International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-9, Issue-12; Dec, 2022
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.912.60

Precision Viticulture Focusing Southern Brazil

J.M. Filippini-Alba, G.R. Crizel, C.L. Girardi, C.A. Flores

Embrapa Clima Temperado, Box Post 403, CEP: 96010-971, Pelotas-RS, Brazil.

Received: 15 Nov 2022,

Receive in revised form: 06 Dec 2022,

Accepted: 12 Dec 2022,

Available online: 31 Dec 2022

***Keywords*— GIS, precision farming, mapping, remote sensing, soil, and wine.**

***Abstract*— *There are four main wine regions in Rio Grande do Sul state, Brazil: (1) "Serra Gaúcha"; (2) São Francisco Valley; (3) "Serra do Sudeste" and (4) "Campos de Cima da Serra". The region (1) is the oldest wine region of Brazil, related to Italian immigration in nineteen century. Regions (2), (3) and (4) are newer, showing similarities but soft changes in climate and soil conditions. Precision viticulture (PV) has advanced in these poles in the last 20 years. Different techniques related to precision viticulture in the context of the precision agriculture (PA) network of Embrapa, including soil mapping, physical properties sensors, remote sensing, spectrorradiometry and miscellaneous methods. Results suggest a medium technological development of PA in Brazil, with the most approaches related to grain production and few enterprises of growing fruit or viticulture, including PV. Most techniques considered an academic context or, in a few specific cases, the productive sector.*

I. INTRODUCTION

Rio Grande do Sul (RS) is a Brazilian State with strong agricultural vocation and native tradition, located in the Southern region of the country, at similar latitude than Australia and South Africa. There are four main wine regions: (1) "Serra Gaucha"; (2) "Serra do Sudeste"; (3) "Campanha"; and, (4) "Campos de Cima da Serra" (Tonietto et al., 2012). (1) is the oldest wine region of Brazil, located near Porto Alegre, between latitudes 28° 30' S to 29° 24' S, longitudes between 50°37' W and 52° W and altitude of 400m to 700m. Italian immigrants arrived in the 19th century, developing the wine production, along with gastronomy, teaching and tourist. Its territory covers 8087 km^2 with geology dominated by basalts and warm humid temperate climate with temperate nights.

"Vale dos Vinhedos" is a small portion of region (1) with detailed soil studies, constrasting geomorphology, and the occurrence of plains and soft undulating terrains in 14.2% of the area, and undulating or heavily undulating terrains in 58.2% of it (Flores et al., 2012). Argisol (31.1%); Cambisol (48.4%); and Neosol (13.4%) dominate soil occurrence.

Region (2) is located some kilometers to south of Porto Alegre, between latitudes of 30°20' S and 32° S, longitudes of 53°40' W to 52°40' W and, altitudes varying among 300m and 450m. Its territory occupies almost 7000km^2 with similar climate to (1) but, less rainy. Dominant geology is granite with occurrence of argisols, cambisols, luvisols, neosols and planosols (Cunha et al., 2005).

"Campanha" region is located to the west of (2) according to a band of 30-60 km adjacent to the frontier Brasil-Uruguay, covering 35701km^2, between latitudes 29° 24' and 31°48', longitudes in the interval 53° to 57° 46' and altitudes of 30m to 230m. Climate is warm, sub-humid with temperate nights. Soil classes variety due to territorial extension and contrasts in geology, with the occurrence of basalts, granites and sedimentary rocks.

The "Campos de Cima da Serra" region is located in the northeast of the state of Rio Grande do Sul, adjacent to the border of Santa Catarina state, between latitudes 27°50' S and 28° S, longitudes from 50° 30' to 51°32' and altitudes greater than 900m. Its total area is of 4740 km^2. Climate is temperate humid with cold nights. Basalts dominate geology and the main soils are cambisol, neosol and latosols. The different conditions of climate, geology, geomorphology and soils of these four wine regions derived on a great variety of red, white and sparkling wines (Tonietto et al., 2012) inducing necessity of standard methods and quality improvement.

Matesse and Gennaro (2015) mentioned, “Vineyards are characterized by a high heterogeneity due to structural factors such as the pedo-geomorphological characteristics, and other dynamics such as cropping practices and seasonal weather. This variability causes different vine physiological responses with direct consequences on grape quality”.

Precision agriculture (PA) technologies have capacity for mapping with zero-order of USDA scale, that is, scales greater than 1:5000. Over the years, its emphasis has changed from simply ‘farming by soil’, through variable rate technologies, to vehicle guidance systems, aiming product quality and environmental management. Actually, in a contemporaneous definition, PA is a whole-farm management approach using information technology, satellite positioning data, remote sensing and proximal data gathering (McBratney et al., 2003).

Grapes and wine production with PA management derives on Precision Viticulture (PV). Viticulture is related to terroir concept; that is, all factors above and below the ground that affect the grape during growth, as climate, relief, soil, geology and viticulture features; excluding biological phenomena as pests, diseases, herbicide, mutations and others (Haynes, 1999). Leeuwen et al. (2010) appointed a different point of view: “Historically, viticulture zoning proved particularly useful in demarcating territories according to their potential to produce wine of a certain quality or typicity. Recently, a deeper knowledge of the spatial variability of certain terroir factors has enabled a choice of the best adapted plant material in each of the zones studied”.

PV raises questions about the utility of the concept of terroir at regional scale, offering robust understanding of the impacts of soil and land attributes on grape and wine production, and therefore enabling fruit management practices and wine quality, over time of at least some aspects of the terroir (Bramley; Hamilton, 2007).

This review article describes several methods of PV, including soil mapping, proximal and remote sensing and specific sensors, considering the four main wine regions of the state of Rio Grande do Sul – Brazil, attempting to predict the potential of adding quality and value to production. Soil is a significant component of the terroir concept, so its study facilitates the understanding of the typicality of wine in the regional context, enhancing geographical indication process.

II. MATERIALS AND METHODS

Bibliographic research considered 56 total references, 63% of which were technical-scientific articles and 25% of them related to books. Half of references dated after 2010. The main themes and the respective percentage of associated references, were the following: electrical conductivity 13%, PA 13%, proximal sensing 8%, PV 11%, remote sensing 14%, geographic information systems 11%, soils 32%, terroir 14% and viticulture 22%. The sum of percentual is greater than 100% due to eventually overlapping of themes. Nine references, or 16% of the total, correspond to the PA network of Embrapa, with 5 of them, tha is 9%, related to PV. The last studies included PA techniques as regular grid sampling, soil mapping, proximal sensing and management of spatial analysis.

About soils, Argisols are soils with a strong difference between horizons, high clay content and textural B-horizon (Santos et al., 2018). Cambisols are soils with incipient B-horizon, a sub-superficial horizon of minimum 10cm thickness, underlying an A or AB horizon. Neosols are few developed soils, shallow, stony and without B-horizon. Luvisol is a textural B-horizon soil consisting of highly active and eutrophic clays, below an A or E horizon, except A chernozenic.

III. RESULTS AND DISCUSSION

3.1 Soil mapping and its attributes

The soil taxonomy systems of the U.S., the Food and Agriculture Organization (FAO), and France established the foundation for the BSSC. The basical principle is the relation between the soil profiles and the landscape (Santos et al., 2018). Scaling problens and legend masking are routine in analogic soil maps so, digital systems appeared since the 1980’s (MacDonald et al., 1984; Van Engelen & Wen, 1995; Rosa et al., 2002; USDA, 2011; Omuto et al., 2013; Samuel-Rosa et al., 2020).

Land relief is a significant soil-forming factor that affects biological activities, climate, erosion processes, texture, and water circulation (Hole & Campbell, 1985). Topographical variables represented 85% of historical cases considered by McBratney et al. (2003) about digital soil mapping. MacMillan et al. (2000) developed a robust approach for describing and segmenting landforms that is directly applicable to PA. The model uses derivatives computed from digital elevation models (DEMs) and a fuzzy rule base to identify 15 geomorphological defined landform facets (slope gradient, profile curvature, plan curvature, wetness index…).

Detailed soil mapping in three vineyards located in the Pilot Unit of Grape for Wine of the Embrapa Network of PA (Flores et al., 2011), Bento Gonçalves municipality, “Vale dos Vinhedos”, RS, Brazil with total size of 2.4ha (Figure 1), defined 10 classes of soils according to the BSSC (Table 1).

Fig.1. Landscape around the vineyards of the pilot unit in Bento Gonçalves, Vale dos Vinhedos, Serra Gaúcha, RS, Brazil.

Filippini-Alba et al. (2012) described a study on of the central vineyard (X), area of 1ha, including regular grid and physic-chemical analysis of superficial samples (0-20cm) of six classes of soil: A2, C1, C2, C3, N3 and N4 (Table 1). Four variables interpolated by kriging according to information layers in the geographic information system (GIS), ArcGIS® and classified according to Table 2 constituted an edaphic zoning in scale of vineyard. Which showed an intermediate aptitude spot, overlapped almost fully to C2 and C3 (Cambisols), with total clay 150-350 g.kg-1 and organic matter 2.5 – 3.5%. A similar little spot with equal total clay content and organic matter lesser than 2.5%, partially overlapped with N3 (Neosol).

Table 1. Description of soil mapping units according to the BSSC in three vineyards of 4ha, located in Bento Gonçalves, RS, Brazil [19]. A = Argisol, C = Cambisol, N = Neosol; Vy = Vineyard, S = South, X = Central, N = North.

Soil class	**Vy**	**Order/Suborder/Great group**	**Sub-group**	**Other information** (relief, stoniness and texture)
A1	S	Argisol/Brown-gray/Alitic	typical	A moderate clayey soft wavy
A2	X,N	Argisol/Brown-gray/Alitic	abruptic	Medium clayey to clayey moderately wavy
A3	N	Argisol/Brown-gray/Alitic	abruptic	A prominent medium clayey to clayey wavy
C1	X,N	Cambisol/Haplic/Eutrofic	tipical	A moderate, clay loam to clayey, wavy, strong wavy, stony
C2	X	Cambisol/Haplic/Eutrofic	tipical	A moderate, clay loam to clayey, strong wavy
C3	X,N	Cambisol/Haplic/Eutrofic	tipical	A moderate sandy clay loam to clayey, strong wavy
N1	S	Neosol/Regolitic/Humic	tipical	Sandy clay loam to loam soft wavy
N2	S	Neosol/Regolitic/Humic	tipical	Sandy clay loam to loam soft moderately wavy
N3	X,S	Neosol/Regolitic/Humic	tipical	Sandy clay loam to loam wavy
N4	X	Neosol/Regolitic/Humic	tipical	Sandy clay loam to loam strong wavy

A new study in the Pilot Unit of Bento Gonçalves, RS-Brazil, considered regular grids of superficial soil samples (0-20cm) and all the three vineyards (Filippini-Alba et al., 2017). Two maps were constructed by interpolation and classification methods, including texture variables (percentage of clay, silt and fine sand) and nutrient elements (C, Ca, K, Mg, N and P). The integration of the two maps, by visual perception, defined four management zones with moderately overlapping to preterit maps (Flores et al., 2011; Filippini-Alba et al., 2012).

Table 2. Classification criteria for the information layers according to micro-zonning in the central vineyard of the Pilot Unit, Bento Gonçalves, RS, Brazil. P = Preferential; R = Recommended; FR = Few Recommended; NR= No Recommended

Variable	Classes of edaphic aptitude for planting vines			
	P	R	FR	NR
Total clay ($g.kg^{-1}$)	150 – 350	350 - 600	<150 ou > 600	Organic
Stoniness (%)	0 – 0.5	0.5-15	15-40	>40
Organic matter (%)	<2.5	2.5 – 3.5	3.5 - 5	> 5
Saturation of bases (%)	20 – 49	50 - 80	<20 ou >80	Salts

Two new management zones may emerge including altitude (mean values of each soil class), and relief (from soil map, Flores et al., 2001). Each management zone showed specific characteristics in at least one case. The spatial distribution of the management zones suggested the influence of relief.

Table 3. Description of management zones related to the Pilot Unit from Bento Gonçalves, RS-Brazil. Adaprted from: Filippini-Alba et al. (2017). MZ = Management Zone; "N and S" indicates north and south.

MZ	FMC	CofN	Soil Class	Altitude	Relief
1	High	Low	A2, A3, C1, C3	564m	Moderately wave to Strong wave
2N	Moderate	Moderate	A2, C3	565m	Moderately wave to wave
2S	Moderate	Moderate	C2, N3, N4	588m	Wave to strong wave
3N	High	Moderate	C2,C3,N4	582m	Strong wave
3S	High	Moderate	A1,N1,N2	595m	Soft wavy to Moderately wave
4	High	High	N1, N2, N3	593m	Soft wavy to Wavy

Miele et al. (2014) studied the antioxidant activity and polyphenols compounds derived from nicrovinification with grapes collected from classes A1, A3, C3, N1 and N4. Wine from A1 showed more colour intensity, and high contents of anthocyanins and total polyphenols, however, content of malvidin was lesser than wine from N1. Wine from A3 showed high myricetin content and together with wine from N4 had the greater tannins contents (both greater than wine from C3), but wine from N4 showed low contents of kaempferol, maldivin, resveratrol and quercetin. A1 and N1 subclasses, or 3S management zone have high altitude, soft wavy to moderately wavy relief and high content of C and N. The authors conclude that the soils of the "Vale dos Vinhedos" correspond to several taxonomic classes, with physic-chemical differentiated characteristics deriving on special tipicity to some wines.

Coipel et al. (2000) appointed that Grenache noire vines planted with water or nitrogen restriction enriched levels of sugars and anthocyanin in grapes. Moreover, quality of grapes would not depend of the type of soil, but to soil depth. Shallow soils provide few water and nitrogen to vines, then, the yield of the vineyard reduced and the quality of berries improved.

One of the most complete reviews about soil-related "terroir" factors appointed: "The relationship between the sensory attributes of a wine and its origin is referred to as the 'terroir' effect" (Leeuven et al., 2018). Besides, a quality index based on the frequency with which the wine from a given parcel was first quality, accordingly a five years period, evaluated seven prestigious winegrowing estates from Bordeaux (France). Each parcel involved the predominant soil defined by the French System. High quality wines associated to PLANOSOL (heavy clay sub-horizon of tertiary origin), ARENOSOL (sandy soil of Quaternary aeolian origin), BRUNISOL (sandy-gravel soil on Quaternary alluvial terraces) and PEYROSOL (gravelly soil on Quaternary alluvial terraces). Quality was lowest on COLLUVIOSOL (deep sandy soil on colluvium from Quaternary substratum), LUVISOL (leached sandy clay soil on Quaternary alluvium) and REDUCTISOL (sandy soil with permanent water table, located in talwegs on Quaternary substratum). Therefore, wine quality varies significantly with soil type, although the mechanisms involved are unexplained. By other side, N and water are significant important inputs for all agricultural crops, however, specifically for viticulture; N stimulates the synthesis of glutathione, a compound that preserves aroma compounds in must and wine, and limits the production of tannins, so, "optimum N supply is different in red and white production".

3.2 Electrical conductivity of soil

Electrical conductivity (EC) and electrical resistivity (ER) significantly correlated with soil properties such as clay, organic matter, salt, or moisture content (Michot et al., 2003; Samouelian et al., 2005; Machado et al., 2006; Bernardi et al., 2019). There are several kinds of commercial sensors; non-contact or non-invasive sensors involve electromagnetic induction while contact sensors introduce an electrical current through electrodes in contact with the ground (Corwin & Lesch, 2013), a frequent PA procedure.

Grapevines are perennial plants what arguably makes PA easier than in extensive annual crops areas, because of this, it certainly appears feasible to delineate management zones using fewer data layers than would be considered necessary in grains (Bramley & Trengove, 2013). However, PV adoption rates remain low in Australia, with most adoption confined to wine companies or regions in which a leading viticulturist has taken on the main role. Therefore, there was the same dearth of consultant support to assist with data processing and spatial analysis as affects the grains industry; along with a perception that the stability of vineyard zones over time means that, less frequent data acquisition is required. Further, yield monitoring is perceived as expensive by comparison with remote sensing which can be purchased when required downturn in the wine industry was associated initially with drought and then more substantially, an oversupplied international market. However, there have been some important recent advances in PV relating to selective harvesting which should promote an irrestricted adoption. Recent work on spatial variation in crop phenology, on the go sensing of fruit quality and viticulture experimentation, may also assist. Yield data integrated into map of EC of soil, with EM38 equipment, in wine grape farms suggested a possible association between poor returns and soil constraints. Although a simple comparison between maps does not suggest similar patterns of variation, careful ground-truthing of the EM38 map would be essential to understand the cause of the variation.

ER mapped on a commercial vineyard located in Logroño, wine region of La Rioja, Spain, related to high rock fragment content within the profile (Rossi et al., 2013). Previously, some trenches allowed studying the first meters of deep. Likely, the rock fragments in the soil were responsible for the high ER values measured in all of the explored layers, what affected vine growth and grape yield in those areas too. Rock fragments increased ER of soil in the order of hundreds of ohm by meter according to their quantity and mineralogical composition. The effect of stones is often strong enough to mask other soil components or even management-induced structural changes in agricultural soils. In addition, the magnitude of soil electrical signals may provide useful information as to the soil components that should investigate in destructive sampling: ER affect many soil materials, and their effects may compensate and mask each other; nevertheless, some values usually reach in the presence of selected materials only. For example, very high ER, as recorded in selected areas at all depths, but especially in deep layers, indicates that resistive soil components (e.g., stones) should be seeked, and this provides a useful direction for the size of soil samples and the type of soil analysis. The authors concluded that soil ER and slope explained the spatial variability of relevant parameters in viticulture (vine girth and yield).

Embrapa, the Brazilian Agricultural Research Corporation, developed a prototype of a soil sensor based on EC. It is an equipment of hand, smaller and more versatile than commercial versions, what allows its use in almost any agricultural area (Rabello & Inamasu, 2014). A test with this prototype in the Pilot Unit of Bento Gonçalves, Vale dos Vinhedo, RS, Brazil (Table 4). EC shallow was greater in C1 than C2-C3, but the reply was different for EC deep, due to altitude and declivity influence on humidity contents perhaps. Anyway, the three subclasses of Cambisol showed different reply of EC, with more similarity for C3 between shallow and deep, what can explain the better development of vines of C3 appointed by micro-zoning (Filippini-Alba et al., 2012). A1 and A2 subclasses have similar values of EC, although they are located far away and at very different altitudes. A3, located near A2, had a different reply of EC. Subclasses of soil N1, N2 and N3 suggested similarity, but N4 had a different reply. So, seven management zones would be defined: (1) C1, (2) C2, (3) C3, (4) A1-A2, (5) A3, (6) N1-N2-N3 and (7) N4. There are some similarities with the previously mentioned management zones (Filippini-Alba et al., 2017), however with local differences.

In fact, each type of material has its own specific EC, so that the measurement of this parameter reflects the characteristics of the soil. For example, the rocky substrate has EC values generally lower than 2–3 mS /m, sand has values between 1 and 10 mS /m, clay between 25 and 100 mS/m, while water can vary the EC values depending on the dissolved salts from a few mS /m up to about 1000 mS /m (Ammoniaci et al., 2021).

Table 4. Altitude (m), declivity (%) and EC of soil values in percentage of the maximum value (AESCd, A2) related to the subclasses of soil in the Pilot Unit, Bento Gonçalves, Vale dos Vinhedos, RS, Brazil (Table 1). A1/2/3= Argisol 1, 2, or 3; C1/2/3 = Cambisol 1, 2 or 3; N1/2/3/4 = Neosol 1, 2, 3 or 4. ECs/d = Shallow soil EC (0-30cm)/Deep soil EC (30-60cm).

Soil unit	N	Altitude	Declivity	ECs	ECd
C1	21	566m	13-20%	87%	78%
C2	24	578m	20-45%	68%	100%
C3	48	574m	20-45%	80%	98%
A1	15	596m	3-8%	79%	99%
A2	29	563m	8-13%	76%	100%
A3	12	560m	12-20%	35%	88%
N1	24	595m	3-8%	59%	48%
N2	10	589m	8-13%	78%	52%
N3	17	593m	13-20%	55%	38%
N4	38	588m	20-45%	69%	80%

Remote sensing

Remote sensing techniques have specific advantages (Jensen, 1996): (1) non-destructive capture; (2) vast cover area; (3) availability in difficult access sites; (4) errors adjustment by historical series assessment; and, (5) multidisciplinary nature of the information. Hyperspectral and multispectral images have supported vegetal mapping stress, fertilizers application, irrigation management and monitoring nutrients in grains and fruits.

Amomoniaci et al. (2021) mentioned several high-resolution systems related to PV approaches in the last years. By instance, RapieEye acquires images of five bands with pixel of 5m, evaluating vegetation index in order to study vine vigour or technological parameters. WorldView, with several bands, including panchromatic, visible and infrared spectra, has better spatial resolution and short time of re-visit, showing good capacity for discriminating vigour, heat stress, vine canopy and varieties of vines. Aircraft are currently unfeasible systems, due to cost and operation aspects. Unmanage areal vehicles (UAV) have more spatial resolution than the improved satellite systems and they avoid errors relate to soil bare reply and size of pixel, improving measures of plant vigour or temperature. Ideal costs corresponds to vineyards greater than 40ha.

Some remote sensing and image analysis techniques are becoming more available over time, including precision digital elevation models, hyperspectral data and classification methods, so, promoting mapping vineyard variables of large areas, what was time consuming and expensive by conventional methods (Hall, 2018) .

Giovos et al. (2021) suggested UAV as the more promising system related to remote sensing vegetation indexes in PV since 2010. They considered 145 publications about viticulture, including 113 related to remote sensing and vegetation indices all over the world. About 50% of the publications correspond to several remote sensing systems of medium to high-resolution precision, 19% related to aircraft and 31% to UAV. The study incluided 97 different vegetation indices types, with NDVI as the most used, followed by GNDVI, SR and MSR (Table 5). Vegetation indices allow predicting the vine status and estimate various parameters of the plant, providing information of vegetation without in situ sampling; however, saturation is a source of error. By other side, 20% of the works considered management zones and 47% performed multitemporal monitoring. Part of the articles (25%) included water stress and irrigation, and a minor part (7%) yield or vine disease. Hyperspectral sensors involved chlorophyll, carotenoids or nutrients estimation.

Table 5. Equations of the mainly used vegetation indexes (Giovos et al., 2021).

Vegetation index	Equation
NDVI	$(NIR – RED).(NIR+RED)^{-1}$
GNDVI	$(NIR – GREEN).(NIR+GREEN)^{-1}$
SR	$NIR.(RED)^{-1}$
MSR	$(NIR/RED-1).(NIR/RED+1)^{-1/2}$

Sassu et al. (2021) compiled 49 works since 2011 related to UAV systems related to viticulture. Most of systems involved the multi-rotor system (ease of use, good camera control but short flight time), usually quadcopter, hexacopter or octocopter, instead of the fixed-wing system (long endurance, large area coverage but harder to fly). Sensors are usually visible or NIR; hiperspectral sensors are expensive, so, few used in viticulture. The objectives of works classified as: (1) vineyard remote analysis for variability monitoring (49%); (2) area and volume of canopy estimation (27%), crop features detection (20%), disease detection (6%) and prescription maps for spray management (4%).

Data derived from remote sensing (Aster, ALOS and SRTM), a geological map and a soil map allowed to characterize two vineyards, with area lesser than 40ha, located at Encruzilhada do Sul, RS, Brazil, wine region of Serra do Sudeste (Hoff et al., 2010). A similar work, including some more detailed strategies were developed in some vineyards, with a total extension of 300ha, located at Seival farm, “Campanha” wine region, RS, Brasil (Hoff et al., 2017).

An economic study about the potential market of UAV in viticulture from Italy context presented the following topics (Mondino & Gajeti, 2017): (1) Provision of services by monitoring with UAV must include other agricultural segments besides PV to reach financial sustainability. (2) A team of two technicians would be the minimal sustainable configuration for an UAV operation company. (3) Actual productivity of UAVs (25 ha/day in Italy) would not be enough to ensure economic sustainability. (4) The sustainable minimal area to map is 20 ha; however, average size of Italian viticulture enterprises is 1.6 ha. Therefore, the need of consortia appears evident for the future. (5) There are no measure of the benefits of UAV adoption today.

Proximal sensing

The concept of proximal sensing uses the same optical principles than remote sensing, but mesuares take place in loco, so knowing the spectral response of any object without the interference from the atmosphere. There are several possibilities: (1) prospection of a specific pattern in remote sensing images (Tommaso & Rubenstein, 2007). (2) Data simulation by calibration with conventional analytical methods (Filippini-Alba et al (2019). (3) The use of pure components spectras with the objective of reconnaissance, specifically for geology and soils (Demattè et al., 2019).

Reflectance spectroradiometry is a short time, nondestructive, low cost method for analysis of minerals, soils, rocks, vegetation and water (Kardeván, 1997). Anyway, there is dependence with conventional analytical methods as calibrating method. Mesure can occur on the field or in laboratory, based on optical properties, as with rermote sensing. These features derive in new possibilities for specific applications such as PV, due to the possibility of compact equipment based on reflectance or fluorescence. The Dualex, a contact hand-held sensor and the Multiplex, a non-contact hand-held optical sensor are examples of these instruments. The latter was more efficient than the former on PV context, due to its capacity for measuring the anthocyanin of grain of grapes (Cerovic et al., 2008).

A study in Microthives, Greece, considered a vineyard of 1 ha, divided in parcels of 8mx20m with conventional evaluation of total soluble solids and yield, and NDVI measures with a CropCircle sensor, during three years, 2009, 2010 and 2011 (Theofanis et al., 2013). Coincidence between yield and NDVI was moderate; however, inside de vineyard occured spatial variability.

The Pilot Unit in Bento Gonçalves, Vale dos Vinhedos, RS, Brazil was monitored with a chlorophyll fluorescence sensor, Multiplex® 3, to assess the anthocyanin content changes in grapes 'Merlot' during two agricultural cycles, 2013/2014 and 2014/2015 (Crizel et al., . Mean values of four plants previously marked after the véraison (50% of color) allowed calibrating the sensor. Three bunches by plant collected weekly during 7 weeks viabilized the measure. The destructive method of the epicarp berries allowed determination of anthocyanins contents. The anthocyanins indexes derived from the sensor correlated with anthocyanins contents obtained by destructive chemical methods, having a high coefficient of determination (R^2= 0.90). Monitoring was weekly during two months, but some specific images were selected (Figure 2). January 14 image shows low values of anthocyanin content, with increasing values until February 11, falling in February 25. Some conclusions were: (1) Need for evaluation during a shorter period, that is, four days. (2) January 26 image suggested different behavior for each vineyard. (3) Maturity point date would be close to February 11. (4) Variations intra-vineyards appear related to altitude, declivity and type of soil, mainly based on images of

January 26 and February 11. Of course, these parameters affect the micro-climatic conditions of each vineyard.

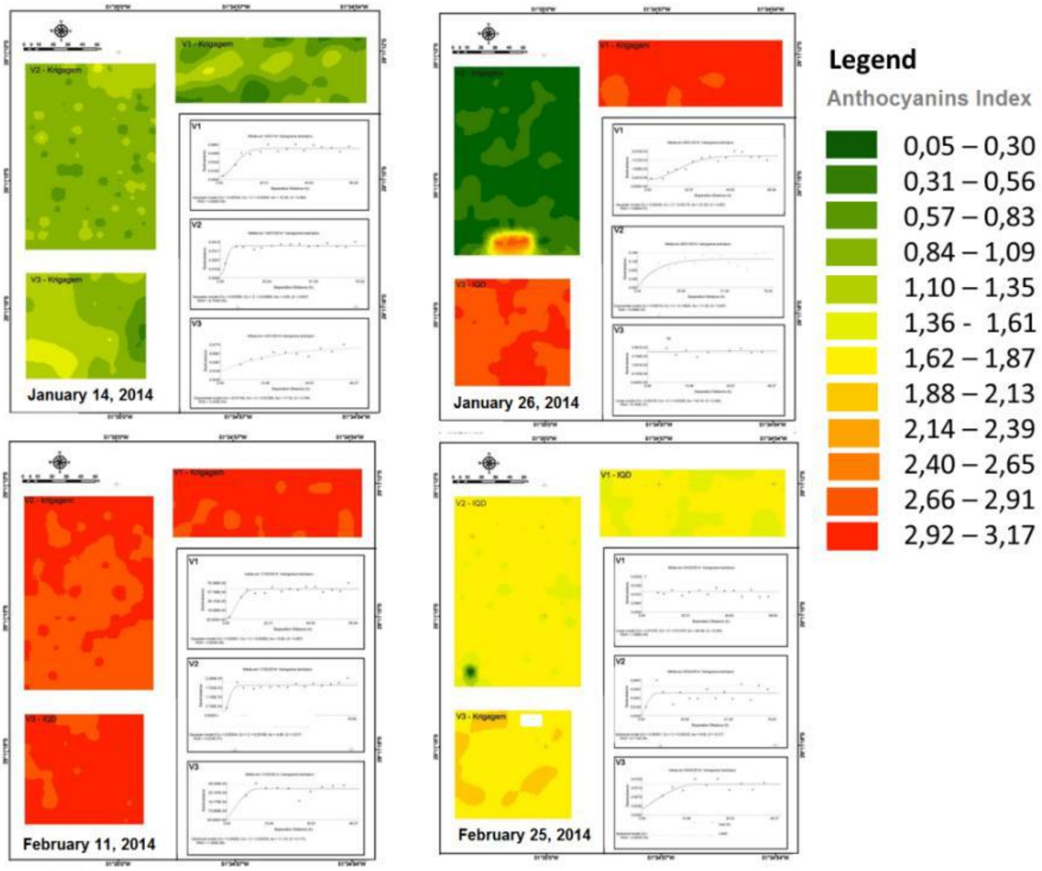

Fig.2. Spatial variation of the anthocyanin content from the three vineyards located at Bento Gonçalves, RS, Brazil, according to the indicated dates.

Miscellaneous methods

The emergence of startups along with the advent of low-cost and open source technologies has led to a wide diffusion of innovations in the scientific community. Wireless Sensor Network (WSN) technologies for remote and real-time monitoring of vineyards, include measures of temperature and humidity in different levels, for plant canopy or soil. A WSN is a network of autonomous devices containing spatially distributed sensors to monitor a physical phenomenon. The nodes distributed by the vineyard can measure variability, communicating with each other over an ad-hoc wireless network, without the need for a base station, or directly to a gateway. Yield sensors based on the volumetric measurement of the grape in the harvester's discharge belt constitute more one example (Matese & Gennaro, 2015). A WSN, the ZigBee multi-powered wireless installed in Douro, Portugal, monitored relative humidity, soil humidity, air and soil temperature, wind speed, wind direction and soil irradiation .

The Variable Network Technology (VRT) in PV allows differentiated management with inputs dosed in time and space. Actually, tractors perform site-specific operations autonomously, based on prescription maps made by monitoring on board sensors. VRT could evolve into robotics in the future, with projects already under development by the European Union (Matese & Gennaro, 2015).

Hall (2018) described simulation of micro-climatic parameters in vineyards based on digital elevation models as approaches to PV. Webber (2011) studied the Serra Gaúcha wine region, in that sense; when the solar radiation was considered, a significant parameter affecting atmosphere-plants-soil interactions. Study included data from four meteorological stations, a digital elevation model, GPS receivers and GIS. The annual global irradiation over the study area ranged from 425 $MJ.m^{-2}$ to 5,045 $MJ.m^{-2}$ with larger variations in south facing slopes. The direct radiation was the component most affected by topography, constituting a major driver of the global radiation variability on surfaces with heterogeneous topography in Serra Gaúcha.

Several of the approaches mentioned on the preceding text have taken advantage of GIS strategies. That is, a virtual representation of the real world by means of overlapping information layers through visual perception or data processing methods. Filippini-Alba (2014) discussed the concept of GSI associated to PA, considering 30 publications in Brazilian context. Half of the references tried about information management and geographical databases and the other half considered management zones or yield improvement by some method of integration. The author considered a GIS approach for multi-criteria decision analysis in rice production. Some authors have highlighted the use of GIS as data integrating method in AP (Bramley & Trengove, 2013). Filippini Alba et al. (2012, 2017, 2021) dicussed GIS approaches in PV from Vale dos Vinhedos, Brazil.

IV. CONCLUSION

Terroir is a significant concept in viticulture; however, its regional nature distances it from PV. Anyway, competition with other segments of the fruit growing market, such as juice production and fresh consumption, results in the need to improve quality and consequently, in PA.

Climate is a significant factor in the terroir effect (Tonietto et al., 2012), and perhaps with a little less consideration, soil type as well (Miele et al., 2014; Leeuwen et al., 2018; Filippini-Alba et al., 2021). The significant influence of some pedological factors (Coipel et al, 2006; Filippini-Alba et al., 2017), as slope or depth, can mask the effects of the type of soil. On the other hand, taxonomic classification is a regional tool, so the variation related to the USDA zero-order (McBratney et al., 2003) is unattainable, unless for AP or PV tools.

The first known register of implementing PA was in the 1920s, with a prescription map of soil pH for hand distribution of corrective doses of limestone. However, the scientific bases of PA were development in the mid-1980 due to four mainly factors: (1) Accurate and cost of global navigation satellite systems (GNSS). (2) Development of GIS for spatial data analysis. (3) Growing availability of georeferenced satellite imagery. (4) Development of VRT.

Geostatistic emerged on the 1960s, providing tools to manage space-time variability; first hand-held sensors appeared in the 1980s and, the GPS for civilian use came available during the 1990s, allowing GNSS guidance in tractors. Ten years later, the interference of the GPS signal dropped, thus enabling the use of VRT and remote sensing images. The ISOBUS standard, a protocol between tractors and operating machines, high-resolution satellite imagery and UAV emerged the last twenty years. PV implementation occurred much later than the other crops, after de mid-2000s only (Ammoniaci et al., 2021).

An Embrapa partner organized AP seminars in 9 Brazilian states (Bahia, Piaui, Maranhão, Goiás, Mato Grosso do Sul, Mato Grosso, Minas Gerais, Paraná and Rio Grande do Sul) in 2012, when a questionnaire was made available, requesting information on AP use. Reply related to 301 questionnaires, allowing the characterization of the PA of Brazil. Soybean and corn are the main cultures in 977ha of conventional agriculture and 2357ha of PA. The Brazilian AP users are young, educated, tech-savvy and computer-literate, and related to large areas of land. The average time of PA adoption is 4 years, and the navigation systems, as light bar and automatic pilot, and VRT are the preferred technologies. Growing fruit was rarely adopted (Bernardi & Inamasu, 2014).

Information related to the PA Brazilian Congresses (2010, 2012 and 2014), internet sites and analogic publications compiled during the period 2005-2014 about PA in Brazil, derived on 91 Brazilian agricultural areas with PA approaches, covering 3700ha. Distribution of the areas was 38% in the southern region, 36% in the southeast, 20% in the mid-west, and 6% in the northeastern region. Applied technologies were classified as "soil sensor", "plant sensor", position instruments (GPS), and yield maps, used in 69%, 27%, 72%, and 20% of cases, respectively. PA for grains production occupied 32% of the total area and growing fruit represented 12% of the total area, there was no specific information about viticulture (Filippini-Alba & Zanella, 2016).

Research on the use of precision and digital agriculture in Brazil, involving 504 questionnaires, showed more interest in communication and information than in technical solutions. The use of data or images from field sensors, remote sensing imagery, GPS, or management software was related to 20% of producers, but 58% of questionnaires were related to informational software and 70% of them to the Internet and connectivity. A few farmers have used PA devices of advanced performance, as automatic/robotic systems and UAV (Bolfe et al., 2020).

The precedent paragraphs suggest a medium technological development of PA in Brazil, with the most approaches related to grain production and few enterprises of growing fruit or viticulture, including PV. Some soil-related databases appeared in recent years as support for digital agriculture (Embrapa, 2014; Demattè et al., 2019; Bolfe et al., 2020). By other side, in still more innovative context, the technological startups have exploded in the traditional agriculture sector of Latin America, with a total of 1,574 companies registered in September 2021, 293 or 19% of them in Brazil (Ribeiro, 2022).

A review of remote sensing vegetation indices in PV (Giovos et al., 2021) suggested an incremental use of the technology in the 2015-2020 period (table 6), when the number of total publications increased significantly, from 29 publications to 84 ones, that is, an increase of 190%, prevailing the local context compared to regional. The countries with the most significant approaches were, in descending order, the USA, Australia, Italy, Spain, France, Greece and Portugal. Few contributions from South America.

The above text suggests a relation among development countries, technology and financial resources. Sustainably area for PV approaches was mentioned as 20ha (Ammoniaci et al., 2021) to 40ha (Mondino et al., 2017). The three vineyards of Pilot Unit of Bento Gonçalves-RS, Brazil have a total size of 2.4ha, what represents 6-12% of the "sustainable" area. The scarce data available for the wine-growing regions of Serra do Sudeste and Campanha indicated vineyards of approximately 20ha and a mosaic of 300ha respectively (Hoff et al., 2010, 2017), what suggest a better perspective for using PV.

Modification of manual PV procedures to on-the-go sensors procedures, involve UAV, automatic systems and robotics. Then, a differentiated relationship appear in terms of work force, technological dependence and costs. Furthermore, as indicated in the case of the economic aspects of PV in Italy (Mondino el al., 2017), there are no reliable data on the benefits of PV for the production system. However, if terroir is a regional concept and spatial variability occurs inside them, as mentioned by some authors, so PV can collaborate significantly to improve quality and the enological properties of wine, with benefits from an environmental perspective too.

REFERENCES

[1] Ammoniaci, M., Kartisiotis, S.P., Perria, R. & Storchi, P. 2021. State of art of monitoring Technologies and Data Processing for precision viticulture. Agriculture 11, 201-220. DOI: /10.3390/agriculture11030201

[2] Bernardi, A.C.C., Pitrat, T., Rabello, L.M., Pezzopane, J.R.M, Bosi, C., Mazzuco, G.G. & Bettiol, G.M., 2019. Differences in soil electrical resistivity tomography due to soil water contents in an integrated agricultural system. Pesquisa Agropecuária Brasileira, 54 (00774), 1-5. DOI: /10.1590/S1678-3921.pab2019.v54.00774

[3] Bernardi, A.C. & Inamasu, R.Y., 2014. Adoção da agricultura de precisão no Brasil. In: Bernardi, A.C., Naime, J.M., Resende, A.V., Bassoi, L.H. & Inamasu, R.Y. (eds). Agricultura de Precisão: resultados de um novo olhar. Embrapa, Brasília. pp. 571-579.

[4] Bolfe, E.L., Jorge, L.A.C., Sanches, I.D., Luchiari Júnior, A., Costa, C.C., Victoria D.C., Inamasu, R.Y., Grego, C.R., Ferreira, V.R. & Ramirez, A.R., 2020. Precision and Digital Agriculture: Adoption of Technologies and Perception of Brazilian Farmers. Agriculture 10: 653-668. DOI:/10.3390/agriculture10120653.

[5] Bramley, R.G.V. & Trengove, S. 2013. Precision agriculture in Australia: present status and recent developments. Engenharia Agrícola 33(3): 575-588. DOI: /10.1590/S0100-69162013000300014.

[6] Bramley, R.G.V. & Hamilton, R.P., 2007. Terroir and precision viticulture: are they compatible? J. Int. Sci. Vigne Vin. 41(1), 1-8.

[7] Cerovic, Z.G., Moise, N., Agati, G., Latouche, G., Ben Ghozlen N. & Meyer, S., 2008. New portable optical sensors for the assessment of winegrape phenolic maturity based on berry fluorescence. J. Food Comp. Anal. 21, 650-654.

[8] Coipel, J., Lovelle, R.B., Sipp, C. & Leeuwen, C., 2006. Terroir effect as result of environmental stress depends more on soil depth than on soil type: Vitis Vinifira L. cv. Grenache Noir, Côtes du Rhône, France, 2000. J. Int. Sci. Vigne Vin. 40(4), 177 – 185. DOI: /10.20870/oeno-one.2006.40.4.867

[9] Corwin, D. & Lesch, S., 2005. Apparent soil electrical conductivity measurements in agriculture. Computers and Electronics in Agriculture 46, 11-43. DOI:10.1016/j.compag.2004.10.005.

[10] Crizel, G., Camargo, S., Ferreira, W.A. & Girardi, C.L. 2013. Método não destrutivo para determinação de antiocianinas e flavonoides em uvas. In: Girardi, C.L., Machado, C.A.E., Santos, H.P., Revers, L.F., Botton, M. & Zanus, M.C. Resumos. 11 Encontro de Iniciação Científica, e 7 Encontro de pós-graduandos da Embrapa Uva e Vinho. Bento Gonçalves-RS, Brazil. July 2013. pp. 12.

[11] Cunha, N.G., Silveira, R.J.C., Severo, C.R.S., Pinto, L.F.S., Mendes, R.G., Silva, J.B., Duarte, R.L. & Schumacher, R.L., 2005. Estudo de solos do município de Encruzilhada do Sul, RS. Embrapa, Pelotas.

[12] Demattê, J.A.M., Dotto, A.C., Paiva, A.F.S., Sato, M.V., Dalmolin, R.S.D., Araújo, M.D.S.B., Silva, E.B., Nanni, M.R., Ten Caten, A, Noronha, N.C., Lacerda, M.P.C., Araújo Filho, J., Rizzo, R., Bellinaso, H., Francelino, M.R., Schaefer, C.E.G.R., Vicente, L.E., Santos, U.J., Sampaio, E.V.S.B., Menezes, R.S.C., Souza, J.J.L.L., Abrahão, W.A.P., Coelho, R.M., Grego, C.R., Lani, J.L., Fernandes, A.R., Gonçalves, D.A.M., Silva, S.H.G., Menezes, M.D., Curi, N., Couto, E.G., Anjos, L.H.C., Ceddia, M.B., Pinheiro, E.F.M., Grunwald, S., Vasques, G.M., Marques Júnior J., Silva AJ, Barreto MCDV, Nóbrega GN, Silva MZ, Souza SF, Valladares GS, Viana JHM, Terra FS, Horák-Terra I, Fiorio PR, Silva RC, Frade Júnior EF, Lima RHC, Filippini-Alba JM, Souza Junior VS, Brefin MLMS, Ruivo MDLP, Ferreira TO, Brait MA, Caetano .R, Bringhenti, I., Mendes, W.S., Safanelli, J.L., Guimarães, C.C.B., Poppiel, R.R., Souza, A.B., Quesada, C.A. & Couto, H.T.Z., 2019. The Brazilian Soil Spectral Library (BSSL): a general view, application and challenges. Geoderma, 2019; 354:1-21. DOI: /10.1016/j.geoderma.2019.05.043

[13] Embrapa. Banco de dados de Solos, 2014. Embrapa, Rio de Janeiro. Available from: https://www.bdsolos.cnptia.embrapa.br/consulta_publica.html. [Accessed: 2022/03/24].

[14] Filippini-Alba, J.M., Cruz, L.E.C., Ducati, J.R, Domingues, J.M.M. & Cunha, H.N., 2019. Processing Spectroradiometry data for the simulation of soil physicochemical parameters. Int. J. Dev. Res., 09, 28875-28882.

[15] Filippini-Alba, J.M., Flores, C.A. & Miele A. Geotechnologies and Soil Mapping for Delimitation of Management Zones as an Approach to Precision Viticulture. Applied and Environmental Soil Science, 2017; Article ID 4180965. DOI:/10.1155/2017/4180965

[16] Filippini-Alba, J.M., Flores, C.A. & Miele, A., 2012. Modelagem espacial dos solos para apoio à viticultura de precisão: Vale dos Vinhedos, Serra Gaúcha, Rio Grande do Sul, Brasil. Revista Brasileira de Viticultura e Enologia 4, 8-17.

[17] Filippini-Alba, J.M., Flores, C.A. & Miele, A., 2021. Relationships between A and B/A2 horizons of 3 soils in the context of viticulture. Journal of Agricultural Studies, 9(1), 440-454.

[18] Filippini-Alba, J.M. & Zanella M. Revisão e Processamento de Informações sobre Agricultura de Precisão no Brasil. Embrapa: Pelotas, 2016. Available from: https://www.embrapa.br/busca-de-publicacoes/-/publicacao/1070875/revisao-e-processamento-de-informacoes-sobre-agricultura-de-precisao-no-brasil. [Accessed: 2020/07/20].

[19] Filippini-Alba, J.M., 2014. Modelagem SIG em agricultura de precisão: conceitos, revisão e aplicações. In: Bernardi, A.C., Naime, J.M., Resende, A.V., Bassoi, L.H. & Inamasu, R.Y., editors. Agricultura de Precisão: resultados de um novo olhar. Embrapa, Brasília. pp. 84-96.

[20] Flores, C.A., Filippini-Alba JM, Levien HF, Zarnott DH, Miele, A., Pavan, C. (2011) Levantamento detalhado dos solos e a viticultura de precisão. In: Anais do XXXIII Congresso Brasileiro de Ciência do Solo. 31 July – 5 August 2011; Uberlândia-MG, Brazil. Sociedade Brasileira de Ciência do Solo. 1 CD-ROM.

[21] Flores, C.A., Pötter, R.O., Sarmento, E.C., Weber, E.J. & Hasenack, H., 2012. Os solos do Vale dos Vinhedos, 1st ed., Embrapa, Brasília, 175p.

[22] Giovos, R., Tassapoulos, D., Kalivas, D., Lougkos, N. & Privolou, A., 2021. Remote sensing vegetation indices in viticulture. A critical review. Agriculture 11, 457 – 476. DOI:/10.3390/agriculture11050457.

[23] Hall, A., 2018. Remote sensing applications for viticultural terroir analyisis. Elements 14, 185-190. DOI: /10.2138/gselements.14.3.185

[24] Haynes, S., 1999. Geology and wine 1. Concept of terroir and the role of geology. Geoscience Canada 26(4), 190-194.

[25] Hoff, R., Ducati, J.R. & Bergmann, M., 2010. Geologic and geomorphologic features applied for identification of wine terroir units by digital image processing, spectroradiometric and GIS techniques in Encruzilhada do Sul-RS, Brazil. In: Proceedings of VIII International Al Terroir Congress; December 2010, Soave, Italy.

[26] Hoff, R., Ducati, J.R. & Farias, A.R., 2017. GIS and remote sensing to support precision viticulture for analysis of vineyards in the Campanha wine region, Brazil. J. Env. & Agric. Sc. 10, 20-32.

[27] Hole, F.D. & Campbell, J.B. Soil landform analysis, 1985. Rowman & Allanheld, Totowa. https://www.embrapa.br/en/solos/sibcs/classificacao-de solos/ordens/cambissolos. [Accessed: 2019/04/24].

[28] Jensen, J.R., 1996. Introductory digital image processing: a remote sensing perspective. Prentice-Hall, Upper Saddle River.

[29] Kardeván, P., 1997. Reflectance spectroradiometer – a new tool for environmental mapping. Carpth. J. Earth Environ. Sc. 2, 29-38.

[30] Leeuwen, C., Roby, J-Ph. & Rességuier, L., 2018. Soil-related terroir factors: a review. OENO One 52 (2), 173-188. DOI: 10.20870/oeno-one.2018.52.2.2208.

[31] Leeuwen, van C., Roby, J. P., Pernet, D., & Bois, B., 2010. Methodology of soil based zoning for viticultural terrois. Bulletin de l'OIV 83 (947/948/949), 13-29.

[32] Liew, S.C., 2001. Principles of Remoter Sensing. CRISP, Singapure. Available from: https://crisp.nus.edu.sg/~research/ tutorial/optical.htm. [Accessed: 2019/02/21].

[33] MacDonald, K.B. & Kloosterman, B., 1984. The Canada Soil Information System (CanSIS) General User's Manual.Land Resource Research Centre, Research Branch, Agriculture Canada, Ottawa.

[34] Machado, P.L.O.A., Bernardi, A.C.C., Valencia, L.I.O., Molin, J.P., Gimenez, L.M., Silva, C.A., Andrade, A.G., Madari, B.E. & Meirelles, M.S.P., 2006. Mapeamento da condutividade elétrica e relação com a argila de latossolo sob plantio direto. Pesquisa Agropecuária Brasileira 41: 1023-1031. DOI: /10.1590/S0100-204X2006000600019.

[35] MacMillan, R.A., Pettapieceb, W.W., Nolanc, S.C. & Goddard, T.W., 2000. A generic procedure for automatically segmenting landforms into landform elements using DEMs, heuristic rules and fuzzy logic. Fuzzy Sets Systens 113: 81-109. Doi: /10.1016/S0165-0114(99)00014-7.

[36] Matese, A. & Gennaro, S.F., 2015. Technology in precision viticulture: a state of the art review. Inn. J. Wine Res. 7, 69-81

[37] McBratney, A.B., Mendonça Santos, M.L. & Minasmy, B., 2003. On digital soil mapping. Geoderma 117, 3-52. DOI: /10.1016/S0016-7061 (03)00223-4

[38] Michot, D., Benderitter, Y., Dorigny, A., Nicoullaud, B., King, D. & Tabbagh A., 2003. Spatial and temporal monitoring of soil water content with an irrigated corn crop cover using electrical resistivity tomography. Water Resource Research 39, 1138-1156. DOI: /10.1029/2002WR001581.

[39] Miele, A., Flores, C.A., Filippini-Alba, J.M. & Badalotti, C.B., 2014. Efeito do tipo de solo nos compostos fenólicos e na atividade antioxidante do vinho. Revista Brasileira de Viticultura e Enologia 6, 40-47.

[40] Mondino, E.B. & Gajeti, M., 2017. Preliminary considerations about costs and potemtial market of remote sensing from UAV in the Italian viticulture context. Journal

of Remote Sensing 50(1), 310-319. DOI: 10.1080/22797254.2017.1328269
[41] Morais, R., Fernandes, M.A., Matos, S.G., Serôdio, C., Ferreira, P.J.S.G. & Reis, M.J.C.S., 2008. A ZigBee multi-powered wireless acquisition device for remote sensing applications in precision viticulture. Comp. Elect. Agric. 62, 94-106. DOI:/10.1016/j.compag.2007.12.004.
[42] Omuto, C., Nachtergaele, F. & Rojas, R.V., 2013. State of the art report on global and regional soil information. FAO, Rome. Available from: https://www.fao.org/3/i3161e/i3161e.pdf. [Accessed: 2021/07/20].
[43] Rabello, L.M. & Inamasu, R.Y., 2014. Conductividade elétrica aparente do solo. In: Bernardi, A.C., Naime, J.M., Resende, A.V., Bassoi, L.H. & Inamasu RY (eds). Agricultura de Precisão: resultados de um novo olhar. Embrapa, Brasília. pp. 48-57.
[44] Ribeiro, G. Agronegócio é terreno fértil para startups na América latina. Curitiba: EBANX. Available from: https://labsnews.com/pt-br/artigos/negocios/agronegocio-e-terreno-fertil-para-startups-na-america-latina/. [Accessed: 2022/03/24]
[45] Rosa, D., Mayol, F., Moreno, F., Cabrera, F., Diaz-Pereira, E. & Antoine, J.A., 2002. Multilingual soil profile database (SDBm Plus) as an essential part of land resources information systems. Environmental Modelling & Software 17, 721-730. DOI:/10.1016/S1364-8152(02)00031-2.
[46] Rossi, R., Pollice, A., Diago, M.P., Oliveira, M., Millan, B., Bitella, G., Amato, M. & Tardaguila, J., 2013. Using an automatic resistivity profiler soil sensor on the go in precision viticulture. Sensors 13, 1121-1136. DOI: /10.3390/s130101121
[47] Samouëlian, A., Cousina, I., Tabaghc, A., Bruand, A. & Richard, G. Electrical resistivity survey in soil science: a review. Soil & Tillage Research, 2005; 83: 173-193.
[48] Samuel-Rosa, A., Dalmolin, R.S.D., Moura-Bueno, J.M., Teixeira, W.G. & Filippini-Alba, J.M., 2020. Open legacy soil survey data in Brazil: geospatial data quality and how to improve it. Scientia Agricola 77, 1-11. DOI:/10.1590/1678-992X-2017-0430.
[49] Santos, H.G., Jacomine, P.K.T., Anjos, L.H.C., Oliviera, V.A., Lumbreras, J.F., Coelho, M.R., Almeida, J.A., Araujo Filho, J.C., Oliveira, J.B. & Cunha, T.J.F., 2018. Sistema Brasileiro de Classificação de Solos. Embrapa, Rio de Janeiro.
[50] Sassu, A., Gambella, F., Ghiani, L., Mercenaro, L., Caria, M. & Pazzona, A.L., 2021. Advances in unmanned aerial system remote sensing for precision viticulture. Sensors 21, 956-976. DOI:/10.3390/s21030956.
[51] Theofanis, G., Fountas, S., Tagarakis, A. & Liakos, V., 2013. Precisino agriculture application in fruit crops: experience in handpicked fruits. Procedia Tech. 8, 324-332.
[52] Tommaso, I.M. & Rubinstein, N., 2007. Hydrothermal alteration mapping using ASTER data in the Infernillo pporphyry deposit, Argentina. Ore Geol. Rev. 32(1), 275-290.
[53] Tonietto, J., Sotés-Ruiz, V. & Gómez-Miguel, V.D. (eds), 2012. Clima, zonificación y tipicidade del vino en regiones vitivinícolas Ibero-americanas. CYTED, Madrid.
[54] USDA. National soil information system (NASIS), 2011. Available from: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/tools/?cid=nrcs142p2_053552. [Accessed: 2021/07/08].
[55] Van Engelen, V.W.P. & Wen, T.T., 1995. Global and national soils and terrain digital databases (SOTER): procedures manual. UNEP-ISSS-ISRIC-FAO, Wageningen. Available from: https://www.isric.org/sites/default/files/isric_report_2013_04.pdf. [Accessed: 2021/07/20].
[56] Webber, E., 2011. Estimation and mapping of solar radiation on surfaces with heterogeneous topography in the Serra Gaucha wine production region. Thesis, Federal University of Rio Grande do Sul, Porto Alegre-RS, Brazil.
[57]