations with soil chemical analysis K, Ca, Mg, Effective CTC and pH 7.0 pH at 0-20 cm depth, 4 moderately negative correlations with Zn, Mg, B of the chemical analysis of the plant tissue and a

correlation with the variable K of the chemical analysis of the soil at a depth of 0-20 cm.

The highest significant correlation coefficient, correlated with the mNDVI-SP index, occurred with the Effective Soil CTC variable at a depth of 0-20 cm (Table 1), with a positive moderate correlation coefficient of 0.508 and determination coefficient (r^2). equal to 0.241, ie 76% of the total change remains unexplained. Proposed by Fuentes et al., (2001) the vegetation index mNDVI (Modified NDVI) correlates with leaf chlorophyll content. For Jurgens (1997), this vegetation index can be used to determine the damage caused by frost on agriculture based on Landsat TM data. The RGR-SP vegetation index reached 11 simple linear correlations, being 2 moderate positive correlations with the variables Ca and CTC Effective soil at a depth of 0-20 cm; 4 moderate negative correlations, being Zn, Mg and K of plant tissue and K in the 0-20 cm depth. The highest significant correlation coefficient, correlated with the RGR-SP index, occurred with variable K at a depth of 0-20 cm (Table 1), with a value of -0.447, and a determination coefficient (r^2) equal to 0.20,; ie, 80% of the total variation remains unexplained.

Gamon, et al. (1999) highlighted the correlation of the RGR index with anthocyanin, being reinforced by the proposition of Fuentes et al., (2001) with the content of chlorophylls and anthocyanins. The NPQI-SP vegetation index obtained 3 negative correlations with K of the vegetal tissue and K and Cu of the soil in the 0-20 cm depth. The highest correlation coefficient occurred with Cu at a depth of 0-20 cm (Table 1), with a moderate negative correlation of -0.472, with its coefficient of determination (r^2) equal to 0.223, ie 78% of the total variation. remain without explanation.

According to Zarco-Tejado (2000) the NPQI (Normalized Phaeophytinization) vegetation index correlates with chlorophyll degradation and early stress detection. The vegetation index P11-SP reached 14 simple linear correlations, being 3 moderate positive correlations with the variables K of the chemical analysis of the vegetal tissue and K and Cu of the chemical analysis of the soil in the depth of 0-20 cm; 3 moderate negative correlations with the soil chemical analysis K, Effective CEC and CEC pH 7.0 variables at 0-20 cm depth.

The highest correlation coefficient obtained by P11-SP occurred with soil's K at a depth of 0-20 cm (Table 1), with a positive moderate correlation of 0.546 and a determination coefficient (r^2) equal to 0.298, ie. 71% of the total variation remains unexplained.

According to Zarco-Tejado (2000) the vegetation index PI1 (Pigment index) correlates with the stress state of the plant. For the PI2-SP vegetation index there were 13 correlations, 2 moderately positive correlations with plant tissue Zn and soil K at 0-20 cm depth and 4 moderately negative correlations with soil variables (K, Ca, Mg, Effective CEC and CEC pH 7.0) at a depth of 0-20 cm.

The highest coefficient occurred with CEC pH 7.0 at the 0-20 cm depth of soil chemical analysis (Table 1), with a moderate negative correlation of -0.545 and a determination coefficient (r^2) equal to 0.297; ie, 71 % of total variation remain unexplained.

According to Zarco-Tejado (2000) the vegetation index PI2 (Pigment index) correlates with the stress state of the plant. With the vegetation index PI3-SP there were 12 correlations, being a moderate positive correlation with the soil CTC variable at pH 7.0 of soil chemical analysis at 0-20 cm depth and 4 moderate negative correlations with the variables: Zn of plant tissue; K of soil at 0-20cm depth and Cu of soil at both depths (0-20 and 20-40 cm).

The highest significant correlation coefficient occurred with plant tissue content of K (Table 1), with a negative correlation coefficient of -0.506 and a determination coefficient (r^2) equal to 0.256, ie 75% of the total variation remained unexplained.

For Lichtenthaler et al. (1996) the PI3 vegetation index (Pigment index) is a vegetation health index and correlates with chlorophyll fluorescence. The vegetative index ARI-SP had 13 simple linear correlations, being 4 correlations moderately positive with the variables tissue content of K, soil content of K and Cu at a depth of 0-20 cm and Cu in the soil at 20-40 cm, and a moderately negative correlation for the variable soil CTC at pH 7.0 at a depth of 20-40 cm.

The highest correlation coefficient occurred with K content in the tissue, with a positive moderate correlation of 0.566 and a determination coefficient (r^2) of 0.321, that is, 68% of the total variation was still unexplained.

CONCLUSION

Significant correlations were observed between the vegetation indexes tested and the attributes of the soil and the plant in the vineyard, demonstrating its potential to assist in planning the collection of targeted laboratory samples, or even in supporting the generation of management zones for further analysis.

In the case of the absence of laboratory resources, Vegetation Indexes that obtained moderate

to significant correlations with the analyzed soil and plant parameters can still serve as a support for decision making, until it is possible to carry out the necessary confirmatory analyzes.

The vegetation indexes that presented the highest correlation coefficient of Pearson (r) at 5% of significance and moderate magnitudes, aiming to support decision making in precision viticulture were: mNDVI-CP with K of soil chemical analysis at depth. 20-40 cm, with negative correlation coefficient of -0.534; mNDVI-SP with positive correlation of 0.508 with Effective CEC of soil at depth of 0-20 cm; ARI-CP with negative correlation of -0.402 with Boron of plant tissue; SR-SP with positive correlation of 0.534 with CEC pH 7.0 of soil at 0-20 cm depth; RGR-SP with negative correlation of -0.447 with soil K at a depth of 0-20 cm; NPQI-SP with negative correlation of -0.472 with Cu of soil at depth of 0-20 cm; PI1-SP with positive correlation of 0.546 with soil K at 0-20 cm depth; PI2-SP with negative correlation of -0.545 with CEC pH 7.0 of soil at depth of 0-20 cm; PI3-SP with negative correlation of -0.506 with K of plant tissue; ARI-SP with positive correlation of 0.566 cm K of plant tissue and, finally, PRI-CP, with positive correlation coefficient of 0.572 with CEC pH 7.0 of soil at depth of 0-20 cm, and coefficient negative correlation of -0.565 with the K of soil chemical analysis at a depth of 0-20 cm.

ACKNOWLEDGEMENTS

This work was supported by Empresa Brasileira de Pesquisa Agropecuária (Embrapa) through project number 11.14.09.001.02.00 (Enabling Technologies 2 for Automation and Precision Agriculture: fruit and coffee) and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for supporting the publication (Finance code 001).

DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

REFERENCES

BRAMLEY, R. G. V.; HAMILTON, R. P. Understanding variability in wine grape production systems 1. Within vineyard

- in yield over several vintages. **Australian Journal of Grape and Wine Research**, 2004, p. 32-35. Available from: <<https://doi.org/10.1111/j.1755-0238.2004.tb00006.x>>. Accessed: Nov. 20, 2020. doi: 10.1111/j.1755-0238.2004.tb00006.x.
- BRAMLEY, R. G. V.; PROFFITT, A. P. B. Managing variability in viticultural production. **The Australian & New Zealand Grapegrower Grape grower & Winemaker**, n.427, 1999, p.11-16. Available from: <<http://www.nwvineyards.net/docs/PVProfitabiltyPaper.pdf>>. Accessed: Nov. 20, 2020. doi: 10.1533/9781845699284.3.445.
- BROWN, R. B.; Let al. Using grape leaf reflectance for spatially variable vineyard management, **ASAE Annual intentional Meeting**, Ottawa, Canada, 2004, p.563-571. Available from: <<http://hdl.handle.net/10938/20331>>. Accessed: Nov. 22, 2020. doi: 10.13031 / 2013.17056.
- CASS, A. Viticultura de precisión: Introducción y objetivos Viticultura de Precisión. In: **Viticultura de precisión**, 8. Madrid: Fundación para la Cultura del Vino, 2013. Available from: <http://culturadelvino.org/fcv/wp-content/uploads/pdf/encuentros/encuentro_2013.pdf>. Accessed: Oct. 15, 2020.
- CEROVIC, Z. G.; et. al. A new optical leaf-clip meter for simultaneous non-destructive assessment of leaf chlorophyll and epidermal flavonoids. **Physiologia Plantarum, Blackwell Publishing Ltd**, 146, 251-260. 2012. Available from: <<http://dx.doi.org/10.1111/j.1399-054.2012.01639.x>>. Accessed: Sept. 24, 2020. doi: 10.1111/j.1399-054.2012.01639.x.
- COMISSÃO DE QUÍMICA E FERTILIDADE DO SOLO RS/ SC. **Manual de Calagem e Adubação para os estados do Rio Grande do Sul e de Santa Catarina, sociedade brasileira de ciência do solo**. Núcleo Regional Sul, Comissão de química e fertilidade do solo, 376p, 11a edição, 2016.
- ESSER, A. A. **Aplicaciones de la viticultura de precisión en Chile**. Trabajo de finalización del curso (Graduación en Agronomía) - Pontificia Universidad Católica de Chile. Santiago. 2002. 26 p.
- FERREIRA, M. C. **Iniciação a análise geoespacial: teoria técnicas e exemplos para geoprocessamento**, 1 ed São Paulo, editora UNESP, 2014, 344p.
- FLORES, C. A.; ALBA, J. M. F.; LEVIEN, H. F.; ZARNOTT, D. H.; MIELE, A.; PAVAN, C. Levantamento detalhado dos solos e a viticultura de precisão. In: CONGRESSO BRASILEIRO DE CIÊNCIA DO SOLO, 33. 2011, **Uberlândia, XXXIII Congresso brasileiro de ciência do solo**. Uberlândia: SBCS 2011. Available from: <<https://www.alice.cnptia.embrapa.br/bitstream/doc/901983/1/13151.pdf>>. Accessed: Sept. 13, 2020.
- FORMAGGIO, A. R.; SANCHES, I. D. Sensoriamento remoto em agricultura. **Oficina de Textos**, 2017.
- FUENTES, D. A.; et al. Mapping Canadian boreal forest vegetation using pigment and water absorption features derived from the AVIRIS sensor. **Journal of geophysical Research**, v.106, 2001, p.33565-33577. Available from: <<https://doi.org/10.1029/2001JD900110>>. Accessed: Nov. 29, 2020. doi: 10.1029/2001JD900110.
- GAMON, J.A.; PEÑUELAS, J.; FIELD, C. B. A narrow-waveband spectral index that tracks diurnal changes in photosynthetic efficiency. **Remote Sensing of Environment**, v.41, ed. 1, 1992, p 35-44. Available from: <[https://doi.org/10.1016/0034-4257\(92\)90059-S](https://doi.org/10.1016/0034-4257(92)90059-S)> . Accessed: Sept. 05, 2020. doi: 10.1016/0034-4257(92)90059-S.
- GAMON, J. A.; SURFUS, J. S. Assessing leaf pigment content and activity with a reflectometer. **The New Phytologist**, v.143, n.1, p.105-117, 1999. Available from: <<https://doi.org/10.1046/j.1469-8137.1999.00424.x>>. Accessed: Nov. 02, 2020. doi: 10.1046/j.1469-8137.1999.00424.x.
- GITELSON, A. A.; et al., Optical properties and nondestructive estimation of anthocyanin content in plant leaves. **Photochemistry and photobiology**, v.74, n.1, 2001, p.38-45. Available from: <[https://doi.org/10.1562/0031-8655\(2001\)0740038OPANE02.0.CO2](https://doi.org/10.1562/0031-8655(2001)0740038OPANE02.0.CO2)> . Accessed: Oct.29, 2020. doi: 10.1562/0031-8655(2001)0740038OPANE02.0.CO2.
- GOMES, F P. **Curso de estatística experimental**. Editora Nobel, Piracicaba, 1985, 466 p.
- GUO, J. and TROTTER, C.M. 2004. Estimating photosynthetic light-use efficiency using the photochemical reflectance index: variations among species. **Functional Plant Biology**, 31, 255-565. Available from: <<https://doi.org/10.1071/FP03185>>. Accessed: nov. 05, 2020. doi: 10.1071/FP03185.
- HALL, A., LOUIS, J. AND LAMB, D. (2003) Characterizing and mapping vineyard canopy using high-spatial resolution aerial multispectral images. **Computers & Geosciences**, 2003, p.813-822. Available from: <[https://doi.org/10.1016/S0098-3004\(03\)00082-7](https://doi.org/10.1016/S0098-3004(03)00082-7)>. Accessed: Nov. 16, 2020. doi: 10.1016/S0098-3004(03)00082-7.
- HERRERA, J; GUESALAGA, A.; AGOSIN, E. Shortwave–near infrared spectroscopy for non-destructive determination of maturity of wine grapes. **Measurement Science and Technology**, v.14, n.5, 2003, p. 689-697. Available from: <<https://doi.org/10.1088/0957-0233/14/5/320>>. Accessed: Oct. 30, 2020. doi: 10.1088/0957-0233/14/5/320.
- HUETE, A. R.; et al., A comparison of vegetation indexes over a global set of TM images for EOS-MODIS. **Remote Sensing of Environment**, 59, 440–451. 1997. Available from: <<https://www.fsantos.utad.pt/bibliografia/A-comparison-of-vegetation-indices-over.pdf>>. Accessed: Nov. 20, 2020. doi: 10.1016/S0034-4257(96)00112-5.
- HUETE, A.; JUSTICE, C.; & LIU, H. Development of vegetation and soil indexes for MODIS-EOS. **Remote Sensing of Environment**, 49, 224– 234. 1994. Available from: <[https://doi.org/10.1016/0034-4257\(94\)90018-3](https://doi.org/10.1016/0034-4257(94)90018-3)> . Accessed: Nov. 20, 2020. doi: 10.1016/0034-4257(94)90018-3.
- INSTITUTO ADOLFO LUTZ – IAL. **Normas analíticas, métodos químicos e físicos para análise de alimentos**. 3 ed. São Paulo, v.1, 1985. 533 p.
- JORDAN, C. F. Derivation of leaf area index from quality of light on the forest floor. **Ecology**, v.50, n.4, 1969, p.663-666. Available from: <<https://doi.org/10.2307/1936256>>. Accessed: Nov. 20, 2020. doi: 10.2307/1936256.
- JURGENS, C. The modified normalized difference vegetation index (mNDVI) a new index to determine frost damages in agriculture based on landsat TM data. **International Journal of Remote Sensing**. v.18, n.17, p.3583-3594, 1997. Available from:

<<https://doi.org/10.1080/014311697216810>>. Accessed: Nov. 22, 2020. doi: 10.1080/014311697216810.

JUSTICE, C. O.; et. Al. Moderate resolution imaging spectroradiometer (modis): Land remote sensing for global change research. **IEEE transactions on geosciences and remote sensing**, 1998. v.36, n.4, p.1228-1247. 10.1109/36.701075.

LACAR, F.; LEWIS, M. & GRIERSON, I. 2001. Use of hyperspectral reflectance for discrimination between grape varieties. **Geoscience and Remote Sensing Symposium**, 2001. IGARSS '01. IEEE 2001 International, v.6, p.2878-2880. Available from: <<https://doi.org/10.1109/IGARSS.2001.978192>>. Accessed: Oct. 30, 2020. doi: 10.1109/IGARSS.2001.978192.

LICHTENTHALER, H. K.; et al., Detection of vegetation stress via a new high resolution fluorescence imaging system. **J. Plant Physiol.**, 106 (1996), p.1127-113. Available from: <[https://doi.org/10.1016/S0176-1617\(96\)80081-2](https://doi.org/10.1016/S0176-1617(96)80081-2)>. Accessed: Sept. 29, 2020. doi: 10.1016/S0176-1617(96)80081-2.

LORD, D.; DESJARDINS, R.L.; DUBÉ, P.A. Sun-angle effects on the red and near infrared reflectances of five different crop canopies. **Canadian Journal of Remote Sensing**, Ottawa, v.14, p.46-55, 1988. Available from: <<https://doi.org/10.1080/07038992.1988.10855118>>. Accessed: Oct. 12, 2020. doi: 10.1080/07038992.1988.10855118.

LORENZ, D. H.; et al., Phenological growth stages of the grapevine (*Vitis vinifera* L. ssp. *vinifera*): Codes and descriptions according to the extended BBCH scale. **Australian Journal of Grape and Wine Research**, Adelaide, v.1, p.100-103, 1995. Available from: <<https://doi.org/10.1111/j.1755-0238.1995.tb00085.x>>. Accessed: Nov. 12, 2020. doi: 10.1111/j.1755-0238.1995.tb00085.x.

MANUAL DE ANÁLISES QUÍMICAS DE SOLOS, PLANTAS E FERTILIZANTES / editor técnico, Fábio Cesar da Silva. - 2. ed. rev. ampl. - Brasília, DF: **Embrapa Informação Tecnológica**, 2009. 627 p.: il.; 22 cm x 16 cm.

MARCUSSI, A. B.; BUENO, C. R.P.; MIQUELONI, D. P.; ARRAES, C. L. Use of index vegetation for the geographic information system. **Caminhos de geografia**, v.11, n.35, 2010. Available from: <<http://www.seer.ufu.br/index.php/caminhosdegeografia/article/view/16000>>. Accessed: Sept. 29, 2020.

MERZLYAK, M. N.; GITELSON, A. A.; CHIVKUNOVA, O. B.; RAKITIN, V. Y. U. Non-destructive optical detection of pigment changes during leaf senescence and fruit ripening. **Physiol Plantarum**, v.106, n.1, p.135-141, 1999. Available from: <<https://onlinelibrary.wiley.com/doi/abs/10.1034/j.1399-3054.1999.106119.x>>. Accessed: Oct. 01, 2020. doi: 10.1034/j.1399-3054.1999.106119.x.

MIELE, A.; FLORES, C. A.; ALBA, J. M. F. Efeito da variabilidade espacial de solos do Vale dos Vinhedos na composição do vinho Merlot – Safra 2012. **Agricultura de Precisão: resultados de um novo olhar**. p.361 – 367. 2014. Available from: <<http://www.alice.cnptia.embrapa.br/alice/handle/doc/986570>>. Accessed: Nov. 30, 2020.

MOLIN, J. P., AMARAL, L. R., COLAÇO, A. F. **Agricultura de precisão**. 1. Ed. São Paulo: Oficina de Textos, 2015. 119-130 p.

PEEL, M. C. FINLAYSON, B. L. MCMAHON, T. A. Updated world map of the Köppen-Geiger climate classification. **Hydrology and Earth System Sciences Discussions, European Geosciences**

Union, 2007, 4 (2), pp.439-473. Available from: <<https://hal.archives-ouvertes.fr/hal-00298818/>>. Accessed: Nov. 12, 2020.

PEÑUELAS, J.; BARET, F.; FILELLA, I. Semiempirical indices to assess carotenoids/chlorophyll a ratio from leaf spectral reflectance. **Photosynthetica, Dordrecht**, v.31, 1995, p.221-230. Available from: <https://www.researchgate.net/publication/229084513_SemiEmpirical_Indices_to_Assess_CarotenoidsChlorophyll-a_Ratio_from_Leaf_Spectral_Reflectance>. Accessed: Sept. 30, 2020. doi: 0000-0002-7215-0150.

PEÑUELAS, J. et al. Estimation of plant water concentration by the reflectance water index WI (R900/ R970). **International Journal of Remote Sensing, Abingdon**, v.18, n.13, 1997, p.2869-2875. Available from: <<https://doi.org/10.1080/014311697217396>>. Accessed: Oct. 17, 2020. doi: 10.1080/014311697217396.

PEREIRA, T. P. et al. O clima da Região dos Campos de Cima da Serra, Rio Grande do Sul: condições térmicas e hídricas. **Pesquisa Agropecuária Gaúcha**, Porto Alegre, v.15, n.2, p.145-157, 2009. Accessed: 20 jul. 2019. Available from: <<http://revistapag.agricultura.rs.gov.br/ojs/index.php/revistapag/article/view/190/161>>. Accessed: Nov. 12, 2020.

PONZONI, F. J.; SHIMBUKURO, Y. E.; KUPLICH, T. M. **Sensoriamento Remoto da Vegetação**. São José dos Campos, SP, Oficina de Textos, 2ª edição, 176 p., 2012.

PROFFITT, T.; BRAMLEY, R.; LAMB, D.; WINTER, E. **Precision viticulture: A new era in vineyard management and wine production**. Ashford: Winetitles, 2006. 90 p. Available from: <<https://hdl.handle.net/1959.11/786>>. Accessed: Sept. 12, 2020.

RABELLO, L. M.; INAMASU, R. Y.; BERNARDI, AC de C. **Sistema de medida de condutividade elétrica do solo**. Embrapa Instrumentação-Circular Técnica (INFOTECA-E), 2010. <<https://www.infoteca.cnptia.embrapa.br/bitstream/doc/884863/1/Cit542010.pdf>>.

RIBEIRO, J. R.; DIGGLE, P. J. A package for geostatistical analysis. **R-NEWS**, v.1, n.2. 2001. ISSN 1609-3631. Available from: <<http://cran.r-project.org/doc/Rnews>>. Accessed: Oct. 10, 2020.

ROBERTSON, G. P. **Geostatistics for the environmental sciences (version 5.1 for windows) – GS+ User's Guide**. Plainwell, Gamma Design Software, 1998. 152p.

ROUSE Jr, J. W.; HASS, R. H.; SCHELL, J. A.; DEERING, D. W. **Monitoring vegetation systems in the Great Plains with ERTS**. 1974. Available from: <<https://ntrs.nasa.gov/api/citations/19740022614/downloads/19740022614.pdf>>. Accessed: Nov. 20, 2020.

SETHURAMASAMYRAJA, B.; SACHIDHANTHAM, S.; WAMPLE, R. Geospatial modeling of wine grape quality indicators (anthocyanin) for development of differential wine grape harvesting technology, **International Journal Geomatics and Geosciences**. v.1, n.3, Fresno, USA, 2010. Available from: <<http://www.ipublishing.co.in/jggsvol1no12010/EIJGGS2008.pdf>>. Accessed: Sept. 20, 2020.

SMIT, J. L.; SIHOLE, G.; STREVER, A. E. Vine signal extraction: an application of remote sensing in precision viticulture. **S. Afr. J. Enol. Vitic.** 31(2), 65-74. Available from: <<http://hdl.handle.net/10019.1/8420>>. Accessed: Sept. 21, 2020. doi: 10019.1/8420. 2010.

STEFFEN, C. A. et.al. Técnicas radiométricas com o Spectron SE-590. **Simpósio Brasileiro de Sensoriamento Remoto**, v.8, 1996, p.9-14. Available from: <<http://marte.sid.inpe.br/attachment.cgi/sid.inpe.br/deise/1999/02.01.11.01/doc/T177.pdf>>. Accessed: Nov. 20, 2020.

WAMPLE, R. L.; MILLS, L.; DAVENPORT, J. R. Use of precision farming practices in grape production. In: **International Conference On Precision Agriculture**, 4. 1998, Saint Paul, Estados Unidos. Minneapolis: University of Minnesota, 1999. p.897-905. Available from: <<https://onlinelibrary.wiley.com/doi/abs/10.2134/1999.precisionagproc4.c86>>. Accessed: Oct. 08, 2020.

XUE, Y.LI. Y.; GUANG, J.; ZHANG, X.; GUO, J. Small satellite remote sensing and applications – history, current and future. **International journal of remote sensing**, v.29,

n.15, 2008. p.4339-4372. Available from: <<https://doi.org/10.1080/01431160801914945>>. Accessed: Sept. 08, 2020. doi: 10.1080/01431160801914945.

ZARCO-TEJADA, P. J. Hyperspectral remote sensing of closed Forest canopies: Estimation of chlorophyll fluorescence and pigment content. **PhD thesis, graduate programme in earth and space science**, York university, Toronto, Ontario, Canada, 2000. 210p. Available from: <https://quantalab.ias.csic.es/pdf/PhD_thesis_zarco_tejada.pdf>. Accessed: Oct. 20, 2020. doi: 0000-0003-1433-6165.

ZWIGGELAAR, R. A review of spectral properties of plants and their potential use for crop/weed discrimination in row-crops. **Crop Protection**, v.17, ed. 3, 1998, p.189-206. Available from: <[https://doi.org/10.1016/S0261-2194\(98\)00009-X](https://doi.org/10.1016/S0261-2194(98)00009-X)>. Accessed: Nov. 22, 2020. doi: 10.1016/S0261-2194(98)00009-X.