

ISSN 1678-3921

Journal homepage: [www.embrapa.br/pab](http://www.embrapa.br/pab)

For manuscript submission and journal contents,  
access: [www.scielo.br/pab](http://www.scielo.br/pab)

# Phosphorus fractions in soil cultivated with vineyards after 62 years of poultry litter addition

**Abstract** – The objective of this work was to evaluate changes in phosphorus fractions in a Humic Cambisol cultivated with vineyards, after 62 years of additional fertilization with poultry litter. Soil samples were collected from two vineyards (V1 and V2) and a forested area adjacent to them. A total of 1,365 and 910 kg ha<sup>-1</sup> P were applied to V1 and V2, respectively, throughout the past 62 years. Samples were collected at 0–10, 10–20, 20–30, and 30–40-cm soil depths for the analysis of soil physicochemical properties. The addition of poultry litter to the soil of the vineyards increased the contents of inorganic P (P<sub>i</sub>) in all fractions, except in the residual fraction (residual-P), mainly at the 0–10-cm soil depth, in comparison with the forested area. The addition of poultry litter as fertilizer does not affect the organic P (P<sub>o</sub>) stock in the Humic Cambisol, it only increases the P<sub>i</sub> contents of the soil.

**Index terms:** *Vitis labrusca*, chemical fractionation of P, grapevine, organic phosphorus, organic residue.

## Frações de fósforo em solo cultivado com vinhedos após 62 anos de adição de cama-de-aves

**Resumo** – O objetivo deste trabalho foi avaliar as modificações de frações de fósforo em um Cambissolo Húmico cultivado com vinhedos, após 62 anos de fertilização adicional com cama-de-aves. Amostras de solo foram coletadas de dois vinhedos (V1 e V2) e de uma área de floresta (F) adjacente a eles. Foram aplicados 1.362 e 910 kg ha<sup>-1</sup> de P ao V1 e ao V2, respectivamente, durante os últimos 62 anos de cultivo. Amostras de solo foram coletadas a 0–10, 10–20, 20–30 e 30–40 cm de profundidade, para análises das propriedades físico-químicas do solo. A adição de cama-de-aves ao solo dos vinhedos aumentou os teores de P inorgânico (P<sub>i</sub>) em todas as frações, exceto na fração residual, principalmente à profundidade de 0–10 cm, em comparação à área de floresta. A adição de cama-de-aves como fertilizante não afeta os estoques de P orgânico (P<sub>o</sub>) do Cambissolo Húmico, apenas aumenta os teores de P<sub>i</sub> do solo.

**Termos para indexação:** *Vitis labrusca*, fracionamento químico de P, videira, fósforo orgânico, resíduo orgânico.

## Introduction

In the subtropical region of Brazil, many vineyard management decisions are based on empirical knowledge, without technical standards or soil testing. As a consequence, vineyard soils are often poor in nutrients. When agricultural liming and fertilization requirements

Djalma Eugênio Schmitt<sup>(1)</sup> ✉, Luciano Colpo Gatiboni<sup>(2)</sup>, Joice Crescêncio Heidemann<sup>(3)</sup>, Daniel João Dall'Orsoletta<sup>(2)</sup>, Gustavo Boitt<sup>(4)</sup> and Gustavo Brunetto<sup>(5)</sup>

<sup>(1)</sup> Universidade Federal de Santa Catarina, Departamento de Agricultura, Biodiversidade e Florestas, Rodovia Ulysses Gaboardi, nº 3.000, Campo da Roça, CEP 89520-000 Curitiba, SC, Brazil. E-mail: [djalma.schmitt@gmail.com](mailto:djalma.schmitt@gmail.com)

<sup>(2)</sup> Universidade do Estado de Santa Catarina, Departamento de Solos e Recursos Naturais, Avenida Luiz de Camões, nº 2.090, Conta Dinheiro, CEP 88520-000 Lages, SC, Brazil. E-mail: [lgatiboni@gmail.com](mailto:lgatiboni@gmail.com), [dani.orsoletta@gmail.com](mailto:dani.orsoletta@gmail.com)

<sup>(3)</sup> Universidade Federal de Viçosa, Departamento de Biologia Vegetal, Avenida P. H. Rolfs, s/nº, CEP 36570-000 Viçosa, MG, Brazil. E-mail: [sunjoyflower@gmail.com](mailto:sunjoyflower@gmail.com)

<sup>(4)</sup> University of Western Australia, M079, Soil Science Building - Soils West, 35 Stirling Highway, Perth 6009, WA, Australia. E-mail: [gustavo.boitt@uwa.au](mailto:gustavo.boitt@uwa.au)

<sup>(5)</sup> Universidade Federal de Santa Maria, Avenida Roraima, nº 1.000, Cidade Universitária, Camobi, CEP 97105-900 Santa Maria, RS, Brazil. E-mail: [brunetto.gustavo@gmail.com](mailto:brunetto.gustavo@gmail.com)

✉ Corresponding author

Received  
May 28, 2018

Accepted  
May 7, 2019

**How to cite**  
SCHMITT, D.E.; GATIBONI, L.C.; HEIDEMANN, J.C.; DALL'ORSOLETTA, D.J.; BOITT, G.; BRUNETTO, G. Phosphorus fractions in soil cultivated with vineyards after 62 years of poultry litter addition. *Pesquisa Agropecuária Brasileira*, v.54, e00817, 2019. DOI: <https://doi.org/10.1590/S1678-3921.pab2019.v54.00817>.



are diagnosed, mainly by soil analyses, lime and other nutrients including phosphorus (P) are often prescribed (Silva et al., 2016).

Phosphorus is highly reactive in the soil – both in alkaline soils (Eriksson et al., 2015) and weathered acid soils (Boitt et al., 2018). When the applications of organic fertilizers are carried out above the exportation by the plants, P accumulation takes place in several fractions (Boitt et al., 2018). Phosphorus accumulations are usually more pronounced in inorganic fractions (He et al., 2008; Boitt et al., 2018) due to part of the organic fertilizer showing Pi (Turner & Leytem, 2004), and also due to the mineralization of part of organic P of the soil (Steffens et al., 2010).

Current technical recommendation for fertilization before grapevine planting is to apply the fertilizers and incorporate them into the soil to approximately 20 cm depth (Hanlon et al., 2005). For side dressing, the fertilizers are only spread on top of the soil, without manual incorporation (Skinner et al. 1988). However, in older vineyards, phosphate fertilizers were often added without technical criteria, and at doses exceeding the requirements for the grapevine (*Vitis* sp.) crop; these issues were especially common for side dressing (Schmitt et al., 2013b).

Since P is poorly absorbed by grapevine, only a small quantity of P is transported to grape bunches (Tecchio et al., 2011), which can lead to an accumulation of P fractions in the soil layers (Wang et al., 2015), and increase the risk of environmental losses of the more labile P fractions (Gatiboni et al., 2015) by surface runoff (Sharpley et al., 1996); surface runoff is a risk for vineyard on steeper slopes. Therefore, frequent monitoring of soil P levels is required.

Simple P extraction methods such as Olsen, Bray, anion-exchange resin, Mehlich-1, and Mehlich-3 only extract part of the labile P from the soil, masking the occluded P and mineral-bound P, which hampers the understanding of P soil dynamics (Yang & Post, 2011). However, in the chemical P fractionation method proposed by Hedley et al. (1982), P is extracted from the soil in stages with different extractors, which allows of a more accurate quantification of P.

There is a lack of research addressing the accumulation and distribution of P fractions in clayey vineyard soils on steep slopes, with high-P adsorption capacity and a long history of organic residue application. Under these conditions, P<sub>1</sub> and P<sub>0</sub> contents of the moderately labile P fractions are

expected to be greater in vineyards with lesser slopes, especially in the near-surface soil. For this reason, successive applications of poultry litter to the vineyard soil surface are supposed to cause P accumulation in different P pools, mainly the most labile forms and in the near-surface soil.

The objective of this work was to evaluate changes in P fractions in a Humic Cambisol cultivated with vineyards, after 62 years of the addition of poultry litter as fertilizer.

## Materials and Methods

The experiment was carried out in the municipality of Videira, in the midwestern of Santa Catarina state, Southern Brazil, in two vineyard (V1 and V2) areas settled in 1950, and in a forested area (F) located next to the vineyards, as a reference. The vineyards were 62 years old, had approximately 2 ha each, and were located at as follows: V1, 26°57'14"S and 51°12'39"W; V2, 26°57'14"S and 51°12'29"W; and F, 26°57'09"S and 51°12'25"W. The V1 and V2 areas had a mean slope of 16 and 26%, respectively. The climate of the region is humid mesothermic with mild summers, according to the Köppen-Geiger's classification (Cfb). The mean annual temperature is 16.5°C, and the mean annual rainfall is 1,400 mm. Soil type of both vineyards, according to Santos et al. (2013), is Cambissolo Húmico, i.e. Humic Cambisol (FAO, 1998), with a predominance of kaolinite in the clay fraction.

*Vitis labrusca* 'Isabel' was grown on ungrafted rootstock in both vineyards, in pergola vine training systems with plants spaced 2.0 m apart, and rows spaced 3.5 m apart (1,525 plants ha<sup>-1</sup>). V1 and V2 soils, were subjected to 6 and 4 Mg ha<sup>-1</sup> poultry litter addition once every 5 year, respectively. Poultry litter was applied at 78 and 52 Mg ha<sup>-1</sup> to the soil surface both in and between rows, without incorporation to the soil, in V1 and V2, respectively. Poultry litter was obtained from raising 6-8 batches of birds, and each application contained 17.5 g kg<sup>-1</sup> P on average (Silva et al., 2016). Thus, over the course of 62 years of grapevine cultivation, total P amounts at 1,365 and 910 kg ha<sup>-1</sup> P were added to V1 and V2, respectively. No other nutrient source was used in the management of the vineyards except for leaf applications of the Bordeaux mixture for disease control, which added Ca, S, and Cu to the system.

In March 2012, five years after the last application of poultry manure, six trenches (60 x 60 cm) were randomly dug in the F, V1 and V2 areas. Soil samples were collected at 0–10, 10–20, 20–30, and 30–40 cm depth, in six replicates. The soil was air-dried and organic coarse material were removed manually. The soil was then ground in an agate mortar and pestle before being stored for analysis.

Soil samples from each depth were analysed by the pipette method for distribution of particle size soil constituents (Claessen, 1997). Organic matter (OM) content was determined by the Walkley-Black method (Claessen, 1997), and soil pH was measured using a 1:1 v/v soil:water suspension test, after 30 min of equilibration time. Available P and exchangeable K were extracted from the soil samples with the Mehlich-1 solution (0.05 mol L<sup>-1</sup> HCl + 0.0125 mol L<sup>-1</sup> H<sub>2</sub>SO<sub>4</sub>), and characterized by spectrophotometry and flame photometry, respectively (Tedesco et al., 1995).

The exchangeable Ca, Mg, and Al were extracted from the soil samples with 1 mol L<sup>-1</sup> KCl solution; Ca and Mg were characterized by atomic absorption spectrometry, and Al was characterized by titration with 0.0125 mol L<sup>-1</sup> NaOH (Tedesco et al., 1995). The effective cation exchange capacity (CEC<sub>e</sub>) was calculated by Al + Ca + Mg + K. The cation exchange capacity at pH 7.0 (CEC<sub>pH7.0</sub>) was calculated as the sum of exchangeable bases (Ca + Mg + K) plus the estimated H + Al, using an SMP buffer solution (Silva et al., 2016). Base saturation (V) was calculated as the sum of Ca + Mg + K divided by CEC<sub>e</sub> and expressed as a percentage. The remaining soil was subjected to chemical fractionation of P, according to the methodology of Hedley et al. (1982), with modifications proposed by Condron & Goh (1989).

Soil samples of 0.5 g were subjected to sequential extraction with anion-exchange resin (AER-P<sub>i</sub>) and then 0.5 mol L<sup>-1</sup> sodium bicarbonate, which extracted inorganic and organic labile P (NaHCO<sub>3</sub>-P<sub>i</sub> and NaHCO<sub>3</sub>-P<sub>o</sub>, respectively). Then, the samples were treated with 0.1 mol L<sup>-1</sup> sodium hydroxide (to extract NaOH I-P<sub>i</sub> and NaOH I-P<sub>o</sub>), 1 mol L<sup>-1</sup> hydrochloric acid (to extract HCl-P<sub>i</sub>), and 0.5 mol L<sup>-1</sup> sodium hydroxide (to extract NaOH II-P<sub>i</sub> and NaOH II-P<sub>o</sub>). Phosphorus extracted by 0.1 and 0.5 mol L<sup>-1</sup> represents inorganic P linked to oxides and silicate clays with intermediate binding energy and the organic P of moderately labile fractions (Gatiboni et al., 2013). HCl-P<sub>i</sub> extracts

inorganic P contained in the calcium phosphates and strongly adsorbed phosphates. The content of HCl-P<sub>i</sub> was evaluated only in the inorganic fraction because the amount of P<sub>o</sub> extracted by HCl in weathered soils is usually small. After all extractions had been performed, the remaining soil was oven-dried at 45°C, and subjected to acid digestion with concentrated H<sub>2</sub>SO<sub>4</sub> + H<sub>2</sub>O<sub>2</sub> + MgCl<sub>2</sub> to measure the residual P.

P<sub>i</sub> extracts resulting from the alkaline extractants (NaHCO<sub>3</sub>-P<sub>i</sub>, NaOH I-P<sub>i</sub>, and NaOH II-P<sub>i</sub>) were determined by the method proposed by Dick & Tabatabai (1977). In these alkaline extracts, total P was determined by digestion in an autoclave with ammonium persulfate and sulfuric acid ((NH<sub>4</sub>)<sub>2</sub>S<sub>2</sub>O<sub>8</sub> + H<sub>2</sub>SO<sub>4</sub>), and P<sub>o</sub> was calculated as the difference between total P and P<sub>i</sub> in the extract. Phosphorus in the acid extracts was determined according to Murphy & Riley (1962).

For the statistical analysis, the P pool was treated as the dependent variable, and the soil layer, the independent one. Phosphorus pools of soil samples from the F and vineyard areas were subjected to analysis of variance, and the significant effects were compared by the Tukey's test, at 5% probability, using the Sisvar 5.3 software (Ferreira, 2011).

## Results and Discussion

The contents of labile P pools (AER-P<sub>i</sub>, NaHCO<sub>3</sub>-P<sub>i</sub>, and NaHCO<sub>3</sub>-P<sub>o</sub>), and moderately labile P pools (NaOH I-P<sub>i</sub>, NaOH I-P<sub>o</sub>, NaOH II-P<sub>i</sub>, NaOH II-P<sub>o</sub>) increased during the grapevine cultivation, mainly at 0–10 cm soil depths (Figures 1 and 2). In comparison to the forested area, the greatest increases of labile and moderately labile P contents in V1 and V2 were observed in the P<sub>i</sub> fractions at 0–10 cm soil depths. In the forested area, the labile P contents were similar throughout the soil profile.

The highest levels of AER-P<sub>i</sub> and NaHCO<sub>3</sub>-P<sub>i</sub>, as well as of NaOH I-P<sub>i</sub> and NaOH II-P<sub>i</sub>, at 0-10 cm soil depths of V1 and V2 can be attributed to the poultry litter added to the soil over the 62 years of cultivation – 1,365 and 910 kg ha<sup>-1</sup> P, respectively. In addition, P accumulation in the labile and moderately labile fractions may be more pronounced in vineyards with longstanding cultivation, which can be attributed to pruning residues and senescent leaves. Furthermore, weeds or cover crops can take P from deeper soil layers

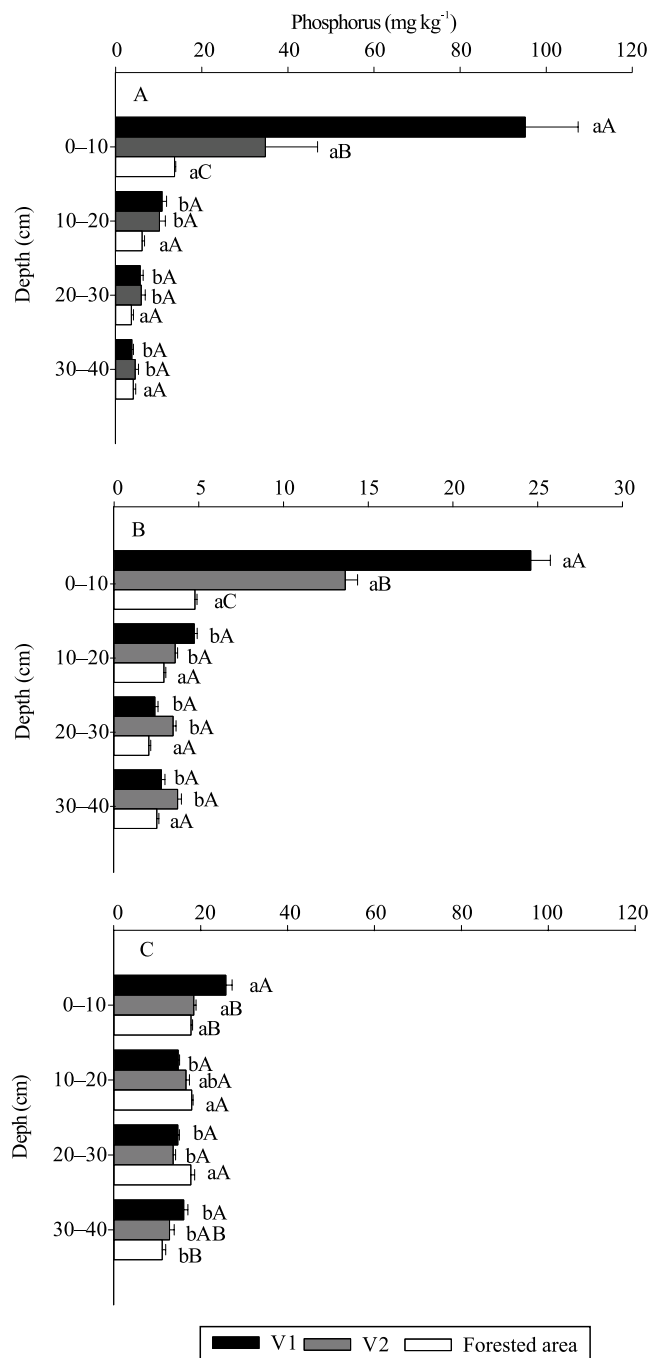
and store it in the shoot tissues, which is later deposited on the soil surface (Brunetto et al., 2011). These plant residues and organic fertilizers are mineralized by soil microorganisms, increasing the  $P_i$  content (Damon et al., 2014), especially in the topsoil (Rubaek et al., 2013). High-P levels in the near-surface soil of vineyards are further elevated due to small quantities of P transported to grape bunches (Tecchio et al., 2011). In general, approximately  $4 \text{ kg ha}^{-1}$  P per year are transported to grape bunches, considering an average annual yield of  $25 \text{ Mg ha}^{-1}$  grapes per year (Tecchio et al., 2011). This low value of P removed from the vineyards reflects the difficulty of establishing a critical P level for fruit species (Brunetto et al., 2015), as mineralized  $P_o$  may be more than sufficient to supply the plant demand (Damon et al., 2014), and total P supply can easily exceed the crop requirement.

In vineyard soil at 0–10 cm depths, high-P contents, both in the labile and the moderately labile fractions extracted by Mehlich-1 (Table 1) exceed the critical P level of  $18 \text{ mg kg}^{-1}$  for the clay class between 21 and 40% (Silva et al., 2016).

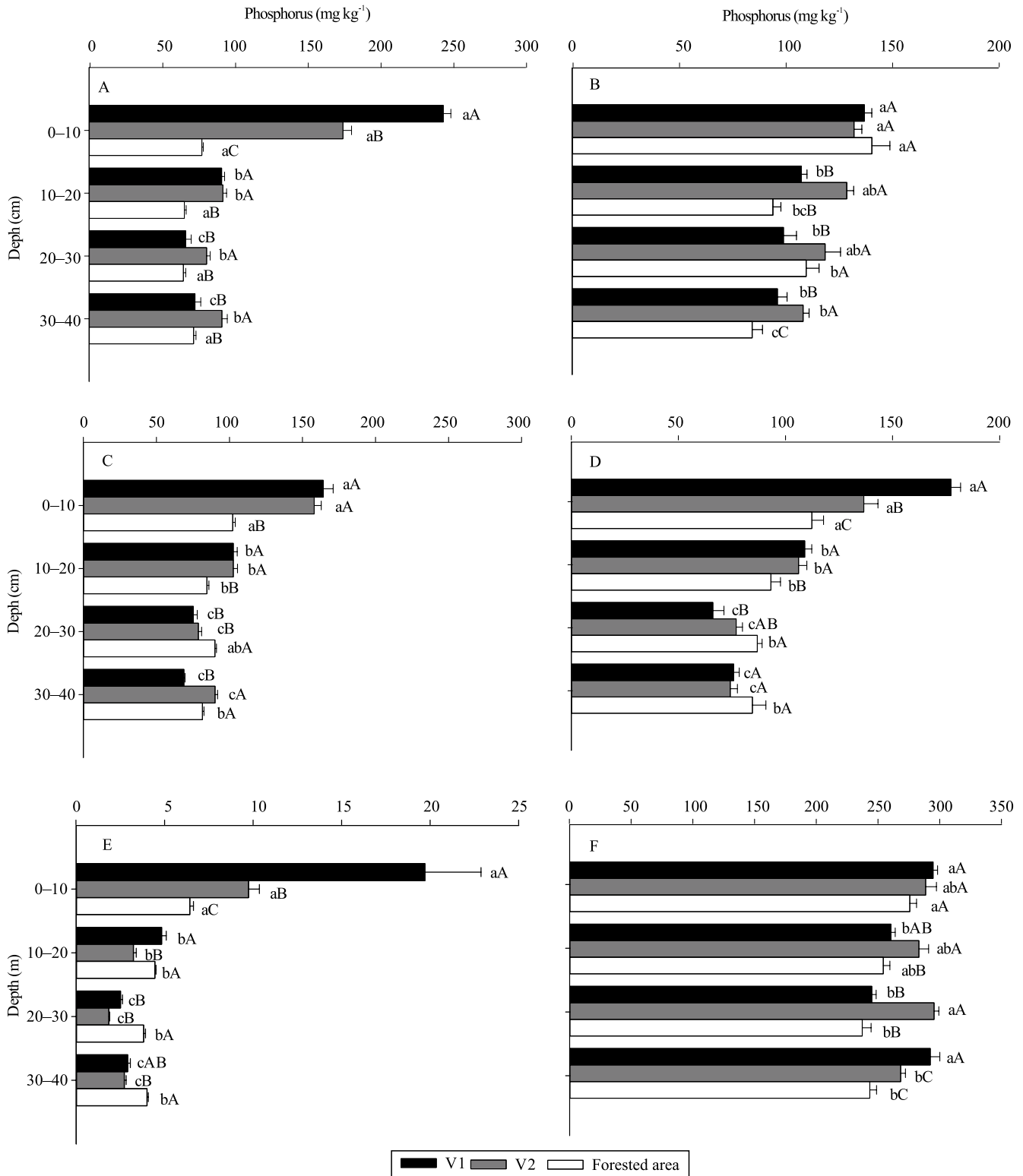
The increase of NaOH I- $P_i$  and NaOH II- $P_i$  (Figure 2) is an indication that the P applications exceeded the uptake capacity of the grapevines and any intercropped cover species, resulting in P accumulation in all fractions (Schmitt et al., 2013a, 2013b). However, the distribution of accumulated P varies with soil type. For instance, in clayey soils, P is high in the fractions associated with Fe and Al oxyhydroxides extracted by sodium hydroxide (Gama-Rodrigues et al., 2014), while in sandy soils, labile fractions of P are predominant (Schmitt et al., 2013a, 2013b).

At all study sites, contents of P in the HCl- $P_i$  pool were low than in other P pools, as determined from the Hedley's procedure. The HCl- $P_i$  pool is related to Ca-P forms which are expected to be very low in weathered soils (Tiecher et al., 2018), such as those in the present study. The HCl- $P_i$  contents at 0–10 cm soil depths were 207 and 52% higher in the V1 and V2 areas than in the forested area, respectively (Figure 2). However, the HCl- $P_i$  fraction in the soils decreased with depth. Higher-HCl- $P_i$  contents at 0–10 cm soil depth of both vineyards were related to the P application rate throughout cultivation, and to higher-pH and Ca levels (Table 1), which increased the  $P_i$  fraction (Borda et al., 2014). Conversely, the residual-P content (Figure 2), which was the greatest P fraction in the soils, was not

influenced by either the grapevine cultivation, poultry litter applications, or the vineyard slopes. Moreover,



**Figure 1.** (A) AER- $P_i$ , (B) NaHCO<sub>3</sub>- $P_i$ , and (C) NaHCO<sub>3</sub>- $P_o$  from the soils of two vineyards (V1 and V2) and forested area. Uppercase letter compare areas within the same depth, and lowercase ones compare the depths within the same area. Bars followed by equal letters do not differ, by Tukey's test, at 5% probability. Error bars indicate standard error of the mean.



**Figure 2.** (A) NaOH I-P<sub>i</sub>, (B) NaOH I-P<sub>o</sub>, (C) NaOH II-P<sub>i</sub>, (D) NaOH II-P<sub>o</sub>, (E) HCl-P<sub>i</sub>, and (F) residual-P from the soils of two vineyards (V1 and V2) and forested area. Uppercase letters compare areas within the same depth, and lowercase ones compare the depths within the same area. Bars followed by equal letters do not differ, by Tukey's test, at 5% probability. Error bars indicate the standard error of the mean.

compared to the forest site, residual P content in both vineyards increased in deeper soil layers, in contrast to the other fractions, which decreased.

The sum of all P fractions measured at 0–10 cm soil depths of V1, V2, and forested area were approximately 1,200, 1,080, and 790 mg kg<sup>-1</sup> P, respectively. At 10–20 cm soil depth, in V1, V2, and forested area measured P amounts were 780, 650, and 730 mg kg<sup>-1</sup> P, respectively; the difference in total P of this layer and at 0–10 cm

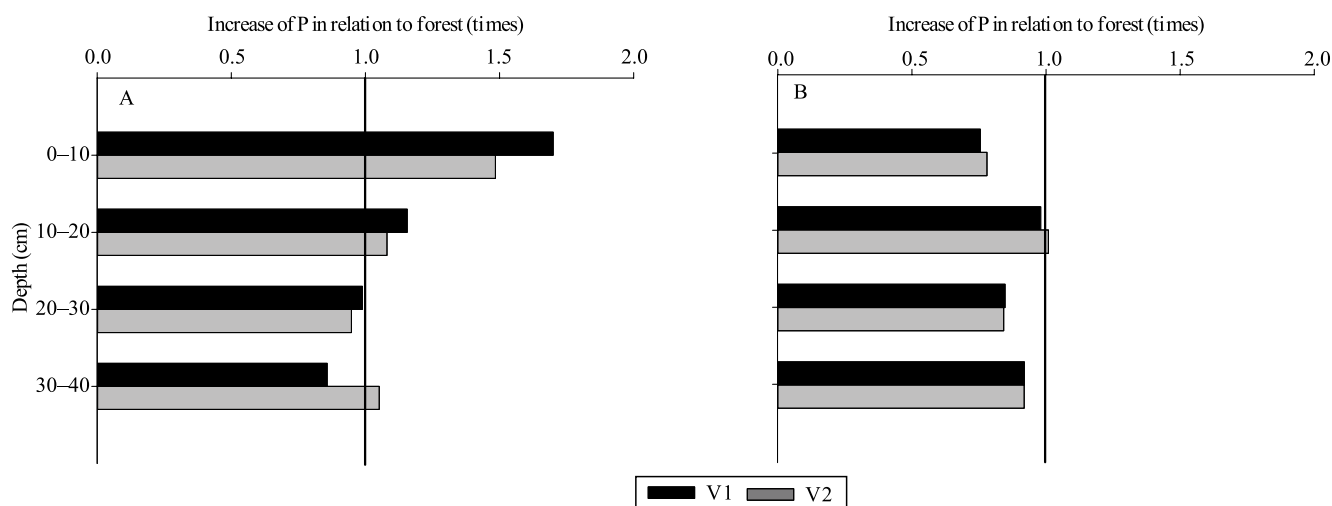
soil depths indicates a P accumulation at the surface layer.

Additionally, in comparison to the P<sub>i</sub> fractions in the forest soil, those in the vineyards changed throughout cultivation (Figure 3); however, P<sub>o</sub> remained stable, despite the organic fertilizer applications. This indicates that the poultry litter and other plant residues were mineralized and transformed into P<sub>i</sub> (Borda et al., 2014). This study indicates that the entire P<sub>o</sub> – added as

**Table 1.** Soil physicochemical properties from depth intervals 0–10, 10–20, 20–30, and 30–40 cm, of a Cambissolo Húmico (Humic Hapludox) in two vineyards (V1 and V2) and a forested area.

Location	Depth (cm)	Clay ----- (g kg <sup>-1</sup> ) -----	Silt ----- (g kg <sup>-1</sup> ) -----	Sand ----- (g kg <sup>-1</sup> ) -----	OM	pH -1:1-	Ca ---- (cmol <sub>c</sub> kg <sup>-1</sup> ) ----	Mg ---- (cmol <sub>c</sub> kg <sup>-1</sup> ) ----	P ---- (mg kg <sup>-1</sup> ) ----	K	CEC <sub>ef</sub> ---- (cmol <sub>c</sub> kg <sup>-1</sup> ) ----	CEC <sub>pH7.0</sub> ---- (cmol <sub>c</sub> kg <sup>-1</sup> ) ----	V (%)
V1	0–10	269dAB	498aA	233aA	66aA	6.5aA	12.5aA	5.4aA	26.8aA	186aA	18aA	20aA	90aA
	10–20	331cB	513aAB	156bA	28bA	6.1bA	8.8bA	4.9aA	5.5bA	160abA	14bA	17abA	85bA
	20–30	440bB	420bA	140bB	23bA	5.7cA	6.8cB	4.2bA	3.2bA	135bcA	11bA	14bB	80cA
	30–40	512aA	378bB	110cB	21bA	5.7cA	9.2bA	4.6abA	2.9bA	117cA	14bA	17abB	82dA
V2	0–10	321dA	524aA	156aB	45aC	6.3aA	12.3aA	3.9aB	22.6aA	134aB	17aA	20aA	84aB
	10–20	421cA	465bB	113bB	32bA	6.1abA	9.2bA	3.6aB	3.4bA	118abAB	13bA	17abA	79bB
	20–30	554aA	364cB	82bC	22bcA	5.8bA	7.5bAB	3.1aB	2.7bA	89bcB	11bA	15bB	74cB
	30–40	483bA	429bA	88bB	17cA	5.3cA	8.0bA	3.0aB	2.7bA	64cB	11bA	15bB	73cB
Forested area	0–10	245bB	545aA	210aA	75aA	6.3aA	13.7aA	4.2aB	3.5aB	201aA	18aA	21abA	86aB
	10–20	254bC	558aA	188aA	40bA	6.0aA	11.2abA	4.1aAB	1.4aA	136bB	16abA	19bA	81bB
	20–30	342aC	463bA	195aA	29bcA	5.6bA	9.8bA	3.4aAB	1.2aA	100bcAB	14bA	22abA	62cC
	30–40	379aB	428bA	193aA	27cA	5.6bA	10.7bA	3.3aB	1.2aA	82cAB	14bA	24 aA	59cC

Clay, sand, and silt contents were measured by the pipette method; OM, organic matter; pH, pH in water 1:1; Ca and Mg extracted by KCl 1 mol L<sup>-1</sup>; P and K extracted by Mehlich-I; CEC<sub>ef</sub>, effective cation exchange capacity; CEC<sub>pH7.0</sub>, cation exchange capacity at pH 7.0; V, base saturation. Uppercase compare the locations within the same depth and, lowercase, the depths within the same location. Means followed by equal letters do not differ, by Tukey's test, at 5% probability.



**Figure 3.** (A) Increase of P<sub>i</sub>, (B) P<sub>o</sub> contents in the soils of two vineyards (V1 and V2), in comparison with the forested area. The line represents the relationship between P<sub>i</sub> and P<sub>o</sub> in the forest area.

poultry litter and field residues – was transformed into  $P_i$ . In comparison to the  $P_i$  amount in the forest soil,  $P_i$  contents in the topsoil (0–10 cm depths) increased by approximately 1.6 and 1.5 times in the vineyards V1 and V2, respectively. However, no differences were observed in the  $P_o$  fractions between the vineyard and forest soils.

### Conclusions

1. The addition of poultry litter as fertilizer does not affect the organic P ( $P_o$ ) stock in a Humic Cambisol; however, it increases the  $P_i$  contents in the soil.

2. Inorganic P is the main form of P accumulation in a Humic Cambisol, even with the long-term use of organic fertilizer based on poultry litter.

### Acknowledgments

To Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), for supporting the productivity grants for the second and sixth authors, and the post-doctorate to the fourth author.

### References

- BOITT, G.; SCHMITT, D.E.; GATIBONI, L.C.; WAKELIN, S.A.; BLACK, A.; SACOMORI, W.; CASSOL, P.C.; CONDRON, L.M. Fate of phosphorus applied to soil in pig slurry under cropping in southern Brazil. *Geoderma*, v.321, p.164-172, 2018. DOI: <https://doi.org/10.1016/j.geoderma.2018.02.010>.
- BORDA, T.; CELI, L.; BÜNEMANN, E.K.; OBERSON, A.; FROSSARD, E.; BARBERIS, E. Fertilization strategies affect phosphorus forms and release from soils and suspended solids. *Journal of Environmental Quality*, v.43, p.1024-1031, 2014. DOI: <https://doi.org/10.2134/jeq2013.11.0436>.
- BRUNETTO, G.; MELO, G.W.B. de; TOSELLI, M.; QUARTIERI, M.; TAGLIAVINI, M. The role of mineral nutrition on yields and fruit quality in grapevine, pear and apple. *Revista Brasileira de Fruticultura*, v.37, p.1089-1104, 2015. DOI: <https://doi.org/10.1590/0100-2945-103/15>.
- BRUNETTO, G.; VENTURA, M.; SCANDELLARI, F.; CERETTA, C.A.; KAMINSKI, J.; MELO, G.W. de; TAGLIAVINI, M. Nutrient release during the decomposition of mowed perennial ryegrass and white clover and its contribution to nitrogen nutrition of grapevine. *Nutrient Cycling in Agroecosystems*, v.90, p.299-308, 2011. DOI: <https://doi.org/10.1007/s10705-011-9430-8>.
- CLAESSEN, M.E.C. (Org.). *Manual de métodos de análise de solo*. 2.ed. rev. e atual. Rio de Janeiro: EmbrapCNPS, 1997. 212p.
- CONDRON, L.M.; GOH, K.M. Effects of long-term phosphatic fertilizer applications on amounts and forms of phosphorus in soils under irrigated pasture in New Zealand. *European Journal of Soil Science*, v.40, p.383-395, 1989. DOI: <https://doi.org/10.1111/j.1365-2389.1989.tb01282.x>.
- DAMON, P.M.; BOWDEN, B.; ROSE, T.; RENGEL, Z. Crop residue contributions to phosphorus pools in agricultural soils: a review. *Soil Biology & Biochemistry*, v.74, p.127-137, 2014. DOI: <https://doi.org/10.1016/j.soilbio.2014.03.003>.
- DICK, W.A.; TABATABAI, M.A. Determination of orthophosphate in aqueous solutions containing labile organic and inorganic phosphorus compounds. *Journal of Environment Quality*, v.6, p.82-85, 1977. DOI: <https://doi.org/10.2134/jeq1977.00472425000600010018x>.
- ERIKSSON, A.K.; GUSTAFSSON, J.P.; HESTERBERG, D. Phosphorus speciation of clay fractions from long-term fertility experiments in Sweden. *Geoderma*, v.241-242, p.68-74, 2015. DOI: <https://doi.org/10.1016/j.geoderma.2014.10.023>.
- FAO. Food and Agriculture Organization of the United Nations. *World reference base of soil resources*. Rome: FAO, 1998. (World Soil Resources Reports 84).
- FERREIRA, D.F. Sisvar: a computer statistical analysis system. *Ciência e Agrotecnologia*, v.35, p.1039-1042, 2011. DOI: <https://doi.org/10.1590/S1413-70542011000600001>.
- GAMA-RODRIGUES, A.C.; SALES, M.V.S.; SILVA, P.S.D.; COMERFORD, N.B.; CROPPER, W.P.; GAMA-RODRIGUES, E.F. An exploratory analysis of phosphorus transformations in tropical soils using structural equation modeling. *Biogeochemistry*, v.118, p.453-469, 2014. DOI: <https://doi.org/10.1007/s10533-013-9946-x>.
- GATIBONI, L.C.; BRUNETTO, G.; RHEINHEIMER, D. dos S.; KAMINSKI, J. Fracionamento químico das formas de fósforo do solo: usos e limitações. In: ARAÚJO, A.P.; ALVES, B.J.R. (Ed.). *Tópicos em ciência do solo*. Viçosa: Sociedade Brasileira de Ciência do Solo, 2013. v.8, p.141-187.
- GATIBONI, L.C.; SMYTH, T.J.; SCHMITT, D.E.; CASSOL, P.C.; OLIVEIRA, C.M.B. de. Soil phosphorus thresholds in evaluating risk of environmental transfer to surface waters in Santa Catarina, Brazil. *Revista Brasileira de Ciência do Solo*, v. 39, p.1225-1234, 2015. DOI: <https://doi.org/10.1590/01000683rbc20140461>.
- HANLON, E.A.; HOCHMUTH, G.J.; OBREZA, T.A.; CHAPLIN, M.H. Phosphorus nutrition of vegetable crops and fruits. In: SIMS, J.T.; SHARPLEY, A.N. (Ed.). *Phosphorus: agriculture and the environment*. Madison: American Society of Agronomy, 2005. p.521-540. (Agronomy, 46).
- HE, Z.; HONEYCUTT, C.W.; CADE-MENUN, B.J.; SENWO, Z.N.; TAZISONG, I.A. Phosphorus in poultry litter and soil: Enzymatic and nuclear magnetic resonance characterization. *Soil Science Society of America Journal*, v.72, p.1425-1433, 2008. DOI: <https://doi.org/10.2136/sssaj2007.0407>.
- HEDLEY, M.J.; STEWART, J.W.B.; CHAUHAN, B.S. Changes in inorganic and organic soil phosphorus fractions induced by cultivation practices and by laboratory incubations. *Soil Science Society of America Journal*, v.46, p.970-976, 1982. DOI: <https://doi.org/10.2136/sssaj1982.03615995004600050017x>.
- MURPHY, J.; RILEY, J.P. A modified single solution method for the determination of phosphate in natural waters. *Analytica Chimica Acta*, v.27, p.31-36, 1962. DOI: [https://doi.org/10.1016/S0003-2670\(00\)88444-5](https://doi.org/10.1016/S0003-2670(00)88444-5).
- RUBAEK, G.H.; KRISTENSEN, K.; OLESEN, S.E.; ØSTERGAARD, H.S.; HECKRATH, G. Phosphorus accumulation and spatial distribution in agricultural soils in Denmark. *Geoderma*, v.209-210, p.241-250, 2013. DOI: <https://doi.org/10.1016/j.geoderma.2013.06.022>.

- SANTOS, H.G. dos; JACOMINE, P.K.T.; ANJOS, L.H.C. dos; OLIVEIRA, V.A. de; LUMBRERAS, J.F.; COELHO, M.R.; ALMEIDA, J.A. de; CUNHA, T.J.F.; OLIVEIRA, J.B. de. **Sistema brasileiro de classificação de solos**. 3.ed. rev. e ampl. Brasília: Embrapa, 2013. 353p.
- SCHMITT, D.E.; COMIN, J.J.; CERETTA, C.A.; GATIBONI, L.C.; TIECHER, T.; LORENSINI, F.; HEINZEN, J.; AMBROSINI, V.G.; MORAES, M.P. de; BRUNETTO, G. Accumulation of phosphorus fractions and contamination potencial in vineyard soils in the southern region of the state of Santa Catarina, Brazil. **Revista Brasileira de Ciência do Solo**, v.37, p.1256-1266, 2013a. DOI: <https://doi.org/10.1590/S0100-06832013000500015>.
- SCHMITT, D.E.; COMIN, J.J.; GATIBONI, L.C.; TIECHER, T.; LORENSINI, F.; MELO, G.W.B. de; 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, 2013b. DOI: <https://doi.org/10.1590/S0100-06832013000200018>.
- SHARPLEY, A.; DANIEL, T.C.; SIMS, J.T.; POTE, D.H. Determining environmentally sound soil phosphorus levels. **Journal of Soil Water and Conservation**, v.51, p.160-166, 1996.
- SILVA, L.S.; GATIBONI, L.C.; ANGHINONI, I.; SOUZA, R.O. (Ed.). **Manual de calagem e adubação para os estados do Rio Grande do Sul e de Santa Catarina**. 11.ed. [Xanxerê]: Comissão de Química e Fertilidade do Solo – RS/SC, 2016. 376p.
- SKINNER, P.W.; COOX, J.A.; MATTHEWS, M.A. Responses of grapevine cvs Chenin Blanc and Chardonnay to phosphorus fertilizer applications under phosphorus-limited soil conditions. **Vitis**, v.27, p.95-109, 1988.
- STEFFENS, D.; LEPPIN, T.; LUSCHIN-EBENGREUTH, N.; YANG, Z.M.; SCHUBERT, S. Organic soil phosphorus considerably contributes to plant nutrition but is neglected by routine soil testing methods. **Journal of Plant Nutrition and Soil Science**, v.173, p.765-771, 2010. DOI: <https://doi.org/10.1002/jpln.201000079>.
- TECCHIO, M.A.; TEIXEIRA, L.A.J.; TERRA, M.M.; MOURA, M.F.; PAIOLI-PIRES, E.J. Extração de nutrientes pela videira “niagara rosada” enxertada em diferentes porta-enxertos. **Revista Brasileira de Fruticultura**, v.33, p.736-742, 2011. Número especial. DOI: <https://doi.org/10.1590/S0100-29452011000500103>.
- TEDESCO, M.J.; GIANELLO, C.; BISSANI, C.A.; BOHNEN, H.; VOLKWEISS, S.J. **Análise de solo, plantas e outros materiais**. 2.ed. rev. e ampl. Porto Alegre: UFRGS, 1995. (UFRGS. Boletim técnico, 5).
- TIECHER, T.; GOMES, M.V.; AMBROSINI, V.G.; AMORIM, M.B.; BAYER, C. Assessing linkage between soil phosphorus forms in contrasting tillage systems by path analysis. **Soil & Tillage Research**, v.175, p.276-280, 2018. DOI: <https://doi.org/10.1016/j.still.2017.09.015>.
- TURNER, B.L.; LEYTEM, A.B. Phosphorus compounds in sequential extracts of animal manures: chemical speciation and a novel fractionation procedure. **Environmental Science & Technology**, v.38, p.6101-6108, 2004. DOI: <https://doi.org/10.1021/es0493042>.
- WANG, B.; LI, J.; REN, Y.; XIN, J.; HAO, X.; MA, Y.; MA, X. Validation of a soil phosphorus accumulation model in the wheat-maize rotation production areas of China. **Field Crops Research**, v.178, p.42-48, 2015. DOI: <https://doi.org/10.1016/j.fcr.2015.03.007>.
- YANG, X.; POST, W.M. Phosphorus transformations as a function of pedogenesis: a synthesis of soil phosphorus data using Hedley fractionation method. **Biogeosciences**, v.8, p.2907-2916, 2011. DOI: <https://doi.org/10.5194/bg-8-2907-2011>.