



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

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### 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 H<sub>2</sub>O, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Al<sup>3+</sup>, P, K<sup>+</sup>, 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 H<sub>2</sub>O, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Al<sup>3+</sup>, 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 riódacitos 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 (Borghazan *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).

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 Iguaçu/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 H<sub>2</sub>O (1:2.5 ratio); available P and K<sup>+</sup>, extracted with Mehlich-1 (0.0125 mol L<sup>-1</sup> H<sub>2</sub>SO<sub>4</sub> and 0.050 mol L<sup>-1</sup> HCl); exchangeable Ca<sup>2+</sup>, Mg<sup>2+</sup>, and Al<sup>3+</sup>, extracted with 1 mol L<sup>-1</sup> KCl; and H + Al, extracted with 0.5 mol L<sup>-1</sup> calcium acetate (pH 7) and titrated with 0.0125 mol L<sup>-1</sup> 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<sup>-1</sup> CaCl<sub>2</sub> and 60 mg L<sup>-1</sup> 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  $0.5 \text{ mol L}^{-1} \text{ NaHCO}_3$  at pH 8; moderately labile phosphorus is extracted with  $0.5 \text{ mol L}^{-1} \text{ H}_2\text{SO}_4$ ; and moderately resistant phosphorus is extracted with  $0.5 \text{ mol L}^{-1} \text{ NaOH}$ .

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

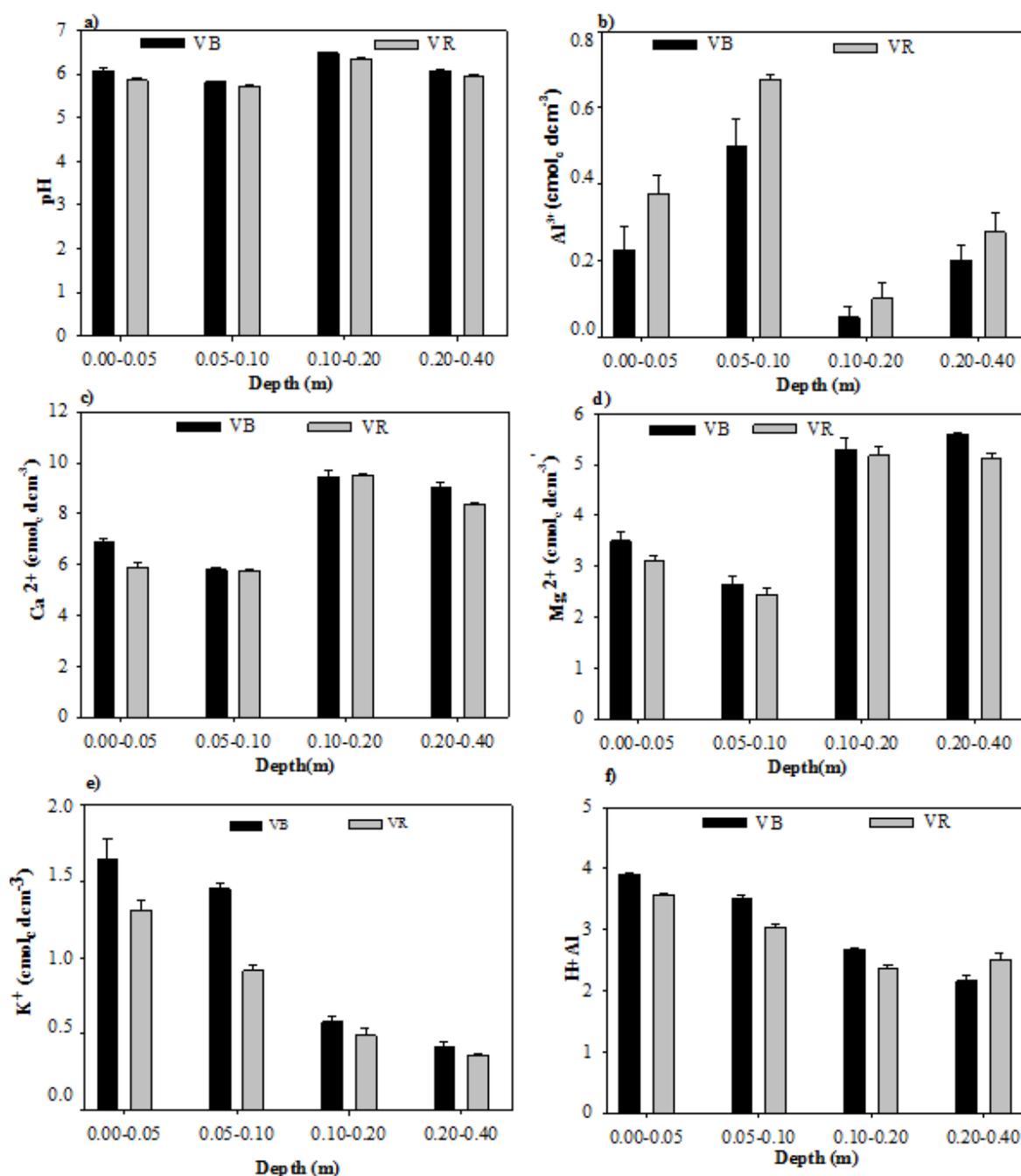
The chemical attributes of vineyard soils are presented in Figure 1. The mean pH value was  $6.22 \pm 0.20$  in the vineyards with basaltic soils (VB) and  $5.86 \pm 0.13$  in the vineyards with rhyodacitic soils (VR) (Figure 1a). Soils were limed to this pH because of their acidic nature; in some cases, liming was performed even after planting. At all depths, the highest  $\text{Al}^{3+}$  values were found in rhyodacitic soils (mean  $\text{Al}^{3+} = 0.44 \pm 0.17 \text{ cmol}_c.\text{dcm}^{-3}$ ) (Figure 1b). In vineyards with basaltic soils the mean value was  $\text{Al}^{3+} = 0.16 \pm 0.09 \text{ cmol}_c.\text{dcm}^{-3}$ . The levels of  $\text{Al}^{3+}$  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  $\text{Al}^{3+}$  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  $\text{Al}^{3+}$  in the soil solution (Dortzbach *et al.*, 2016; Clemente and Azevedo, 2007).

Basaltic soils showed higher levels of  $\text{Ca}^{2+}$  at all depths (mean  $\text{Ca}^{2+}$  in VB =  $9.09 \pm 0.50 \text{ cmol}_c.\text{dcm}^{-3}$  and  $\text{Ca}^{2+}$  in VR =  $6.09 \pm 0.42 \text{ cmol}_c.\text{dcm}^{-3}$ ). In all soils the  $\text{Ca}^{2+}$  levels were higher in the 0.10–0.20 m depth than in the 0.05–0.10 m depth layer. Similarly,  $\text{Mg}^{2+}$  contents were higher in basaltic soils (mean  $\text{Mg}^{2+}$  in VB =  $5.30 \pm 0.28 \text{ cmol}_c.\text{dcm}^{-3}$  and mean  $\text{Mg}^{2+}$  in VR =  $2.93 \pm 0.38 \text{ cmol}_c.\text{dcm}^{-3}$ ). Also, the highest  $\text{Mg}^{2+}$  levels were observed at the 0.05–0.10 and 0.10–0.20 m depths.  $\text{K}^+$  levels were also higher in the vineyards with basaltic soils (mean  $\text{K}^+$  in VB =  $1.23 \pm 0.26 \text{ cmol}_c.\text{dcm}^{-3}$  and mean  $\text{K}^+$  in VR =  $0.46 \pm 0.09 \text{ cmol}_c.\text{dcm}^{-3}$ ) 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  $\text{cmol}_c \text{ dcm}^{-3}$  (mean H+Al in VB =  $2.43 \pm 0.19 \text{ cmol}_c.\text{dcm}^{-3}$  and mean H+Al in VR =  $3.51 \pm 0.25 \text{ cmol}_c.\text{dcm}^{-3}$ ). 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 ( $20\text{--}35 \text{ g kg}^{-1}$ ) were higher in basaltic soils at all depths (mean TOC in VB =  $28.1 \pm 5.8 \text{ g.kg}^{-1}$  and mean TOC in VR =  $24.7 \pm 4.1 \text{ cmol}_c.\text{dcm}^{-3}$ ). This difference was particularly pronounced at the 0.10–0.20 m depth.

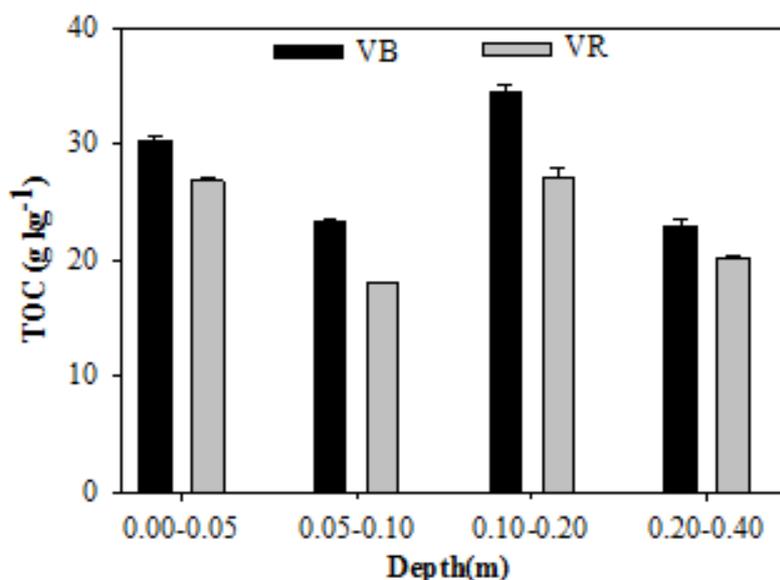
Soil TOC levels generally decrease with depth, as surface layers are high in biological activity and plant litter. However, tillage or other soil preparation techniques can alter this profile, leading to higher TOC levels in subsurface layers. The differences in TOC levels between vineyard soils of different 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

(Dieckow *et al.*, 2009; Dalmolin *et al.*, 2006).

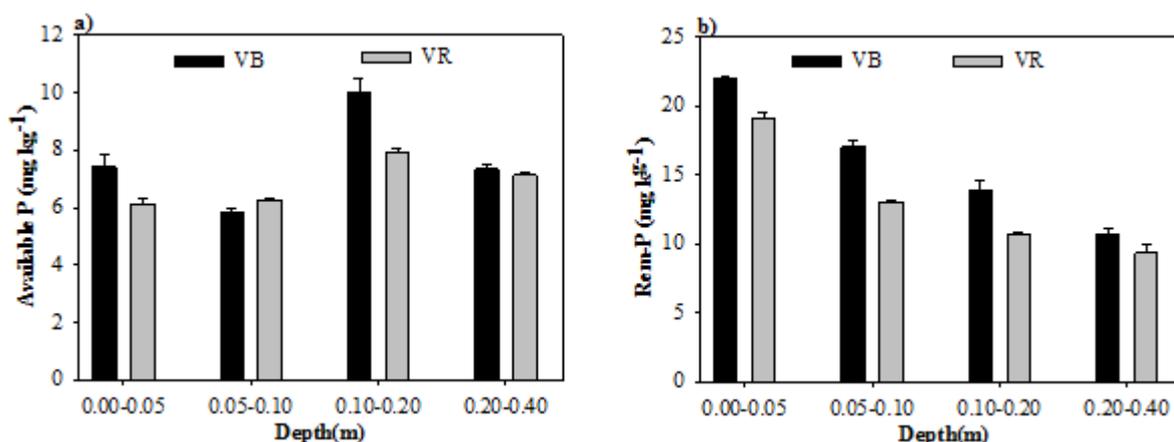


**Figure 1.** Chemical attributes of vineyard soils of basaltic (VB) and rhyodacitic (VR) origin at depths of 0.00–0.05, 0.05–0.10, 0.10–0.20, and 0.20–0.40 m.

Available and solution equilibrium P levels are presented in Figure 3. Available P levels ranged from 6 to 10 mg kg<sup>-1</sup> (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<sup>2+</sup> and Mg<sup>2+</sup> 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.

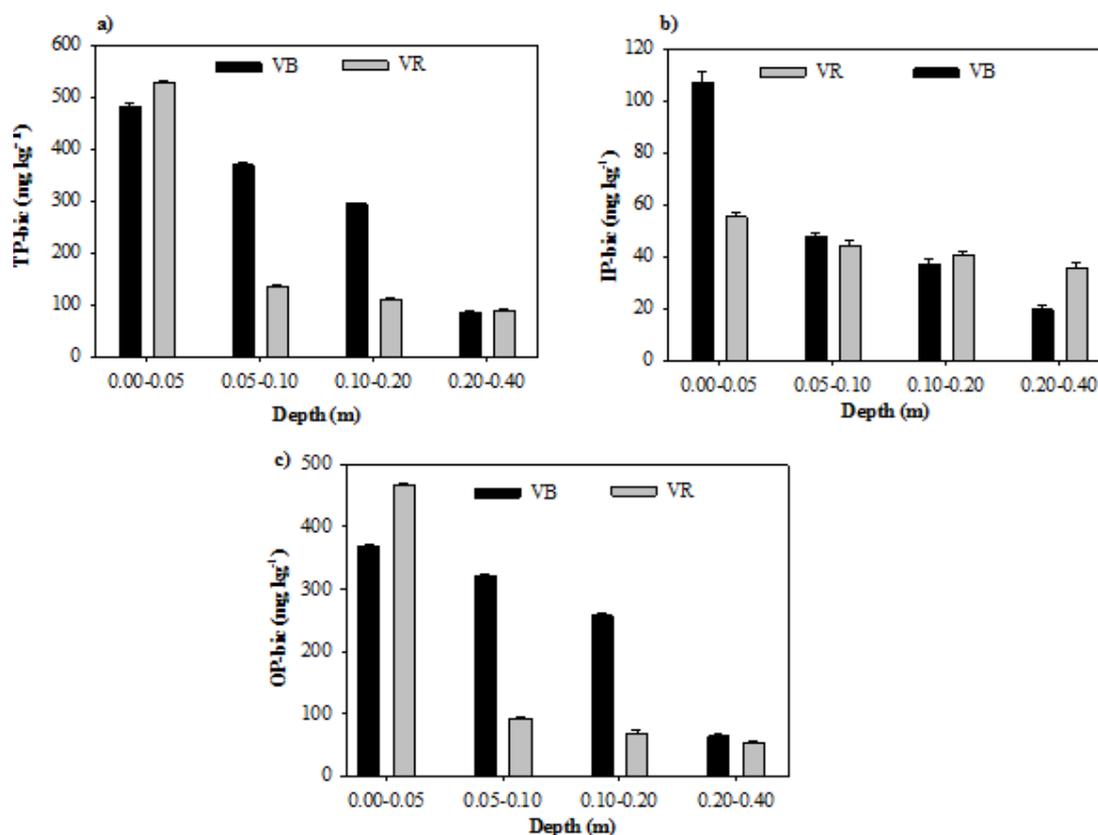


**Figure 3.** Available and solution equilibrium P contents in vineyard soils of basaltic (VB) and rhyodacitic (VR) origin at depths of 0.00–0.05, 0.05–0.10, 0.10–0.20, and 0.20–0.40 m.

Solution equilibrium P contents (10–23 mg kg<sup>-1</sup>) (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 4 shows the levels of labile P extracted with sodium bicarbonate. Total P extracted with sodium bicarbonate ranged from 100 to 550 mg kg<sup>-1</sup> (Figure 4a) and was higher in basaltic soil at 0.05–0.20 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<sup>-1</sup>, 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<sup>-1</sup> (Figure 4c).



**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 ( $\text{NaHCO}_3$ ); IP-bic, inorganic P extracted with  $\text{NaHCO}_3$ ; OP-bic, organic P extracted with  $\text{NaHCO}_3$ .

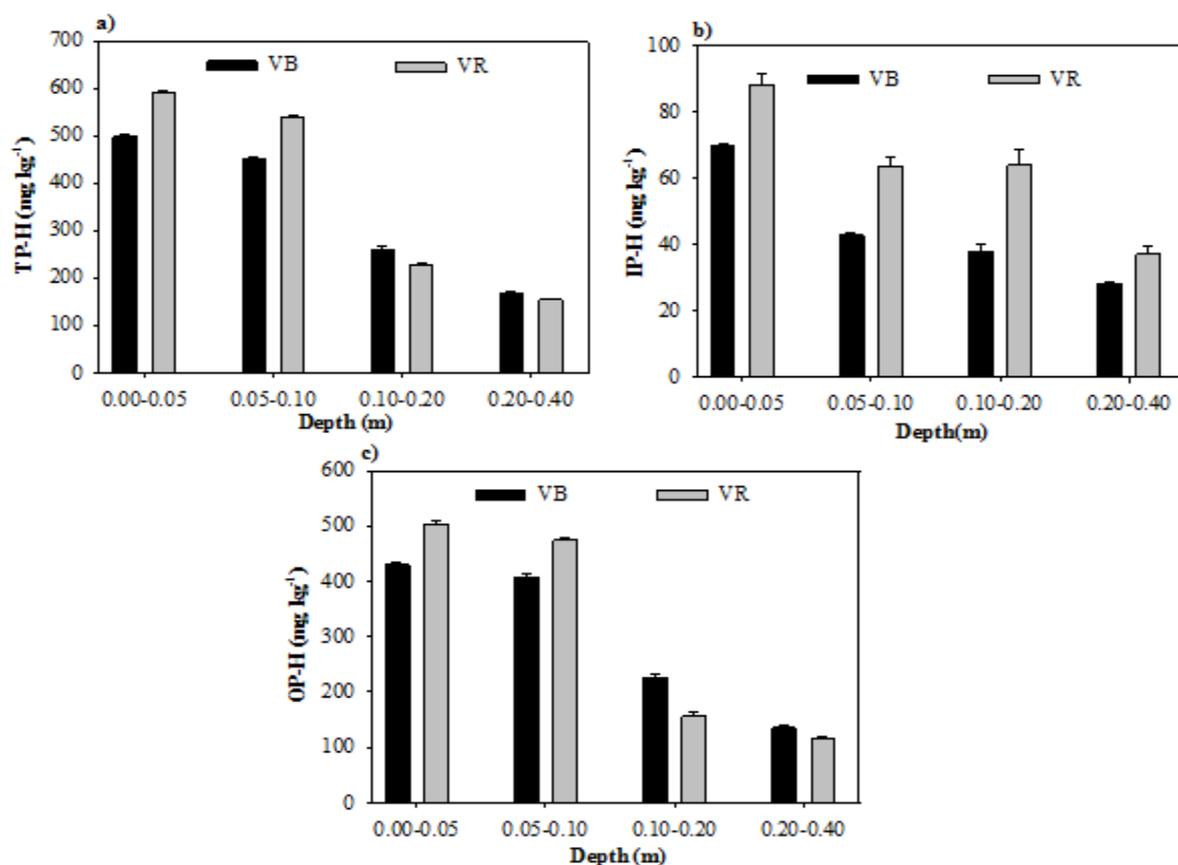
P extracted with sodium bicarbonate is considered highly stable (Bowman and Cole, 1978). The high levels of P fractions extracted with sodium bicarbonate in basaltic soil can be attributed to P turnover, which was more intense in this soil because of the use of phosphate fertilizers (Gatiboni *et al.*, 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  $\text{H}_2\text{SO}_4$  are moderately labile (Bowman and Cole, 1978). Total P contents in the moderately labile fraction ranged from 200 to  $600 \text{ mg kg}^{-1}$  (Figure 5a), inorganic P contents from 30 to  $90 \text{ mg kg}^{-1}$  (Figure 5b), and organic P contents from 100 to  $500 \text{ mg kg}^{-1}$  (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).



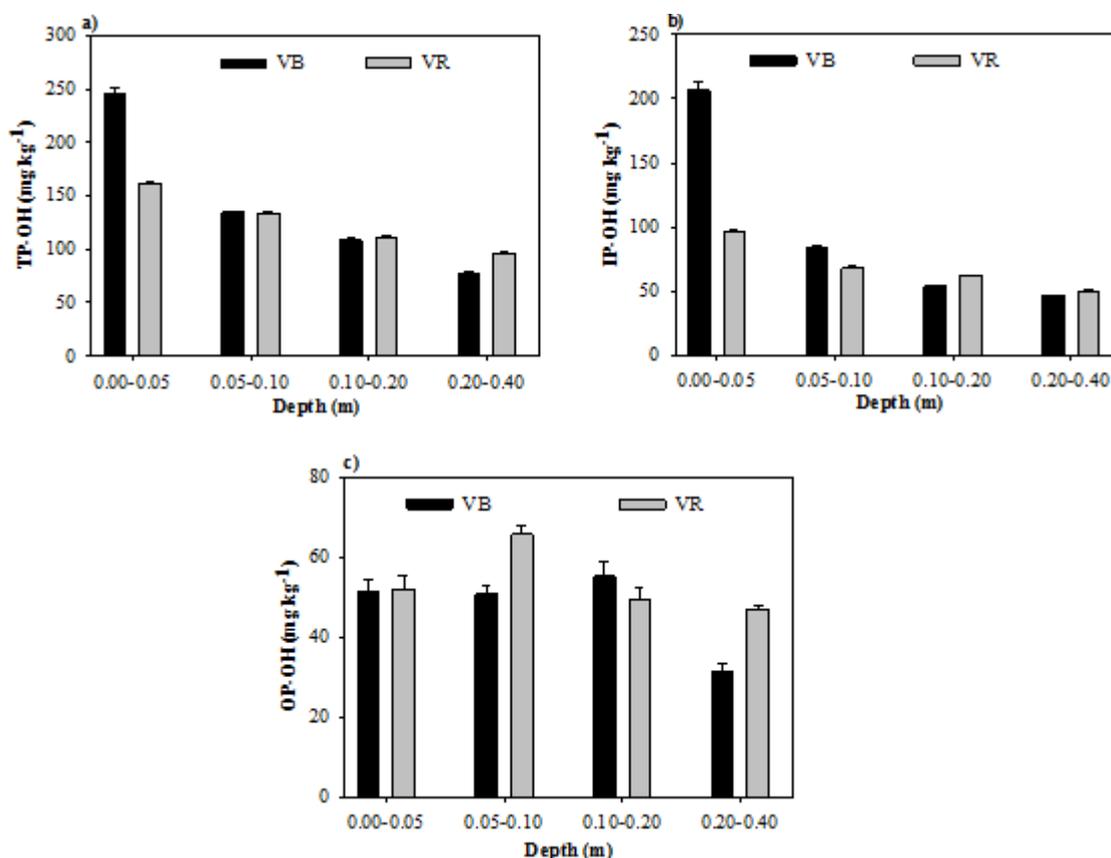
**Figure 5.** Moderately labile phosphorus (P) fraction in vineyard soils of basaltic (VB) and rhyodacitic (VR) origin at depths of 0.00–0.05, 0.05–0.10, 0.10–0.20, and 0.20–0.40 m. TP-H, total P extracted with sulfuric acid (H<sub>2</sub>SO<sub>4</sub>); IP-H, inorganic P extracted with H<sub>2</sub>SO<sub>4</sub>; OP-H, organic P extracted with H<sub>2</sub>SO<sub>4</sub>.

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<sup>-1</sup>, 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<sup>-1</sup> (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<sup>-1</sup> (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.** 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

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