Influence of parent material on organic phosphorus fractions in vineyard soils in Santa Catarina, Brazil

ARTICLES doi:10.4136/ambi-agua.2546

Received: 26 Mar. 2020; Accepted: 23. Jun. 2020

Shirlei Almeida Assunção1; Marcos Gervasio Pereira1*; Denilson Dortzbach2; Eduardo Carvalho da Silva Neto1*

1Departamento de Solos, Instituto de Agronomia. Universidade Federal Rural do Rio de Janeiro (UFRRJ), BR 465, km 7, CEP: 23897-000, Seropédica, RJ, Brazil. E-mail: shirleiaassuncao@gmail.com, netocseduardo@gmail.com

2Centro de Informações de Recursos Ambientais e de Hidrometeorologia de Santa Catarina (CIRAM). Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina (EPAGRI), Rodovia Admar Gonzaga, n° 1347, CEP: 88034-901, Florianópolis, SC, Brazil. E-mail: denilson@epagri.sc.gov.br

*Corresponding author. E-mail: mgervasiopereira01@gmail.com

ABSTRACT

Phosphorus (P) is an essential element for vineyard productivity. This study assessed the influence of parent material on organic P fractions in vineyard soils of basaltic and rhyodacitic origin. The experiment was conducted in four municipalities located in mountainous regions in Santa Catarina, Brazil: Urubici, São Joaquim, Campos Novos, and Água Doce. Disturbed soil samples were collected between grapevine rows at depths of 0.00–0.05, 0.05–0.10, 0.10–0.20, and 0.20–0.40 m. Soil chemical attributes (pH in H2O, Ca2+, Mg2+, Al3+, P, K+, and H + Al), total organic carbon (TOC), available and residual P, labile P (extracted with sodium bicarbonate), moderately labile P (extracted with sulfuric acid), and moderately resistant P (extracted with sodium hydroxide) were determined. Soil parent material influenced the dynamics of phosphorus in vineyard soils. Both P forms (available and solution equilibrium P) and P organic fractions (labile, moderately labile, and moderately resistant P), are affected by the parent material. Basaltic soils had higher TOC, available and residual P, and moderately labile and moderately resistant P, whereas rhyodacitic soils showed higher labile P. The high levels of moderately labile and moderately resistant P fractions in basaltic soil were attributed to its high TOC, available P, and residual P contents. Parent material was found to influence organic P fractions in vineyard soils.

Keywords: grapevine, organic carbon, soil acidity, soil management, wine.

Influência do material de origem nas frações de fósforo orgânico em solos de vinhedos em Santa Catarina, Brasil

RESUMO

O fósforo (P) é um elemento essencial para a produtividade dos vinhedos. Este estudo avaliou a influência do material de origem nas frações orgânicas de P em solos de vinhedos formados e áreas de solos origem basáltica e riodacítica. O estudo foi conduzido em quatro municípios localizados nas regiões montanhosas de Santa Catarina, Brasil: Urubici, São Joaquim, Campos Novos e Água Doce. Amostras de solo foram coletadas nas entrelinhas das
videiras nas profundidades de 0,00-0,05, 0,05-0,10, 0,10-0,20 e 0,20-0,40 m. Foram avaliados os atributos químicos do solo (pH em H₂O, Ca²⁺, Mg²⁺, Al³⁺, P, K + e H+Al), carbono orgânico total (COT), P disponível e residual, P lábil (extraído com bicarbonato de sódio), moderadamente lábil (extraído com ácido sulfúrico) e P moderadamente resistente (extraído com hidróxido de sódio). Nas áreas de solos formados a partir de material de origem de natureza basáltica foram verificados os maiores teores de COT, P disponível e residual, e P moderadamente lábil e moderadamente resistente, enquanto naqueles formados a partir de rochas como riodacitos observaram-se valores de P lábil mais elevados. Os altos níveis das frações P moderadamente lábeis e moderadamente resistentes nos solos formados a partir de basalto foram atribuídos ao seu alto COT, P disponível e conteúdo residual de P. Verificou-se que o material de origem dos solos influencia as frações orgânicas de P nos solos dos vinhedos.

Palavras-chave: acidez do solo, carbono orgânico, manejo do solo, videira, vinho.

1. INTRODUCTION

Brazil is the fifth-largest wine producer in the Southern Hemisphere and has one of the fastest-growing wine markets in the world, with over 79 thousand hectares of vineyards (Ibravin, 2018). Wine production is mainly concentrated in the southern region, where, in addition to being an important economic activity, it has a significant sociocultural value. In 2012, 21 million liters of wine were produced in Santa Catarina, 72.57% of which was table wine (Mello, 2013).

Grapes produced in Santa Catarina differ from those produced in other regions of the country because of the unique climate characteristics of the state. Santa Catarina’s mild summers allow grapevines to have a long growth cycle and reach full maturation, important factors to produce high-quality wines (Borghezan et al., 2011). The organoleptic properties, quality, and types of wine are influenced by viticultural and enological practices (human factors) as well as geographical and environmental factors, such as soil, vegetation, and climate (Tonietto, 2001). High altitudes affect night temperatures at harvest, resulting in a more complete phenolic maturation and, thus, better product quality (Camargo et al., 2011).

The importance of soil quality for grapevine cultivation is recognized by most producers; however, it is considered of secondary importance compared with climate and viticultural techniques (Santos, 2006). Adequate nutrient and soil management can contribute greatly to increasing yield and quality of grapes and, consequently, of wine. These aspects denote the importance of using a land agricultural suitability evaluation system adapted to this crop and its management (Dortzbach et al., 2016).

Phosphorus (P) is essential for crop productivity (Liu et al., 2017). In Santa Catarina, the cold and humid climate favors the leaching of base cations, leading to an increase in the levels of exchangeable aluminum (Al) and soil acidity (Almeida et al., 2000) and a consequent decrease in P availability. P fractions have very complex dynamics influenced by soil texture (Tokura et al., 2011), fertilization (Cereta et al., 2010), management (Guareschi et al., 2015), and biotic and abiotic factors (Resende et al., 2011). P occurs in organic and inorganic forms in soil. Inorganic P is soluble or bound to soil organic matter (SOM) or mineral fractions (Shen et al., 2011).

High-altitude soils in the state of Santa Catarina naturally present nutritional limitations, and phosphorus is the most limiting macronutrient, whose application to the soil is required for the crop to express its maximum productive potential (Dortzbach et al., 2016). Very low and very high phosphorus contents can cause problems to grape production. This nutrient is important for the formation of the canopy, fruiting, root development. It favors wort fermentation and strengthens the aroma and flavor of wines (Regina et al., 2006).
Influence of parent material on organic phosphorus …

Considering the importance of P for the production and management of vineyards, this study aimed to assess the influence of different soil parent materials on organic P fractions in vineyard soils.

2. MATERIAL AND METHODS

The study area is located within the Serra Geral Formation. It comprises four municipalities located in mountainous regions of the state of Santa Catarina, Brazil: Urubici, São Joaquim, Campos Novos and Água Doce. The region is a major producer of quality wine from high-altitude regions in the state of Santa Catarina (Dortzbach et al., 2016).

The soil parent material consists of rocks with different levels of resistance to weathering, such as basalt and rhyodacite. The region’s primary characteristic is its heterogeneity caused by different magma cooling conditions which act on the textural and mineralogical composition of each geological deposition (Dortzbach et al., 2016). The geomorphology is characterized by two geomorphological units which occur, the Planalto dos Campos Gerais that is distributed in the landscape as isolated blocks, and the Planalto Dissecado Rio Iguatemi/Rio Uruguai (Santa Catarina, 1986).

The dominant soil types in Urubici, São Joaquim, and Água Doce are Dystric Cambisols associated with Rhodic Nitisols and Litholic Neosols (FAO, 2015). In Campos Novos, the soils are predominantly Rhodic Nitisols associated with Dystric Cambisols and Rhodic Latosols (FAO, 2015). In general, these soils are characterized by high acidity, high Al levels, and high SOM accumulation in surface horizons.

The local climate is humid subtropical with mild summers (Cfb in the Köppen climate classification). Rainfall is evenly distributed throughout the year, and there are no dry seasons. The average temperature of the warmest month is below 22°C. The primary vegetation is subtropical forest, particularly Araucaria forests, a type of mixed ombrophilous forest that extends from the coastal mountains to the Santa Catarina Plateau, mainly at elevations above 500 m. Subtropical grasslands are the dominant vegetation of the Santa Catarina Plateau (Santa Catarina, 1986).

The sampled sites included six vineyards planted in 2001–2005 for wine production from three different rural properties. In each property, a vineyard with basaltic (VB) and rhyodacitic (VR) soil was sampled. Disturbed soil samples were collected between grapevine rows at the 0.00–0.05, 0.05–0.10, 0.10–0.20, and 0.20–0.40 m depths, comprising the plowing soil layer. At each sampling point, five samples were taken from each depth, forming composite samples. Samples were identified and packed in plastic bags, transported to the laboratory, air-dried, ground, and sieved through 2 mm sieves to obtain air-dried fine earth for analysis.

Total organic carbon (TOC) was quantified according to Yeomans and Brenner (1988). The following parameters were determined: pH in H₂O (1:2.5 ratio); available P and K⁺, extracted with Mehlich-1 (0.0125 mol L⁻¹ H₂SO₄ and 0.050 mol L⁻¹ HCl); exchangeable Ca²⁺, Mg²⁺, and Al³⁺, extracted with 1 mol L⁻¹ KCl; and H + Al, extracted with 0.5 mol L⁻¹ calcium acetate (pH 7) and titrated with 0.0125 mol L⁻¹ NaOH (Teixeira et al., 2017).

Solution equilibrium P was determined according to Alvarez and Fonseca (1990). Five cubic centimeters of air-dried fine earth was added to 0.01 mol L⁻¹ CaCl₂ and 60 mg L⁻¹ P for 1 h. After agitation, solid and liquid phases were separated, and the solution equilibrium P concentration was determined in the equilibrium solution by the molybdenum blue/ascorbic acid method. Sample absorbance was read using a spectrophotometer (Braga and Defelipo, 1974).

The extraction and quantification of P fractions in the soil was done according to the method proposed by Bowman (1989). In summary, the P fractionation method is based on the sequential extraction of labile, moderately labile and moderately resistant forms in a sample of 1.00 g of air-dried fine earth, in which the Po and Pi forms are separated according to their
availability to plants using, sequentially, extractors from the lowest to the highest extraction intensity. Labile phosphorus is extracted with 0.5 mol L\(^{-1}\) NaHCO\(_3\) at pH 8; moderately labile phosphorus is extracted with 0.5 mol L\(^{-1}\) \(\text{H}_2\text{SO}_4\); and moderately resistant phosphorus is extracted with 0.5 mol L\(^{-1}\) NaOH.

The determination of the P of each fraction is obtained by colorimetry method, after the reduction of the phosphomolybdic complex with ascorbic acid, in the presence of bismuth salt (Teixeira et al., 2017). The total P in each fraction is determined in an aliquot that was submitted to perchloric digestion and inorganic P in undigested extracts (Bowman, 1989). Organic P was calculated as total P minus inorganic P.

This is a measurement study based on pseudo-replication and, therefore, data do not meet the assumptions of conventional experimental designs. Data (\(n = 4\)) were subjected to descriptive analysis, and results are presented as mean and standard error.

3. RESULTS AND DISCUSSION

The chemical attributes of vineyard soils are presented in Figure 1. The mean pH value was 6.22 ± 0.20 in the vineyards with basaltic soils (VB) and 5.86 ± 0.13 in the vineyards with rhyodacitic soils (VR) (Figure 1a). Soils were limed to this pH because of their acidic nature; in some cases, liming was performed even after planting. At all depths, the highest Al\(^{3+}\) values were found in rhyodacitic soils (mean Al\(^{3+}\) = 0.44 ± 0.17 cmol\(_c\).dcm\(^{-3}\)) (Figure 1b). In vineyards with basaltic soils the mean value was Al\(^{3+}\) = 0.16 ± 0.09 cmol\(_c\).dcm\(^{-3}\). The levels of Al\(^{3+}\) increased from the 0.00–0.05 m to the 0.05–0.10 m layer, decreasing sharply at higher depths, especially in rhyodacitic soils. High Al\(^{3+}\) levels were probably due to the characteristics of the parent material. Rhyodacite is an acidic rock; thus, its weathering results in soil with high levels of bases, which are easily leached under humid conditions, favoring the accumulation of Al\(^{3+}\) in the soil solution (Dortzbach et al., 2016; Clemente and Azevedo, 2007).

Basaltic soils showed higher levels of Ca\(^{2+}\) at all depths (mean Ca\(^{2+}\) in VB = 9.09 ± 0.50 cmol\(_c\).dcm\(^{-3}\) and Ca\(^{2+}\) in VR = 6.09 ± 0.42 cmol\(_c\).dcm\(^{-3}\)). In all soils the Ca\(^{2+}\) levels were higher in the 0.10–0.20 m depth than in the 0.05–0.10 m depth layer. Similarly, Mg\(^{2+}\) contents were higher in basaltic soils (mean Mg\(^{2+}\) in VB = 5.30 ± 0.28 cmol\(_c\).dcm\(^{-3}\) and mean Mg\(^{2+}\) in VR = 2.93 ± 0.38 cmol\(_c\).dcm\(^{-3}\)). Also, the highest Mg\(^{2+}\) levels were observed at the 0.05–0.10 and 0.10–0.20 m depths. K\(^+\) levels were also higher in the vineyards with basaltic soils (mean K\(^+\) in VB = 1.23 ± 0.26 cmol\(_c\).dcm\(^{-3}\) and mean K\(^+\) in VR = 0.46 ± 0.09 cmol\(_c\).dcm\(^{-3}\)) and decreased with soil depth. These results are similar to those observed in other studies conducted in southern Brazil (Dortzbach et al., 2016; Almeida et al., 2000; Clemente and Azevedo, 2007).

The H+Al contents ranged from 2.5 to 4.0 cmol\(_c\).dcm\(^{-3}\) (mean H+Al in VB = 2.43 ± 0.19 cmol\(_c\).dcm\(^{-3}\) and mean H+Al in VR = 3.51 ± 0.25 cmol\(_c\).dcm\(^{-3}\)). Up to the 0.20 m depth, H + Al levels were higher in basaltic soils, whereas at the 0.20–0.40 m depth, levels were higher in rhyodacitic soils. H + Al levels are positively correlated with SOM; that is, a high H+Al content indicates a high SOM content (Simas et al., 2005). The reduction in TOC with depth (Figure 2) corroborates the low H + Al levels observed in subsoil layers. TOC levels (20–35 g kg\(^{-1}\)) were higher in basaltic soils at all depths (mean TOC in VB = 28.1 ± 5.8 g kg\(^{-1}\) and mean TOC in VR = 24.7 ± 4.1 cmol\(_c\).dcm\(^{-3}\)). This difference was particularly pronounced at the 0.10–0.20 m depth.

Soil TOC levels generally decrease with depth, as surface layers are high in biological activity and plant litter. However, tillage or other soil preparation techniques can alter this profile, leading to higher TOC levels in subsurface layers. The differences in TOC levels between vineyard soils of different origins may be explained by the basic nature of basalt. Soils formed on basic parent material have a more clayey texture, which decreases organic carbon oxidation, whether by adsorption of organic molecules on clay or by aggregate formation.
Available and solution equilibrium P levels are presented in Figure 3. Available P levels ranged from 6 to 10 mg kg$^{-1}$ (Figure 3a). Available P was highest at the 0.20 m depth in basaltic soil. At the 0.20–0.40 m depth, both types of soil showed similar available P levels. The higher available P content in basaltic soil can be explained by P fertilization and decomposition of basaltic rock. Both factors contribute to an increased level of exchangeable bases in soil, thereby influencing the amount of available P (Dieckow et al., 2009). This assumption is supported by the higher concentrations of Ca$^{2+}$ and Mg$^{2+}$ at the 0.10–0.20 and 0.20–0.40 m depths (Figure 1c and d).
Figure 2. Total organic carbon (TOC) content in vineyard soils of basaltic (VB) and rhyodacitic (VR) origin at depths of 0.00–0.05, 0.05–0.10, 0.10–0.20, and 0.20–0.40 m.

Solution equilibrium P contents (10–23 mg kg\textsuperscript{-1}) (Figure 2b) were highest in basaltic soil at all layers and decreased with increasing depth. P adsorption is greater in oxidic and acid soils because of the strong interactions between Fe and Al oxides and phosphate (Dortzbach et al., 2016; Almeida et al., 2010).

P is found in organic and inorganic forms in soil. The predominance of one form over the other varies with the solubility of ionic species. P can form highly stable compounds with SOM and mineral fractions (Shen et al., 2011). Organic P forms are important sources of P for plants; they comprise microbial biomass and compounds released during organic matter decomposition with varying degrees of recalcitrance (Nash et al., 2014).

Figure 3. Available and solution equilibrium P contents in vineyard soils of basaltic (VB) and rhyodacitic (VR) origin at depths of 0.00–0.05, 0.05–0.10, 0.10–0.20, and 0.20–0.40 m.

Figure 4 shows the levels of labile P extracted with sodium bicarbonate. Total P extracted with sodium bicarbonate ranged from 100 to 550 mg kg\textsuperscript{-1} (Figure 4a) and was higher in basaltic soil at 0.05–0.020 m depths. Inorganic P was higher in basaltic than in rhyodacitic soil at all depths; the highest levels were found at the 0.00–0.05 m depth (>100 mg kg\textsuperscript{-1}, Figure 4b). Organic P was higher in rhyodacitic soil at the 0.00–0.05 m depth but higher in basaltic soil at other depths, ranging from 80 to 500 mg kg\textsuperscript{-1} (Figure 4c).
Influence of parent material on organic phosphorus ...

Rev. Ambient. Água vol. 15 n. 5, e2546 - Taubaté 2020

Figure 4. Labile phosphorus (P) fraction in vineyard soils of basaltic (VB) and rhyodacitic (VR) origin at depths of 0.00–0.05, 0.05–0.10, 0.10–0.20, and 0.20–0.40 m. TP-bic, total P extracted with sodium bicarbonate (NaHCO₃); IP-bic, inorganic P extracted with NaHCO₃; OP-bic, organic P extracted with NaHCO₃.

P extracted with sodium bicarbonate is considered highly stable (Bowman and Cole, 1978). The high levels of P fractions extracted with sodium bicarbonate in basaltic soil can be attributed to P turnover, which was more intense in this soil because of the use of phosphate fertilizers (Gatiboni et al., 2008). Phosphate fertilization contributes to P lability, resulting from the gradual saturation of high-affinity P adsorption sites (Bravo et al., 2007). Labile P is essential for grapevine growth because it increases nutrient availability for plants (Schmitt et al., 2013).

In tropical climate regions, P occurs mostly in inorganic forms linked to mineral fractions (adsorbed P) and organic forms that are physically and chemically stable (Santos et al., 2008). Labile P is mainly found in the organic form. The higher levels of labile P in surface layers is likely due to the presence of plant litter, phosphate fertilizer, microbial biomass, and byproducts of their decomposition (Schmitt et al., 2013; Martinazzo et al., 2007).

P fractions extracted with H₂SO₄ are moderately labile (Bowman and Cole, 1978). Total P contents in the moderately labile fraction ranged from 200 to 600 mg kg⁻¹ (Figure 5a), inorganic P contents from 30 to 90 mg kg⁻¹ (Figure 5b), and organic P contents from 100 to 500 mg kg⁻¹ (Figure 5c). The major part of moderately labile P occurred in the organic form. In general, rhyodacitic soil had higher levels of moderately labile P in all layers, except for total and organic P at the 0.10–0.20 and 0.20–0.40 m depths.

The higher P levels in the moderately labile fraction of rhyodacitic soil can be attributed to its lower clay content. This leads to low P adsorption, contributing to the presence of moderately labile P fractions. When P is applied to the soil in higher quantities than that absorbed by plants, it accumulates in moderately labile forms, affecting P uptake. However, when P is applied in small quantities, moderately labile P can act as a source of P, meeting the nutrient demands of...
the crop (Schmitt et al., 2013; Gatiboni et al., 2008).

![Figure 5. Moderately labile phosphorus (P) fraction in vineyard soils of basaltic (VB) and rhyodacitic (VR) origin at depths of 0.00–0.05, 0.05–0.10, 0.10–0.20, and 0.20–0.40 m. TP-H, total P extracted with sulfuric acid (H$_2$SO$_4$); IP-H, inorganic P extracted with H$_2$SO$_4$; OP-H, organic P extracted with H$_2$SO$_4$.](image)

The degree of stability of the P forms is influenced by the microbial activity, the content of organic matter in the soil, the degree of weathering, the texture and mineralogical composition of the soil (Rheinheimer and Anghinoni, 2001). In general, the most prevalent forms of P in Brazilian soils are the slightly labile inorganic ones, because in the intensely weathered tropical soils the cycling of organic phosphorus from labile fractions is intense and accelerated.

P fractions extracted with NaOH are moderately resistant, as reported by Bowman and Cole (1978). In highly weathered soil, P usually occurs in moderately recalcitrant forms, which are highly correlated with Fe and Al oxides, kaolinite, and organic matter (Conte et al., 2003). Total P levels in the moderately resistant fraction (100–250 mg kg$^{-1}$, Figure 6a) were higher in basaltic soil at the 0.00–0.05 m depth. At other depths, both types of soil showed similar total P levels. Inorganic P contents ranged from 50 to 200 mg kg$^{-1}$ (Figure 6b) and were higher in basaltic soils at all depths. Different from that observed in labile and moderately labile P fractions, inorganic fractions were more predominant than organic fractions. Organic P contents ranged from 55 to 70 mg kg$^{-1}$ (Figure 6c); levels were highest at the 0.05–0.10 m depth in rhyodacitic soil but did not differ between soils at the 0.00–0.05 m depth.

The higher levels of moderately resistant P in basaltic soil can be explained by the high TOC content (Figure 2), as this fraction is highly correlated with SOM (Cunha et al., 2007; Beutler et al., 2015). The clayey texture of the soil may also have influenced the results. In the soil, phosphorus can be found in inorganic and organic forms, representing two large groups,
retained in clay minerals and present in organic compounds with varying degrees of energy. Organic phosphorus originates from organic residues added to the soil, from the tissue of microbial biomass and from its decomposition products. The biological and biochemical processes regulate the dynamics and distribution of P in the edaphic system, and the recycling of the organic form is an important factor in making this macronutrient available to vegetables (Rossi et al., 2013).

![Figure 6](image)

Figure 6. Moderately resistant phosphorus (P) fraction in vineyard soils of basaltic (VB) and rhyodacitic (VR) origin at depths of 0.00–0.05, 0.05–0.10, 0.10–0.20, and 0.20–0.40 m. TP-OH, total P extracted with sodium hydroxide (NaOH); IP-OH, inorganic P extracted with NaOH; OP-OH, organic P extracted with NaOH.

4. CONCLUSIONS

Soil parent material influenced the dynamics of phosphorus in vineyard soils. Both P forms (available and solution equilibrium P) and P organic fractions (labile, moderately labile, and moderately resistant P), are affected by the parent material. Vineyard soils of basaltic origin contained higher levels of labile and moderately labile P, whereas vineyard soils of rhyodacitic origin had higher levels of moderately resistant P. The predominance of the more labile P fractions in basaltic vineyard soil may be related to the higher TOC and available and solution equilibrium P contents.

5. ACKNOWLEDGEMENTS

This study was financed in part by the Brazilian Federal Agency for Support and Evaluation of Graduate Education (CAPES, Finance Code 001).
6. REFERENCES

ALMEIDA, J. A.; MAÇANEIRO, K. C.; KLAMT, E. Mineralogia da fração argila de solos vermelhos com horizontes superficiais brunados do Planalto de Lages (SC). Revista Brasileira de Ciência do solo, v. 24, p. 815-828, 2000. https://doi.org/10.1590/S0100-0683200000400014

ALVAREZ, V. H.; FONSECA, D. M. Definição de doses de fósforo para determinação da capacidade máxima de adsorção de fosfatos e para ensaios em casa de vegetação. Revista Brasileira de Ciência do Solo, v. 14, p. 49-55, 1990. https://doi.org/10.1590/S0103-90162007000600007

BEUTLER, S. J.; PEREIRA, M. G.; LOSS, A.; PERIN, A.; CUNHA dos ANJOS, L. H. Humic substances and phosphorus fractions in areas with crop-livestock integration, pasture and natural Cerrado vegetation in Goiás, Brazil. Tropical and Subtropical Agroecosystems, v. 18, n. 1, p. 11-25, 2015.

BORGHEZAN, M.; GAVIOLI, O.; PIT, F. A.; SILVA, A. L. da. Comportamento vegetativo e produtivo da videira e composição da uva em São Joaquim, Santa Catarina. Pesquisa Agropecuária Brasileira, v. 46, n. 4, p. 398-405, 2011. https://doi.org/10.1590/S0100-204X2011000400009

BOWMAN, R. A. A sequential extraction procedure with concentrated sulfuric acid and dilute base for soil organic phosphorus. Soil Science Society of America Journal, v. 53, p. 326-366, 1989. https://dx.doi.org/10.2136/sssaj1989.03615995005300020008x

BOWMAN, R. A.; COLE, C. V. Transformation of organic phosphorus substrates in soil as evaluated by NaHCO₃ extraction. Soil Science, v. 125, p. 95-101, 1978.

BRAGA, J. M.; DEFELIPO, B. V. Determinação espectrofotométrica de fósforo em extratos de solo e material vegetal. Revista Ceres, v. 21, p. 73-85, 1974.

BRAVO, C. A.; GIRALDEZ, J. V.; ORDOÑEZ, R.; GONZALEZ, P.; TORRES, F. P. Long term influence of conservation tillage on chemical properties of surface horizon and legume crops yield in a Vertisol of Southern Spain. Soil Science, v. 172, n. 2, p. 141-148, 2007. https://dx.doi.org/10.1097/ss.0b013e31802db198

CAMARGO, U. A.; TONIETTO, J.; HOFFMANN, A. Progressos na viticultura brasileira. Revista Brasileira de Fruticultura, v. 33, p. 144-149, 2011. https://doi.org/10.1590/S0100-29452011000500017

CERETA, C. A.; LORENSINI, F.; BRUNETTO, G.; GIROTTO, E.; GATIBONI, L. C.; LOURENZI, C. R.; TIECHER, T. L.; TRENTIN, G.; MIOTTO, A. Frações de fósforo no solo após sucessivas aplicações de dejetos de suínos em plantio direto. Pesquisa Agropecuária Brasileira, v. 45, p. 593-602, 2010. https://doi.org/10.1590/S0100-204X2010000600009

CLEMENTE, C. A.; AZEVEDO, A. C. Mineral weathering in acid saprolites from subtropical, Southern Brazil. Scientia Agricola, v. 64, p. 601-607, 2007. https://doi.org/10.1590/S0103-90162007000600007
CONTE, E.; ANGHINONI, I.; RHEINHEIMER, D. S. Frações de fósforo acumuladas em Latossolo argiloso pela aplicação de fosfato no sistema plantio direto. *Revista Brasileira de Ciência do Solo*, v. 27, n. 5, p. 893-900, 2003. https://doi.org/10.1590/S0100-0683200300500014

CUNHA, G. D. M.; da GAMA-RODRIGUES, A. C.; COSTA, G. S.; VELLOSO, A. C. X. Fósforo orgânico em solos sob florestas montanas, pastagens e eucalipto no norte fluminense. *Revista Brasileira de Ciência do Solo*, v. 31, n. 4, p. 667-672, 2007. https://doi.org/10.1590/S0100-06832007000400007

DALMOLIN, R. S. D.; GONÇALVES, C. N.; DICK, D. P.; KNICKER, H.; KLAMT, E.; KÖGEL-KNABNER, I. Organic matter characteristics and distribution in Ferralsol profiles of a climosequence in southern Brazil. *European Journal of Soil Science*, v. 57, n. 5, p. 644-654, 2006. https://doi.org/10.1111/j.1365-2389.2005.00755.x

DIECKOW, J.; BAYER, C.; CONCEIÇÃO, P. C.; ZANATTA, J. A.; MARTIN-NETO, L.; MILORI, D. B. M.; HERNANI, L. C. Land use, tillage, texture and organic matter stock and composition in tropical and subtropical Brazilian soils. *European Journal of Soil Science*, v. 60, n. 2, p. 240-249, 2009. https://doi.org/10.1111/j.1365-2389.2008.01101.x

DORTZBACH, D.; PEREIRA, M. G.; ANJOS, L. H. C. D.; FONTANA, A.; SILVA NETO, E. D. C. Genesis and classification of soils from subtropical mountain regions of southern Brazil. *Revista Brasileira de Ciência do Solo*, v. 40, p. 1-16, 2016. https://doi.org/10.1590/18069657rbcs20150503

FAO. *World reference base for soil resources 2014*: International soil classification system for naming soils and creating legends for soil maps: Update 2015. Rome, 2015.

GATIBONI, L. C.; BRUNETTO, G.; KAMINSKI, J.; RHEINHEIMER, D. S.; CERETTA, C. A.; BASSO, C. J. Formas de fósforo no solo após sucessivas adições de dejetó líquido de suínos em pastagem natural. *Revista Brasileira de Ciência do Solo*, v. 32, p. 1753-1761, 2008. https://doi.org/10.1590/S0100-06832008000400040

GUARESCHI, R. F.; PEREIRA, M. G.; PERIN, A. Adsorption of P and forms of iron in no-tillage areas in the 'Cerrado' biome. *Acta Scientiarum Agronomy*, v. 37, n. 1, p. 109-116, 2015. http://dx.doi.org/doi:10.4025/actasciagron.v37i1.17686

IBRAVIN. *Panorama Geral*. 2018. Available at: http://www.ibravin.org.br/panorama-geral. Access: 12 Sep. 2019.

LIU, S.; MENG, J.; JIANG, L.; YANG, X.; LAN, Y.; CHENG, X.; CHEN, W. Rice husk biochar impacts soil phosphorus availability, phosphatase activities and bacterial community characteristics in three different soil types. *Applied Soil Ecology*, v. 116, p. 12-22, 2017. https://doi.org/10.1016/j.apsoil.2017.03.020

MARTINAZZO, R.; RHEINHEIMER, D. S.; GATIBONI, L. C.; BRUNETTO, G.; KAMINSKI, J. Fósforo microbiano do solo sob sistema plantio direto em resposta à adição de fosfato solúvel. *Revista Brasileira de Ciência do Solo*, v. 31, p. 563-570, 2007. https://dx.doi.org/10.1590/S0100-06832007000300016

MELLO, L. M. R. de. *Vitivinicultura Brasileira*: panorama 2012. Bento Gonçalves: Embrapa Uva e Vinho, 2013.
NASH, D. M.; HAYGARTH, P. M.; TURNER, B. L.; CONDRON, L. M.; MCDOWELL, R. W.; RICHARDSON, A. E.; HEAVEN, M. W. Using organic phosphorus to sustain pasture productivity: a perspective. *Geoderma*, v. 221, p. 11-19, 2014. https://doi.org/10.1016/j.geoderma.2013.12.004

NOVAIS, R. F.; SMYTH, T. J.; NUNES, F. N. Fósforo. In: NOVAIS, R. F.; ALVAREZ V.; V. H.; BARROS, N. F.; FONTES, R. L. F.; CANTARUTTI, R. B.; NEVES, J. C. L. (Eds.) *Fertilidade do solo*. Viçosa, MG: SBCS, 2007. p. 471-537.

REGINA, M. A.; FRÁGUAS, J. C.; ALVARENGA, A.; SOUZA, C. R.; AMORIM, D.; FÁVERO, R. Implantação e manejo do vinhedo para produção de vinhos de qualidade. *Informe Agropecuário*, v. 27, n. 234, p. 16-31, 2006. https://doi.org/10.1590/S0100-29452011000500017

RESENDE, J. C. F.; BUSTAMANTE, M. M. C.; MARKEWITZ, D.; KLINK, C. A.; DAVIDSON, E. A. Phosphorus cycling in a small watershed in the Brazilian Cerrado: impacts of frequent burning. *Biogeochemistry*, v. 105, p. 105-118, 2011. https://doi.org/10.1007/s10533-010-9531-5

RHEINHEIMER, D. S.; ANGHINONI, I. Distribuição do fósforo inorgânico em sistemas de manejo de solo. *Pesquisa Agropecuária Brasileira*, v. 36, n. 1, p. 151-160, 2001. https://doi.org/10.1590/S0100-204X2001000100019

ROSSI, C. Q.; PEREIRA, M. G.; GARCÍA, A. C.; PERIN, A.; GAZOLLA, P. R.; GONZÁLEZ, A. P. Fósforo em cronossequência de cana-de-açúcar queimada no cerrado goiano: análise de ácidos húmicos por RMN de 31P. *Química Nova*, v. 36, n. 8, p. 1126-1130, 2013. https://doi.org/10.1590/S0100-40422013000800009

SANTA CATARINA. Gabinete de Planejamento e Coordenação Geral. Subchefia de Estatística, Geografia e Informática. *Atlas de Santa Catarina*. Florianópolis, 1986. 173p.

SANTOS, H. P. Aspectos ecofisiológicos na condução da videira e sua influência na produtividade do vinhedo e na qualidade dos vinhos. Bento Gonçalves: Embrapa Uva e Vinho, 2006. 9 p. (Comunicado Técnico, 71).

SANTOS, J. Z. L.; FURTINI NETO, A. E.; RESENDE, Á.V.; CURI, N.; CARNEIRO, L. F.; COSTA, S. E. V. G. A. Frações de fósforo em solo adubado com fosfatos em diferentes modos de aplicação e cultivado com milho. *Revista Brasileira de Ciência do Solo*, v. 32, p. 705-714, 2008. https://doi.org/10.1590/S0100-06832008000200025

SCHMITT, D. E.; COMIN, J. J.; GATIBONI, L. C.; TIECHER, T.; LORENSINI, F.; MELLO, G. W. B.; GIROTTO, E.; GUARDINI, R.; HEINZEN, J.; BRUNETTO, G. Phosphorus fractions in sandy soils of vineyards in southern Brazil. *Revista Brasileira de Ciência do Solo*, v. 37, p. 472-481, 2013. https://doi.org/10.1590/S0100-06832013000200018

SHEN, J.; YUAN, L.; ZHANG, J.; LI, H.; BAI, Z.; CHEN, X.; ZHANG, F. Phosphorus dynamics: from soil to plant. *Plant physiology*, v. 156, n. 3, p. 997-1005, 2011. https://dx.doi.org/10.1104/pp.111.175232

SIMAS, F. N.; SCHAEFER, C. E.; FERNANDES FILHO, E. I.; CHAGAS, A. C.; BRANDAO, P. C. Chemistry, mineralogy and micropedology of highland soils on crystalline rocks of Serra Da Mantiqueira, southeastern Brazil. *Geoderma*, v. 125, n. 3-4, p. 187-201, 2005. https://doi.org/10.1016/j.geoderma.2004.07.013
TEIXEIRA, P. C.; DONAGEMMA, G. K., FONTANA, A., TEIXEIRA, W. G. Manual de métodos de análise de solo. Embrapa, Brasília. 2017, 434p.

TOKURA, A. M., FURTINI, A. E.; CARNEIRO, L. F.; CURI, N.; SANTOS, J. Z. L.; ALOVISI, A. A. Dynamics of phosphorus forms in soils with contrasting texture and mineralogy cultivated with rice. Acta Scientiarum. Agronomy, v. 33, p. 171-179, 2011. https://doi.org/10.4025/actasciagron.v33i1.1435

TONIETTO, J. Valorização do ecossistema: importância da regionalização vitivinícola na produção de vinhos de qualidade. In: CONGRESO LATINOAMERICANO DE VITICULTURA Y ENOLOGIA, 8., 2001, Montevideo. Annales[...] Montevideo: Asociación de Enólogos del Uruguay, 2001. p.1-9. (CD rom).

YEOMANS, J. C.; BREMNER, J. M. A rapid and precise method for routine determination of organic carbon in soil. Communication in Soil Science and Plant Analysis, v. 19, p. 1467–1476, 2008. https://doi.org/10.1080/001036288093680271988