

Quality Characteristics of Vineyard Soil in the Conventional and Biodynamic Cultivation System of Chardonnay Vinifers

Cláudia Brazil Marques¹, João Armando Dessimon², Paulo César do Nascimento³, and Fabrício Moraes de Almeida⁴

¹Universidade Federal do Rio Grande do Sul- UFRGS- Departamento de Pós -Graduação Doutorado em Agronegócios - CEPAN- Av. Bento Gonçalves, 7712 CEP 91540-000 - Porto Alegre - RS – Brasil.

²Universidade Federal do Rio Grande do Sul, Faculdade de Ciências Econômicas, Departamento de Ciências Econômicas. Av. João Pessoa, 31 - Sala 11- Centro- 90040-000 - Porto Alegre, RS - Brasil

³Universidade Federal do Rio Grande do Sul, Faculdade de Agronomia, Departamento de Solos. Av. Bento Gonçalves, 7712- Agronomia. Porto Alegre, RS - Brasil

⁴PhD in Physics (UFC), with post-doctorate in Scientific Regional Development (DCR/CNPq). Researcher of the Doctoral and Master Program in Regional Development and Environment (PGDRA/UFRO). Leader of line 2 - Technological and Systemic Development, and Researcher of GEITEC — Federal University of Rondônia, Brazil.

Abstract— Viticulture, particularly in the production of viniferous varieties, is one of the most present crops in the State of Rio Grande do Sul. Soil indicators can be highlighted attributes linked to organic carbon, which have often been used, to assess soil quality. The objectives here were: a) to evaluate and compare soil quality characteristics of vineyards in the conventional and biodynamic cultivation system of chardonnay vinifers, together with areas of native forest, in the localities where the vineyards exist; b) to estimate the susceptibility to environmental impacts and possible soil degradation processes caused in soil management from cultivation systems and practices. The study was descriptive, exploratory and comparative of quantitative analysis. The sample was 26 vineyards and 19 corresponding native forests about 8 to 10 sub-samples, at a depth of 0 to 20 cm. The results showed an intermediate condition of VBI in relation to VCO and VAT, confirming the tendency of loss of initial soil characteristics from cultivation, but maintaining several attributes in a condition closer to that observed under natural vegetation.

Keywords— viticulture; organic matter; Natural forest; management; soil.

I. INTRODUCTION

Agricultural activity is increasingly referenced in paradigms that seek sustainability, within a multidimensional vision of this concept. In this sense, the environmental aspect becomes important as it is one of the fundamental requirements for achieving sustainable development models (UNITED NATIONS ORGANIZATION, 1987; MILLENNIUM, 2005). The soil, as one of the fundamental natural resources for agricultural production and for the maintenance of life on the planet in general, takes a priority position on the environmental issue.

Soil quality can be defined as "the ability of a soil to function within the limits of the ecosystem to sustain biological productivity, environmental quality and maintain animal and plant health" (DORAN and PARKIN, 1994). This cannot be measured directly, but can be evaluated by

measuring changes in some of its attributes, which are considered indicators (VEZZANI and MIELNICZUK, 2009; GIACOMO et al., 2015).

Among the soil indicators, attributes linked to organic carbon, which have often been used, can be highlighted to assess soil quality. In addition, attributes such as phosphorus and nitrogen contents, soil acidity and cation exchange capacity, in addition to trace element contents, have been shown to be sensitive to prolonged soil management practices and cultural practices related to different crops, affecting soil and water quality (NASCIMENTO et al., 2014; LOPES et al, 2007).

Viticulture, particularly in the production of viniferous varieties, is one of the most present crops in the State of Rio Grande do Sul, with annual production of around 65,540,421 thousand tons, with reference to the year 2018 (IBRAVIN, 2019). The culture is expanding rapidly,

and thus there is also a great variety in production, in terms of localities, regions and environmental conditions, as well as production systems (IBRAVIN, 2019).

Wine production requires techniques, practices and cultivation systems that enable agricultural management, with maintenance and improvement of the quality of natural resources used. The concern of the International Organization of Vine and Wine (OIV), and entities of the *Vitis vinifera* chain, has been to raise awareness of actions in rural areas to reduce the use of agrochemicals and human interventions to alter the balance of the ecosystem. Actions may show sparse effects on ecosystem size (EDWARDS et al., 2015; TANENTZAP et al., 2015), but they reflect the responsibility of the wine grower (SELG, 1924). However, due to concerns about the intensive use of agrochemicals in vine cultivation, there is a rethinking of soil management practices, in search of alternatives for cultivation with less chemical treatments and care for the environment and the farmers themselves. At the same time, the vision of integrating agricultural activity with its environment, both in a more local and macro level (the harmony and interaction with the "Cosmos"), and the valorization of knowledge and experiences acquired by the farmer himself gains space. In this sense, Biodynamic Agriculture emerges (ABAB, 2015; ASSISI and JESUS, 2002).

The biodynamic system of cultivation shows itself in philosophical opposition to the use of agrochemical pesticides and herbicides, both routinely used in the conventional cultivation system (TILMAN et al., 1997). It is characterized by a systemic view of property and crops, as an organism. Management includes the production of preparations and treatments in the care of the soil, plants and animals in the agricultural unit itself, providing sustainability and balance of biodiversity in the cultivation system (REGANOLD et al. 1993, MÄDER et al. 2002). Furthermore, it emphasizes the construction of the soil and the high diversity of cultures, animals and wildlife habitat through practices in alignment with the astronomical calendar, making use of the exchange relationship between the planet earth and the cosmos (KOEPPF et al. 1990).

Based on these assumptions, the objectives of the study were: a) to evaluate and compare soil quality characteristics of vineyards in the conventional and biodynamic cultivation system of chardonnay vinifers, together with areas of native forest, in the localities where the vineyards exist; b) to estimate the susceptibility to environmental impacts and possible soil degradation processes caused in soil management from cultivation systems and practices.

II. MATERIAL AND METHODS

The work was developed in the region of Encosta do Nordeste, in the state of Rio Grande do Sul. It is located in the Central-Northeast region, according to NUTEP (Figure 1). The climate is humid subtropical, with rainfall between 1500 and 1700 mm, distributed regularly during the year, but with records of water deficit between December and March. The relief is wavy to strong wavy, with geology formed by basalts from the Serra Geral Formation, with presence, in areas of higher elevation, of influence of acidic extrusive rocks, such as rhyolites or rhodocites. The vegetation is composed mainly of semideciduous seasonal forest, with contacts with Araucaria forest. The main taxonomic soil units are Argissolos, Cambissolos, Neossolos and Luvisolos (CPRM, 2006; STRECK et al., 2018).

The criteria for choosing areas and properties was that they work with the Chardonnay variety, this being the object of the research. Obeying this requirement, nineteen vineyards from the conventional cultivation system and seven from biodynamic cultivation (the latter inserted in seven properties) were found, totaling 26 vineyards, being a method of sample choice used for convenience (LEVINE et al., 2008).

In the conventional production system, the correction and fertilization of the soil have participation of synthetic fertilizers, such as NPK formulations, and the use of pesticides, for protection against infestation by pests and diseases. Some practices of a more conservationist and resource-saving nature are also used, such as organic fertilization (composting based on animal waste) and the use of grout for plant health. Examples are sulpho-calcium slurry and ash, also used in ecologically based production (LEÃO et al., 2014; NACHTIGAL and SCHNEIDER, 2007). The use of practices such as green fertilization and soil cover was variable among the properties studied. Biodynamic-based production, in turn, takes advantage of the presence of nutrient elements in compartments such as the atmosphere and the biosphere, and increases this availability through the use of biodynamic preparations for plant nutrition and health, as well as for the improvement of soil conditions. These preparations use plant extracts such as nettle (*Urtica* sp.), chamomile (*Matricaria* sp.) and oak leaves (*Quercus* sp.), sometimes wrapped in animal bones such as the skull or horns. Practices such as the use of crop consortia and green cover species are also used in several properties with vines in biodynamic system (HERRENKIND, 2006; CHALKER-SCOTT, 2013).

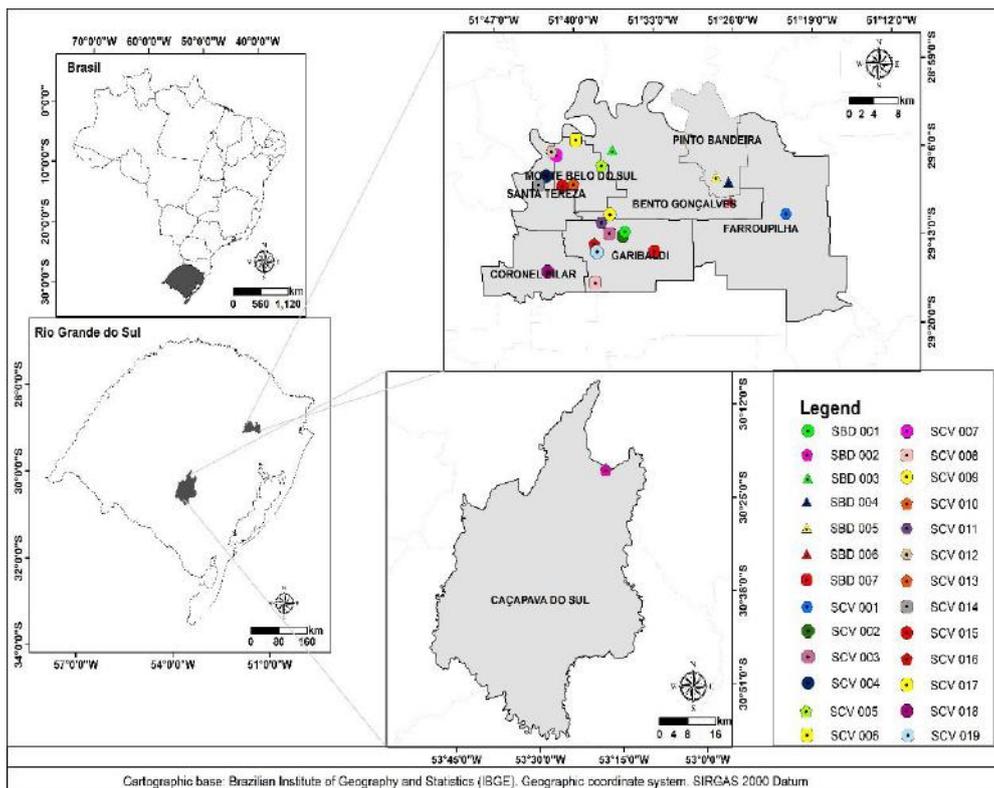


Fig.1: Map of the State of Rio Grande do Sul, and the region of Encosta do Nordeste and Caçapava do Sul.

Source: Prepared based on IBGE, 2019

The soil collections were held between July and August 2018. In the study areas, about 8 to 10 sub-samples were collected at a depth of 0 to 20 cm. for composite sample formation. In the same regions, 19 areas of native forest were selected, where the same soil sampling procedure was performed. The collection areas, both under woodland and vineyards, extend over 0, 5 and 4 ha, usually in wavy to strong relief.

Laboratory analyses consisted of determining the clay content by the densimeter method; pH in water; organic matter content by acid combustion; phosphorus and potassium by extraction in weak acid solution (Mehlich's method), with colorimetric determination for the first and by flame spectrophotometer for the second; Ca, Al and Mg contents determined by extraction with potassium chloride and determination by atomic absorption spectroscopy; estimated potential acidity by obtaining pH in solution with SMP; and micronutrient contents (Cu, Mn, Zn). The methods of analysis followed the recommendations of EMBRAPA (2011). Based on the results obtained, the parameters of cation exchange capacity and saturation by bases were calculated.

The statistical analyses were performed using the Software Statistical Package for Social Sciences (SPSS), comparing mainly the three land use groups (vineyards in

conventional and biodynamic systems, and native forest), using the Analysis of Variance (ANOVA) at 10% significance, and using the Tukey test in case of rejection of the hypothesis of difference between treatments. Some attributes, which did not obey the assumption of homogeneity of variances, underwent data transformations, or the application of non-parametric analyses (KRUSKALL WALLIS and MANN WHITNEY). Multivariate analysis was also applied, through discriminant analysis, to reclassify the samples in relation to the original groups, based on values obtained by each sample in relation to discriminant functions obtained (VARELLA, 2004).

III. RESULTS AND DISCUSSION

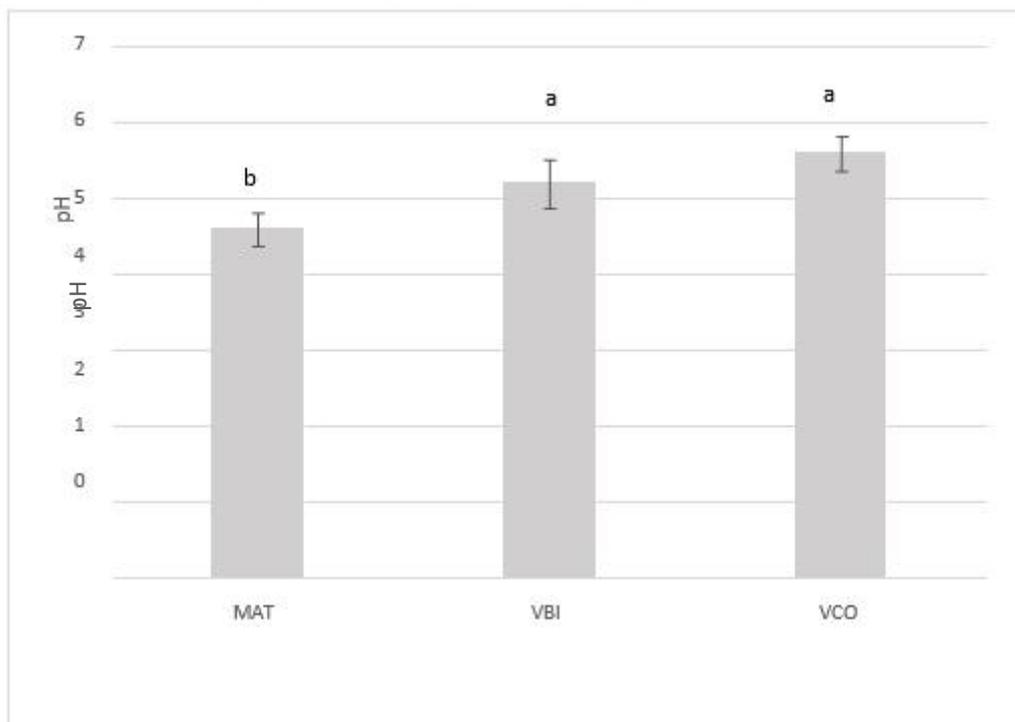
Clay contents were variable, but concentrated between 25 and 40%, characterizing soils with a clayey and loamy texture (SANTOS et al., 2015). Based on this value distribution, and considering that this attribute is not subject to significant changes by anthropic use and management, the clay content was not used as an attribute statistically analyzed. For the purpose of analyzing element contents, soils were mostly classified in class 3, according to ROLAS (2016).

The pH values proved to be higher in vineyard soils than in the forest. In this case, the difference in management

can be observed, with the adoption of liming and systematic fertilization, both chemical and organic. In addition to liming, the addition of elements such as potassium and

magnesium, by means of fertilizers (mainly organic), also implies an increase in the pH in both production systems (ABAB, 2015) (Chart 1).

Graph 1: Average soil pH values for different land uses.



The soil organic matter (MOS) contents had great heterogeneity of variances between treatments, which required the application of non-parametric methods. Thus, the Kruskal - Wallis test was applied, and from the detection of differences between treatments, the Mann Whitney test was applied for "two by two" analyses between land uses. The differences between the production systems can be seen, where the VBI, conducted based on systems such as consortium and green fertilization, provided significantly higher levels of MOS than the VCO, equating to VHV (Chart 2). The VCO presented some areas under management with these practices, but in a less systematic and intensive way, with intervals of some years for the repetition of the installation of these covering plants. Ruiz-Colmenero et al., (2011) found a significant increase in MOS levels in areas cultivated with green manure in seasonal consortium with grapevines. The practices used in agroecological-based systems tend to increase organic carbon stocks in the soil, stimulating diversity and microbial activity (MAZZANCINI et al., 2010). The VHV and VBI uses did not present significant differences between them, unlike VHV and VCO, thus indicating an approximation between the VHV and VBI uses.

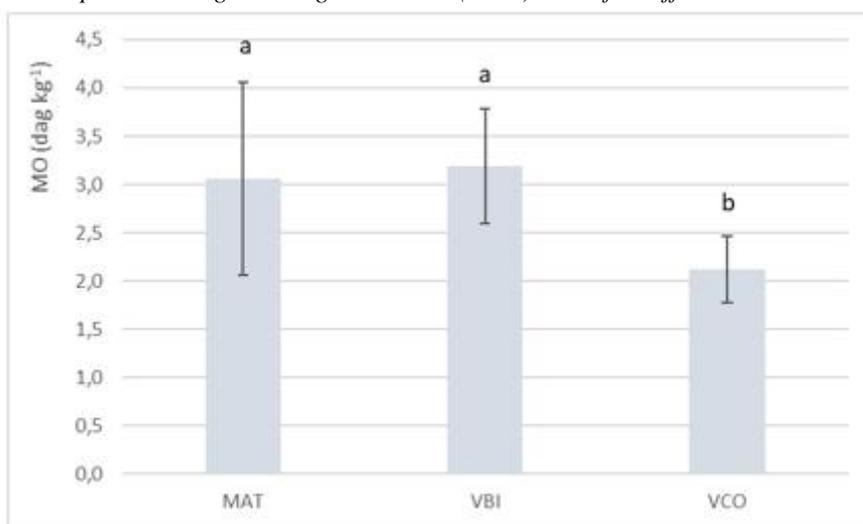
The cation exchange capacity (CTC) and base saturation (V) values did not have significant differences between land uses (not shown). A trend towards lower base saturation values is observed for VHV, which is also a reflection of the greater use of soil correction through liming and fertilization, which can be used in both systems (NACHTIGAL and SCHNEIDER, 2007; ABAB, 2015). CTC did not follow the increase of MO in VHM, however a correlation between MO and CTC of $r = 0.31$ ($p < 0.05$) was perceived. For the study areas, it can be seen that the variations within each treatment contributed to the absence of significance, expressed by standard deviations considered high especially for base saturation, which is directly dependent on fertilization and liming practices. In addition, it can be considered that the natural characteristics of the soils in the region, originating from basalt, lead to high values of V, even in uncultivated areas, such as MAT (STRECK et al., 2008). Nascimento et al. (2014), working in the same region of the Lower Slope of Northeast RS, found no significant differences for areas cultivated with vineyards under organic production and forest, among other types of land use.

The P levels had to be analyzed by non-parametric method (Kruskal Wallis). The difference detected was

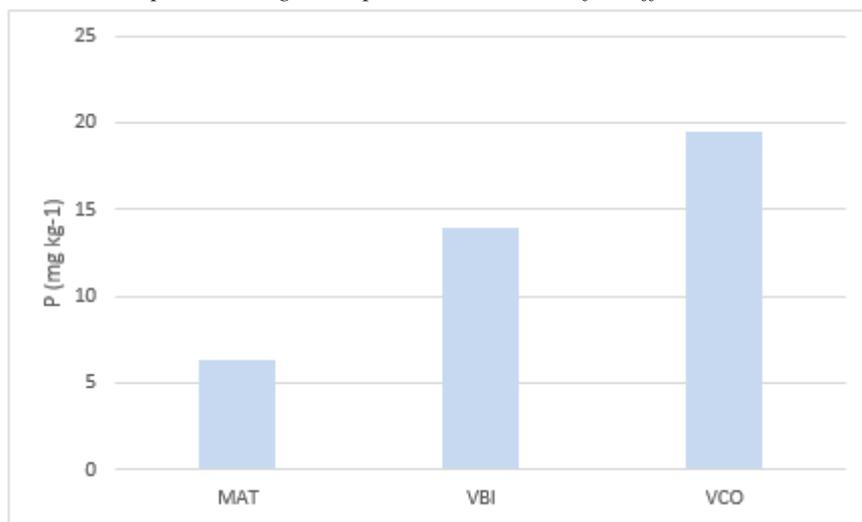
between VHV and VCO, with significantly higher values for these (Chart 3). Conventional crops usually associate synthetic and organic sources of fertilizer, the former being more soluble, such as simple superphosphate, leading to high levels of P in the soil (SCHMITT et al., 2013). Matos et al. (2006) indicate that organic fertilizers result in increases inorganic forms of the element. This is repeated in the present work, since no direct relationship was detected between phosphorus contents and organic matter, probably

due to the rather labile character of the latter, with rapid decomposition and release of the element to the soil. The great variation in the values presented among the areas cultivated under biodynamic system is represented by the standard deviation values, indicating that there are great differences in the forms of management, specifically regarding forms and quantities of compounds used in fertilization.

Graph 2 - Average soil organic matter (MOS) levels for different land uses.



Graph 3: Average Phosphorus levels in soil for different land uses.



Despite the significantly higher values in the vineyards, the phosphorus contents reached a maximum of about 50 ppm, not reaching critical values for the mobilization of this element in the soil, and consequently the contamination of nearby springs (GEBRIM et al., 2010).

The levels of micronutrients, specifically Zn and Cu, are quite high in VCO vineyard areas, with significant differences from VHV and VBI, which in turn showed no differences between them (table 1). Areas under fruit farming in general have relatively high Cu contents, either by phytosanitary treatments, based on grouts, or by the

fertilization normally used with animal manure compounds (LEÃO et al., 2004; LOURENZI et al., 2016).

In the work in question, Cu and Zn levels were very high (ROLAS, 2016), and may even characterize a potential for soil contamination. The correlation between it is $r = 0.80$ ($p < 0.05$), indicating probable origin from the same factors. Brunetto et al. (2018) found that increases in Cu and Zn yields are normal in conventional vineyard areas, increasing with the time of use under this crop. The authors also highlight the presence of Cu in forms more available to plants, due to the greater affinity of Zn with more energetic connections with the mineral fraction of the soil. This may

have been accentuated in this work, since the soils have medium to clay texture. In relation to the Mn, higher values are perceived for the areas of native forest.

It should be considered that these areas, for the most part, are formed by soils originated from basalt rocks, with high levels of the element. The intensive application of other elements, by means of phytosanitary treatments and fertilizers, may have reduced the presence of Mn by displacing them in the soil exchange sites. Nascimento et al. (2014), working in areas of floriculture and fruit farming in Encosta da Serra, obtained similar results, indicating the influence of material rich in levels of this element.

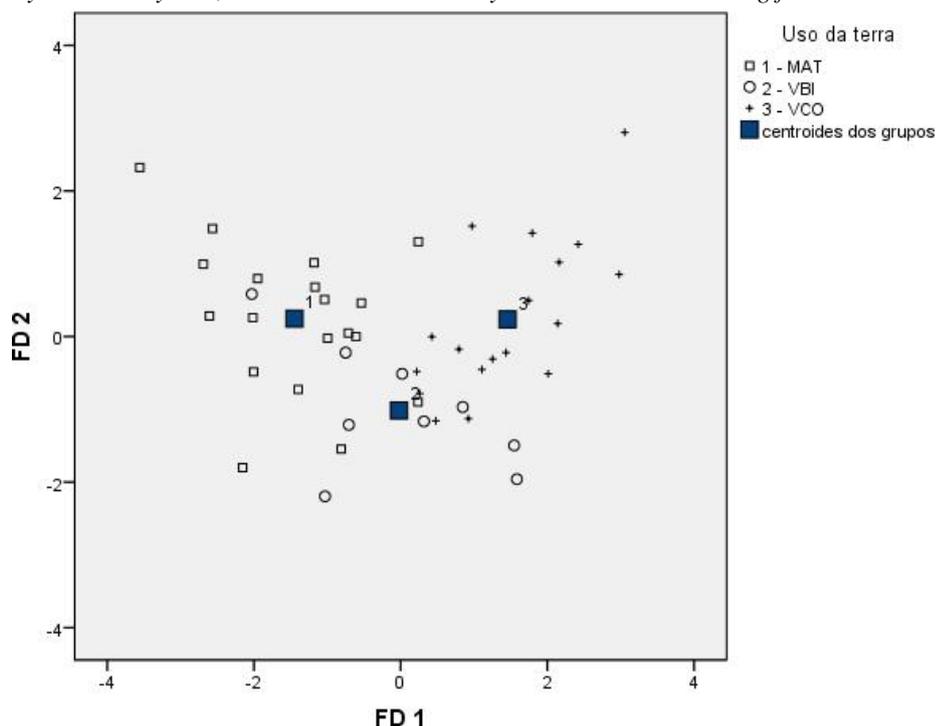
Table 1: Mean and standard deviation for sulfur contents and some micronutrients in soils of the Northeast Slope of Rio Grande do Sul, according to the type of use.

mg kg-1	S	Cu*	Zn*	Mn*
MAT	15.7 (6.3) ns	5,3 (10,2) B	5,0 (3,4) B	83,5 (45,8) A
VBI	11.5 (3.0) ns	20,6 (31,0) B	8.6 (6.1) AB	37,8 (33,2) B
VCO	12.9 (6.6) ns	76,9 (97,2) A	10,5 (6,9) A	30,5 (14,8) B

*Presentation of original data, analysis performed by non-parametric methods.

The values obtained for all the attributes in each of the 47 samples were analyzed together in a multivariate analysis. The discriminant analysis was performed in order to promote the reclassification of each sample, through the analysis of the vector corresponding to the values obtained by this sample, with the centroids of each group. For this analysis discriminating functions (FDs) were used, which define limits of resulting values for the characterization of each land use (Natural Forest, Biodynamic Vineyard, Conventional Vineyard) (Graph 4). FD 1 correlated with pH, Mn, Cu and P levels, while FD 2 had greater correlations with organic matter, clay and P levels.

Chart 4: Values of samples and centroids of land use types from discriminant analysis. MAT: natural forest; VBI: biodynamic vineyards; VCO: conventional vineyards. FD: discriminating function.



The distribution of the number of samples for each type of land use, from the results obtained by the FDs (Table 2). From the 47 representative samples of the glebas, 9 were altered or reclassified in relation to land use. These data

indicate a relatively high degree of coincidence between the field classification and that established by the FDs (around 80% of the glebas), which allows us to infer well defined and discriminated characteristics for each type of land use.

Table 2: Comparison of land use classifications by field verification and discriminant analysis.

	MAT	VBI	VCO	Field classification
MAT	17	2	0	19
VBI	2	6	1	9
VCO	0	4	15	19
FD Classification	19	12	16	

Theodoro et al. (2003) used the analysis of main components for coffee plantations with different types of management, compared with native forests, achieving a very clear discrimination between treatments, even those characterized as transition between organic and conventional production systems. In the present case, it is observed that the reclassified areas involve the use of VBO land, which from nine glebas detected in the field, presented in one case behavior more related to VCO, and in two cases more related to VHV.

On the other hand, four glebas with VCO and two glebas with MAT are characterized as being more related to the VBI. This data shows an intermediate character of these production systems, between VCO and VHV, which can also be seen by the centroid positions in table 2. This configuration may indicate the fulfillment of the objectives of adopting the biodynamic system, considering specifically the environmental aspect, since this system advocates the development and health of plant species from the integration with soil quality, expressed by the greater presence of biomass and capture and transmission of energy through biodynamic preparations (HERRENKIND, 2006).

IV. FINAL CONSIDERATIONS

The cultivation and management of the vineyards has led to important changes in the chemical characteristics of the soils. The effects were basically related to the use of correctives and fertilizers, especially those of higher solubility and faster availability for the plants. These were the cases of pH, higher in VCO, as well as the levels of P, Cu and Zn, the latter may even generate toxicity and losses by erosion or leaching.

On the other hand, the organic matter contents were directly influenced by the maintenance of biomass and biodiversity in the areas, resulting in the contribution and accumulation of organic material from the soil. This process occurred in a similar way in VHV and VBI slabs, with significant differences from the VCO. The joint analysis of the

attributes showed an intermediate condition of the VBI in relation to the VCO and VAT, confirming the tendency of loss of the initial characteristics of the soil from the cultivation, but maintaining several attributes in a condition closer to that observed under natural vegetation.

REFERENCES

- [1] ABAB- Associação Brasileira de Agricultura Biodinâmica – Normas de Produção para o uso das marcas, Deméter, Biodinâmica e Associadas. Botucaut (SP), 2015.
- [2] ASSIS, R. L. e JESUS, E. L. Histórico, conceitos e princípios da Agroecologia. In: Agroecologia em Mato Grosso do Sul: Princípios, Fundamento e Experiências. Padovan et al. (Editores). Empresa Brasileira de pesquisa Agropecuária (EMBRAPA) – Instituto de Desenvolvimento Agrário, Pesquisa, Assistência Técnica e Extensão Rural do Mato Grosso do Sul – IDATERRA. Dourados (MT), 2002.
- [3] BRUNETTO, G. et al. Copper and zinc accumulation, fractionation and migration in vineyard soils from Santa Catarina State, Brazil. *Bragantia*, 77: 141-151, 2018.
- [4] CPRM - Comissão de Pesquisa em Recursos Minerais. (2006) Mapa geológico do estado do Rio Grande do Sul. Escala 1:750.000. Projeto Geologia do Brasil ao Milionésimo.
- [5] DORAN, J. D and PARKIN, T. B. **Defining and accessing Soil Quality**. In: Defining Soil Quality for a Sustainable Environment. Doran, J. W. et al. (Edictors). Soil Science Soc. of America – American Society of Agronomy. Madison, Wisconsin - EUA, 1994.p. 3 – 21.
- [6] EDWARDS, D. P., et al. Land-sparing agriculture best protects avian phylogenetic diversity. *Current biology*, 2015, 25.18: 2384-2391.
- [7] EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária. Segunda Edição. Centro Nacional de Pesquisa de Solos. Manual de Métodos de Análise de Solos. Brasília, 2011.
- [8] GEBRIM, F. O. et al. Mobility of inorganic and organic phosphorus forms under different levels of phosphate and poultry litter fertilization in soils. *Revista Brasileira de Ciência do Solo*, v. 34, n. 4, p. 1195-1205, 2010.
- [9] GIACOMO, R. G.; PEREIRA, M. G.; GUARESCHI, R. F. e MACHADO, D. L. Atributos químicos e físicos do solo, estoques de carbono e nitrogênio e frações húmicas em

- diferentes formações vegetais. **Ciência Florestal**, 25:617-631, 2015
- [10] HERRENKIND, R (Edictor). **Steiner's impulse for agriculture**. Demeter Institute. Darmstadt, Germany, 2006.
- [11] IBGE -Instituto Brasileiro de Geografia e Estatística – Censo Agropecuário 2017 Rio Grande do Sul. Disponível em <https://censoagro2017.ibge.gov.br> . Acesso em outubro 2019.
- [12] KOEPF, W.; RING, P. A relativistic theory of superdeformations in rapidly rotating nuclei. **Nuclear Physics A**, 1990, 511.2: 279-300.
- [13] LEÃO, P. C. S. (Editor). **Cultivo da Videira. EMBRAPA, Sistemas de Produção 1, 2004**. Disponível: <https://ainfo.cnptia.embrapa.br>. Acesso em 25 de março 2019.
- [14] LEVINE, D. M., STEPHAN, D. F., KREHBIEL, T. C., BERENSON, M. L. **Estatística: Teoria e Aplicações**. 5ª ed. Rio de Janeiro: LTC, 2008.
- [15] LOPES, F. ; MERTEN, G. H. ; FRANZEN, M. ; GIASSON, E. ; HELFER, F.; CYBIS, L. F. A.. Utilização de P-index em uma bacia hidrográfica através de técnicas de geoprocessamento. **Revista Brasileira de Engenharia Agrícola e Ambiental** (Online), v. 11, p. 312-317, 2007.
- [16] LOURENZI, C. R. et al. Atributos químicos de Latossolo após sucessivas aplicações de composto orgânico de dejetos líquido de suínos. **Pesquisa Agropecuária Brasileira**, Brasília 51, 233-242, 2016.
- [17] MÄDER, P., et al. Soil fertility and biodiversity in organic farming. **Science**, 2002, 296.5573: 1694-1697.
- [18] DA SILVA MATOS, E, et al. Formas de fósforo no solo em sistemas de milho exclusivo e consorciado com feijão sob adubação orgânica e mineral. **Revista Brasileira Ciência do Solo**, 2006, 30.4: 625-632.
- [19] MAZZONCINI, M. et al. Comparison of organic and conventional stockless arable systems: A multidisciplinary approach to soil quality evaluation. **Applied Soil Ecology**. 44:124-132, 2010.
- [20] VAN JAARSVELD, A. S., et al. Measuring conditions and trends in ecosystem services at multiple scales: The Southern African Millennium Ecosystem Assessment (SA f MA) experience. **Philosophical Transactions of the Royal Society B: Biological Sciences**, 2005, 360.1454: 425-441.
- [21] NACHTIGAL, J. C. e SCHNEIDER. Recomendações para produção de videiras em base ecológica. **Empresa Brasileira de Pesquisa Agropecuária- EMBRAPA-UVA E VINHO**. Bento Gonçalves, RS, 2007. NASCIMENTO, P. C. et al., 2014. **Uso da terra e atributos do solo do Estado do Rio Grande do Sul**. Revista Brasileira de Engenharia Agrícola e Ambiental, 18:920-926, 2014.
- [22] ROLAS SC-RS- Rede Oficial de Laboratórios de Análise de Solos. **Manual de Adubação e Calagem**. Sociedade Brasileira de Ciência do Solo. Segunda Edição. Porto Alegre (RS), 2016.
- [23] REGANOLD, J P., et al. Soil quality and financial performance of biodynamic and conventional farms in New Zealand. **Science**, 1993, 260.5106: 344-349.
- [24] RUIZ-COLMENERO, M.; BIENES, R.; MARQUES, M. J. Soil and water conservation dilemmas associated with the use of green cover in steep vineyards. **Soil and Tillage Research**, 117:211-223, 2011.
- [25] SCHMITT, D. E. et al. Accumulation of phosphorus fractions and contamination potential in vineyard soils in the southern region of the state of Santa Catarina, Brazil. **Revista Brasileira de Ciência do Solo**, v. 37, n. 5, p. 1256-1266, 2013.
- [26] STRECK, E. V. et al. **Solos do Rio Grande do Sul**. 2. ed. Porto Alegre: EMATER/RS; UFRGS, 2008.
- [27] TANENTZAP, A. J., et al. Resolving conflicts between agriculture and the natural environment. **PLoS biology**, 2015, 13.9: e1002242.
- [28] THEODORO, V. C. A. et al. Alterações químicas em solo submetido a diferentes formas de manejo do cafeeiro. **Revista Brasileira de Ciência do Solo**, v. 27, n. 6, p. 1039-1047, 2003.
- [29] TILMAN, D., C. L. LEHMAN, and K. T. THOMSON. Plant diversity and ecosystem productivity: theoretical considerations. **Proceedings of the National Academy of Sciences (USA)** 1997. 94:1857–1861.
- [30] UNITED NATIONS ORGANIZATION. WORLD COMMISSION OF ENVIRONMENT AND DEVELOPMENT. Our Common Future. Oslo (Norway), 1987 <https://www.un.org/documents/ga/res/42/ares42-187.htm>. Acesso em jun de 2019.
- [31] VARELLA, C. A. A. **Análise Discriminante**. Universidade Federal Rural do Rio de Janeiro, Seropédica (RJ), Brasil, 2004.
- [32] VEZZANI, F. M. e MIELNICZUK, J. Uma visão sobre qualidade do solo. **Revista Brasileira de Ciência do Solo**, v. 33, n. 4, p. 743-755, 2009.