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Phosphorus fertilization for young grapevines of Chardonnay and Pinot Noir in sandy soil

Fertilización fosfatada para plantas jóvenes de vid Chardonnay y Pinot Noir en suelo arenoso

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ABSTRACT

Sandy soils of the Campanha Gaúcha region have naturally low levels of available phosphorus (P), which is why special attention to pre-planting fertilization is important. However, there are no studies that enable a proper calibration method to determine P content available in soil for young grapevines. The study aimed to evaluate phosphorus fertilization for young grapevines of Chardonnay and Pinot Noir in order to provide support for the recommendation of P in sandy soils. In October, 2011 we applied six doses of P (0, 10, 20, 40, 60 and 100 kg P_2O_5 ha^{-1} yr^{-1}) in soil and transplanted cultivars of Chardonnay (experiment 1) and Pinot Noir (experiment 2). The design of each experiment was randomized blocks with ten plants and three replications. We evaluated P content in the soil and leaves. We determined plant height, stem diameter and dry matter of the pruned material from crop seasons 2011/12 to 2014/15. The addition of increasing P doses elevated P content available in soil three years after implementing the experiments, but exclusively in doses above 40 and 60 kg P_2O_5 ha^{-1} in Pinot Noir and Chardonnay, respectively. However, P content in soil for every applied P dose remained below sufficiency level, and therefore growth parameters and leaf P content were virtually unaffected.

Keywords: Phosphorus fertilizer, growth, Leaf P, *Vitis vinifera.*

RESUMEN

Los suelos arenosos de la región Campanha Gaúcha son naturalmente bajos en contenidos de fósforo (P) disponible, por lo que requiere una atención especial con la fertilización previo a la siembra. Sin embargo, aún no existen trabajos de investigación que permitan una calibración adecuada para determinar el contenido de P disponible en suelos para el cultivo de vides viníferas jóvenes. El objetivo de esta investigación fue evaluar la fertilización fosfatada en las variedades jóvenes de vid Chardonnay y Pinot Noir a fin de sugerir dosis a la recomendación de P, en suelos arenosos. En Octubre de 2011 fueron aplicadas seis dosis de P (0, 10, 20, 40, 60 y 100 kg P_2O_5 ha^{-1} $año^{-1}$) en suelo y transplantadas las variedades Chardonnay (experimento 1) y Pinot Noir (experimento 2). El diseño experimental fue de bloques completos al azar, con tres repeticiones, y diez plantas. Fueron evaluados los contenidos de P en el suelo, en hojas, altura de las plantas, diámetro del tallo y materia seca del material podado durante las cosechas del 2011/12 a 2014/15. La adición de dosis crecientes de P incrementó el contenido de P disponible en el suelo después de los tres años del establecimiento de los experimentos cuando las dosis fueron superiores de 40 y 60 de P_2O_5 ha^{-1} en las variedades Pinot Noir y Chardonnay, respectivamente. En todos los tratamientos los contenidos de P en suelo, fueron suficientes, por lo tanto, el crecimiento y contenido de P en las hojas, no fueron afectados.

Palabras claves*: Fertilización fosfatada, crecimiento, P en hojas,* Vitis vinífera*.*

Introduction

The state of Rio Grande do Sul (RS) has the largest wine-growing area in Brazil, which is approximately 50,000 hectares (IBGE, 2011). The Campanha Gaúcha region of RS, located in the Pampa Biome bordering Uruguay and Argentina, is the second largest wine-producing region in the state, and one that has the largest area annually incorporated with the cultivation of grapevines, where grape is mainly intended for the production of fine wines and sparkling wines. This is because

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the area has adequate sunshine, favoring the quality of the grape, undulated relief, which favors mechanization of management practices, and land area with low purchase values. However, the soils are acidic and have low fertility (Brunetto *et al.*, 2008; Brunetto *et al.*, 2009, Melo *et al.*, 2012), and therefore nutrient application including phosphorus (P) is typically necessary.

Determining the need for and dose of P in pre-planting fertilization of young grapevines grown in the states of RS and Santa Catarina (SC) is done according to P content available in soil, extracted by Mehlich-1 and interpreted in accordance with clay content (CQFS-RS/SC, 2004). When we establish the need to apply P, phosphate fertilizers are applied on the soil surface over the entire area with subsequent incorporation into the soil up to a depth of approximately 20 cm (Brunetto *et al.*, 2015). Afterwards, young grapevines are transplanted and new applications of phosphate fertilizers are only carried out in maintenance fertilization. However, there is still a lack of information regarding adequate P doses and P content available to grapevines (Schmitt *et al.*, 2013; Melo & Zalamena, 2016), as well as the real impact of P application on nutritional status and growth parameters such as stem diameter and height in different cultivars (Piva *et al.*, 2014). We expect that if P doses promote the increase of available phosphorus content in the soil to proper levels for the grapevines, plants will grow faster, thus anticipating the start of grape production, which is desirable.

The study aimed to evaluate phosphorus fertilization for young grapevines of Chardonnay and Pinot Noir in order to provide support for the recommendation of P in sandy soils.

Material and methods

The experiment was conducted in the city of Santana do Livramento, located in the Campanha Gaúcha region of Rio Grande do Sul, Brazil (Latitude 30º48'31" S and Longitude 55º22'33" W). The soil is a Sandy Typic Hapludalf (Embrapa, 2013) with the following characteristics in the 0-20 cm layer: clay = 9.4 g kg^{-1}, organic matter = 12.0 mg kg^{-1}, pH in water = 5.0; exchangeable Ca = 1.28 $cmol_c$ kg^{-1}, exchangeable Mg = 1.1 $cmol_c$ kg^{-1}, exchangeable Al = 0.4 $cmol_c$ kg^{-1} (extracted by KCl 1 mol l^{-1}); available P = 7.6 mg kg^{-1} (low content according to CQFS-RS/SC, 2004) and exchangeable K = 80 mg kg^{-1} (extracted by Mehlich-1); $CEC_{effective}$ = 2.7 $cmol_c$ kg^{-1} and $CEC_{pH\ 7.0}$ = 4.7 $cmol_c$ kg^{-1}. The climate is humid subtropical Cfa2according to the Köppen classification (1931), characterized by mild temperatures and rainfall with little variation throughout the year. Average annual rainfall is 1600 mm. Average temperature of the hottest month (January) is 23.8 ºC and average temperature of the coldest month (July) is 12.4 ºC. Data of average monthly temperatures and rainfall during the experiment are shown in Figure 1.

In August, 2011 we applied 3800 kg ha^{-1} of dolomitic limestone (to raise pH to 6.0), 80 kg ha^{-1} (urea source) and 40 kg ha^{-1} borax on the soil surface and then incorporated it by plowing, followed by subsoiling and harrowing to 20 cm depth. In October, 2011 we applied six doses of P (0, 10, 20, 40, 60 e 100 kg P_2O_5 ha^{-1} yr^{-1}) to the soil and transplanted the seedlings of Chardonnay (experiment 1) and Pinot Noir (experiment 2). The P source was triple superphosphate. Before planting the seedlings we applied P doses on the soil surface and immediately incorporated them by plowing, subsoiling (once) and harrowing (twice) to 20 cm depth. Next we transplanted young grapevines of Chardonnay and Pinot Noir grafted on Paulsen rootstock, with 1.0 m between plants and 2.5 m between rows (4000 plants ha^{-1}). In the following years we applied doses of P on the soil surface, in the projection of the plant canopy, without incorporation. The design of each experiment was randomized blocks with three replications; each experimental plot consisted of ten plants distributed along the planting row. We performed evaluations on the eight central plants.

We used an espalier conduction system, and every year pruning was carried out in winter and lateral shoots were removed in summer. The following cover crops predominated between the rows of grapevines: *Paspalum notatum*, *Desmodium affine* Schltdl. and *Lolium multiflorum*. We mowed cover crops four times a year between the rows and deposited the residues on the soil surface. Vegetation was desiccated on the vine rows with the use of non-residual herbicide. We used drippers to irrigate twice per week from November to January, totaling approximately 22.75 mL of water per plant per week.

In November, 2014 we collected soil samples of the 0-10 and 10-20 cm layers on the planting row

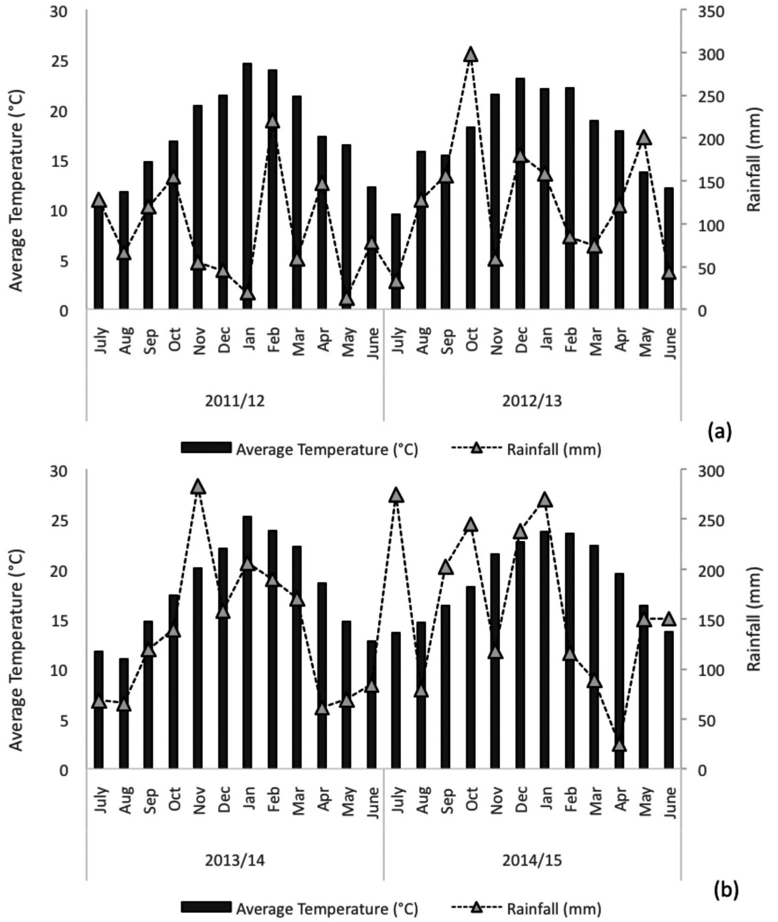

Figure 1. Average temperature (ºC) and rainfall (mm) in crop seasons 2011/12 and 2012/13 (a), and 2013/14 and 2014/15 (b) in the city of Santana do Livramento, RS.

of each plant. The soil was air-dried and passed through a 2 mm mesh sieve. Then we extracted available P (by Mehlich-1) (Tedesco *et al.*, 1995) and analyzed P according to the method of Murphy & Riley (1962), using a spectrophotometer (Spectrophotometer, Bel Photonics).

In March 2012, 2013, 2014 and 2015 we collected three leaves from the middle part of each plant. The leaves were air-dried in an oven with forced air circulation at 65 ºC to constant weight and then were ground and stored. The tissue was prepared and submitted to P analysis according to the methodology proposed by Tedesco *et al.* (1995).

In March 2012 and 2013, we measured the height of each plant using a metric tape. The stem diameter was measured at 10 cm from the soil surface, using a digital caliper. Winter pruning was done in July of every year. In 2012 and 2013, the pruned material was collected, dried in an oven with forced air at 65 ºC and weighed on a digital scale.

The results obtained in experiments 1 and 2 were subjected to analysis of variance, and when significant, regression equations for phosphorus dose were fit by choosing the best model for the F test with probability of error of less than 5% ($p < 0.05$).

Results and discussion

After three years of conducting experiment 1 (Chardonnay), available phosphorus content in the soil increased with the P doses that were applied (Table 1). The highest P contents available in the soil were observed with the application of 60 and 100 kg P_2O_5 ha^{-1}. Stem diameter and dry mass

Table 1. Available phosphorus content in soil (mg kg^{-1}) of experiments 1 (Chardonnay) and 2 (Pinot Noir), three after years the implementation of increasing annual doses of P, crop season 2013/14.

Exp.	Depth (cm)	P_2O_5 (kg ha^{-1} year^{-1}) dose						Equation	R^2
		0	10	20	40	60	100		
1	0-10	10.6	9.0	9.1	9.9	13.4	13.2	$y=9.39+0.030x+0.000117x^2$	0.80*
	10-20	4.3	4.9	4.0	4.5	6.6	7.0	$y=4.05+0.030x$	0.88*
2	0-10	8.9	7.4	8.2	10.2	11.4	12.6	$y=7.90+0.049x$	0.84*
	10-20	5.2	3.8	3.6	6.1	5.3	4.6	$y=4.22+0.033x+0.0003x^2$	0.40*

* = significant at 5% probability.

of the pruned material in crop seasons 2011/12 and 2012/13, as well as plant height in 2011/12 were not affected by the application of P doses in the soil (Table 2). The application of P in the soil did not affect leaf P content in crop seasons 2011/12, 2012/13 or 2014/15 (Table 2). However, leaf P content in 2013/14 increased quadratically with increasing P dose in the soil. There was a negative relationship between soil P content and leaf P content (Figure 2a).

After three years of conducting experiment 2 (Pinot Noir), the highest content of available phosphorus in the soil was observed with doses of 40, 60 and 100 kg P_2O_5 ha^{-1}. In crop seasons 2012/13, P application in the soil did not affect shoot length or P content in the tissue of the pruned shoots (Table 3). However, in 2013/14, leaf P content increased quadratically with the P dose applied in the soil. The relationship between soil P and leaf P was negative (Figure 2b).

After three years of applying P_2O_5, P content in the soil still remained low in every dose (between 7.1 and 14.0 mg P dm^{-3} for soils with less than 20% clay) (CQFS-RS/SC, 2004) in both experiments and in the planting rows. This demonstrates the need to adjust doses of P_2O_5 used to cultivate young grapevines and other crops.

The application of 100 kg P_2O_5 ha^{-1} was not enough to elevate P content available in soil up to sufficiency level (between 21.1 and 42.0 mg P kg^{-1} for soils with less than 20% clay), even though it was incorporated into the

Table 2. Growth parameters, dry matter of the pruned material and leaf P content of experiment 1 (Chardonnay) in crop seasons 2011/12, 2012/13, 2013/14 and 2014/15 subjected to annual addition of P doses.

	P_2O_5 (kg ha^{-1} year^{-1}) dose						
	0	10	20	40	60	100	CV%
	– 2011/12 –						
Stem diameter (cm)	0.464^{ns}	0.495	0.408	0.51	0.408	0.942	24.69
Plant height (cm)	34.63^{ns}	43.46	32.79	42.14	36.33	33.98	23.98
Dry matter of pruned material (kg ha^{-1})	126.56^{ns}	129.67	94.58	105.59	85.69	79.55	30.13
Leaf P (g kg^{-1})	1.55^{ns}	1.32	1.47	1.13	1.46	1.22	30.39
	– 2012/13 –						
Stem diameter (cm)	0.754^{ns}	0.796	0.758	0.821	0.746	0.725	10.77
Dry matter of pruned material (kg ha^{-1})	53.46^{ns}	72.06	52.36	58.08	43.66	46.76	23.34
Leaf P (g kg^{-1})	2.22^{ns}	2.22	1.53	20.3	1.40	1.81	27.49
	– 2013/14 –						
Leaf P (g kg^{-1})	1.48$^{(1)}$	1.41	0.81	0.78	0.92	0.61	34.59
	– 2014/15 –						
Leaf P (g kg^{-1})	1.57^{ns}	1.40	1.48	1.57	1.30	1.40	12.29

^{ns} = not significant at 5% probability; $^{(1)}$ $y = 0.1452 - 0.0022x + 0.4366x^2$, ($R^2 = 0.75^*$); * = significant at 5% probability.

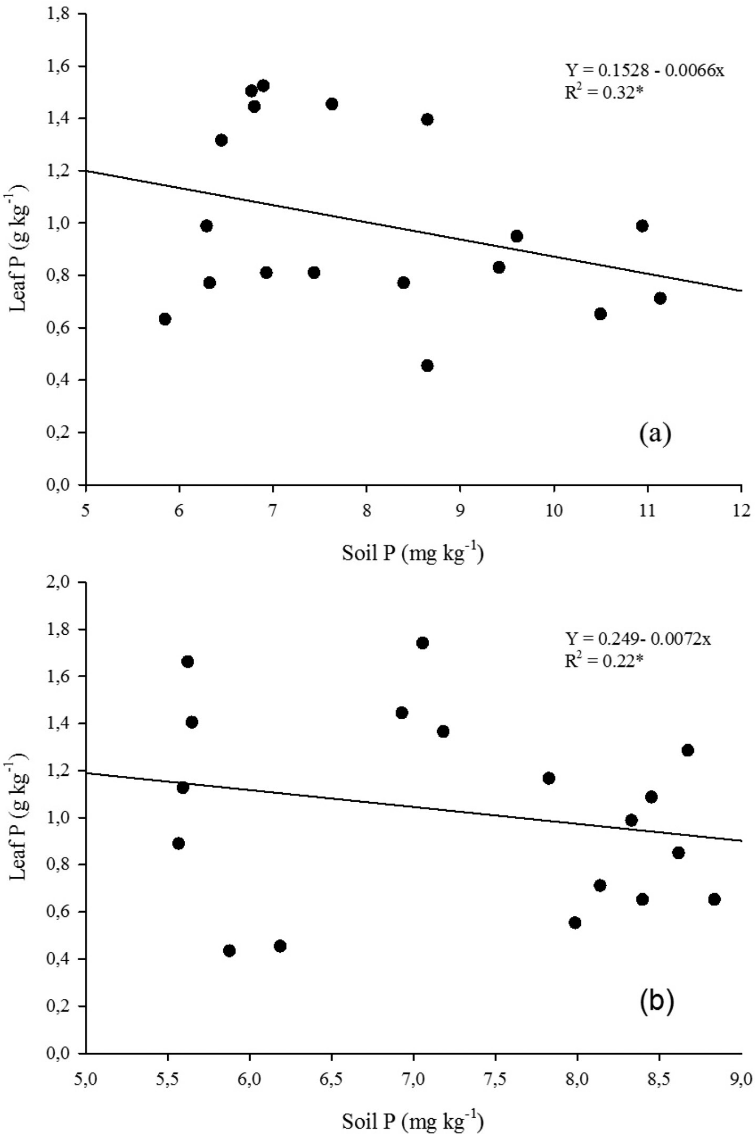

Figure 2. Relationship between the values of available phosphorus in soil (mg kg^{-1}) and P content in leaves (g kg^{-1}) in crop season 2014/15 in Chardonnay (a) and Pinot Noir (b) subjected to application of increasing doses of P. * = significant at 5% probability.

soil to 0.20 m at grapevine planting and with surface applications (done annually and in the projection of the plant canopy). This may have happened primarily because of the application of P doses on the soil surface, followed by soil incorporation with plowing (once) and harrowing (twice). Even with soil sampling of the 0-0.10 and 0.10-0.20 m layers, part of the P that was applied may have been diluted in the soil mass, thus hindering the diagnosis of P by soil sampling and by the Mehlich-1 extraction method, as well as P absorption by the vine roots (Kareem, 2013; Schmitt, *et al.*, 2014).

Phosphorus fertilization in both experiments did not affect the growth parameters stem diameter, plant height or weight of the pruned material in crop season 2011/12, or stem diameter and dry weight of the pruned material in 2012/13. This may have happened due to the slight increase in P content available in soil with the increase of the P dose, which did not reach sufficiency level. This condition reduces P supply to plants, which

Table 3. Growth parameters, dry matter of the pruned material and leaf P content of experiment 1 (Pinot Noir) in crop seasons 2011/12, 2012/13, 2013/14 and 2014/15 subjected to annual addition of P doses.

	P_2O_5 (kg ha^{-1}) dose						CV%
	0	10	20	40	60	100	
	– 2011/12 –						
Stem diameter (cm)	0.396^{ns}	0.432	0.458	0.479	0.508	0.489	18.67
Plant height (cm)	37.54$^{(1)}$	42.94	44.68	49.71	59.26	52.54	24.98
Dry matter of pruned material (kg ha^{-1})	91.92^{ns}	106.49	104.56	132.91	112.70	105.83	22.29
Leaf P (g kg^{-1})	1.43$^{(2)}$	1.09	1.45	1.49	1.66	1.44	16.84
	– 2012/13 –						
Stem diameter (cm)	0.658^{ns}	0.779	0.725	0.767	0.842	0.800	15.80
Dry matter of pruned material (kg ha^{-1})	55.78^{ns}	71.71	47.95	77.92	124.29	51.35	62.98
Leaf P (g kg^{-1})	1.89^{ns}	1.98	2.09	1.60	2.67	1.16	48.65
	– 2013/14 –						
Leaf P (g kg^{-1})	1.52$^{(3)}$	1.40	0.59	0.99	0.94	0.72	39.43
	– 2014/15 –						
Leaf P (g kg^{-1})	1.49^{ns}	1.41	1.39	1.45	1.42	1.37	11.26

^{ns} not significant; $^{(1)}$ $y = 37.002 + 0.5443x - 0.0041x^2$, R^2 0.89*; $^{(2)}$ $y = 0.1258 + 0.0009x - 13.028x^2$, R^2 0.34*; $^{(3)}$ $y = 0.143 – 0.002181x + 0.00001787x^2$, R^2 0.49*; * = Significant at 5% probability.

takes place primarily via diffusion to the roots (Dissanayaka *et al*., 2015, Batista *et al*., 2016). Thus we expect that a smaller amount of P is absorbed by grapevines, reducing photosynthesis, carbohydrate production, protein synthesis, and transfer and accumulation of energy, which are P-dependent functions in the plant (Brunetto *et al*., 2015).

The P content in vine leaves observed in crop seasons 2011/12, 2012/13 and 2014/15 for every dose in both experiments was interpreted as normal (between 1.2 e 4.0 g kg^{-1}) (CQFS-RS/SC, 2004). In crop season 2013/14, grapevines of Chardonnay (experiment 1) and Pinot Noir (experiment 2) showed leaf P content below normal (<1.2 g kg^{-1}) when grown in soil with the application of 20 kg P_2O_5 ha^{-1} or higher doses (Tables 2 and 3). The decrease in leaf P content throughout the crop seasons in both experiments and for every dose may have happened because of vine growth in both experiments, which promoted dilution of P. However, it could also be due to redistribution of P among organs (e.g. from the leaves to other perennial organs such as shoots, stems and roots) (Filho *et al*., 2015; Lorensini *et al*., 2015; Piva *et al*., 2015). In the subsequent cycle, part of the P accumulated in the perennial organs may be redistributed to growth organs (Zanotelli *et al*., 2014). Thus P cycling in fruit trees is a strategy to reduce dependence of soil P (Brunetto *et al*., 2013). However, this was not enough to meet plant needs for P. Therefore, higher levels of P_2O_5 should be studied in order to meet plant needs accurately for P in the early years of implementing and managing young grapevines in sandy soils of the Campanha Gaúcha region of RS.

Conclusion

Assessment of P_2O_5 doses greater than 100 kg ha^{-1} yr^{-1} for the cultivation of young grapevines of Chardonnay and Pinot Noir in sandy soils is essential. The use of this dose incorporated into the soil up to 20 cm during the implementation of the vineyards, in addition to three annual applications on the planting rows, were not enough to increase P content available in soil (in the 0-10 cm layer and on the row) to the desired level, i.e., sufficiency level. Even with the increase in P content available in soil with doses higher than 40 and 60 kg P_2O_5 ha^{-1} in Pinot Noir and Chardonnay, respectively, growth parameters and leaf P content in grapevines were virtually unaffected.

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