Growth, mineral composition, fruit yield, and mycorrhizal colonization of feijoa in response to lime and phosphorus application

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Abstract – The objective of this work was to investigate the effect of liming and phosphorus fertilization on the growth, mineral composition of the leaves, fruit yield, and mycorrhizal colonization of young feijoa (*Acca sellowiana*) plants. Treatments consisted of four liming levels – 0, 25, 50, and 100% of the dose required to raise the soil pH to 6.5 – and of five levels of P – 0, 60, 120, 180, and 240 kg ha^{-1} P_2O_5 –, placed in a randomized complete block design, in a split-plot arrangement, with three replicates. The orchard was established in 2010 with the Helena cultivar. In 2012, 2013, and 2014, plant growth was evaluated by measuring trunk perimeter, plant height, and tree canopy width. Mineral composition of the leaves, regarding P, N, K, Ca, and Mg contents, was assessed annually. Mycorrhizal colonization was evaluated in 2012, and fruit yield was determined in 2014. No interaction was observed between the studied factors. P contents had no effect on the evaluated variables. Liming, however, increases plant growth, mycorrhizal colonization, fruit yield, and Ca and Mg leaf contents, besides reducing K leaf contents.

Index terms: *Acca sellowiana*, mineral nutrition, mycorrhizal colonization, nutritional status, phosphorus fertilization, soil acidity.

Crescimento, composição mineral, produção e colonização micorrízica de goiabeira serrana em resposta à aplicação de calcário e fósforo

Resumo – O objetivo deste trabalho foi avaliar o efeito da calagem e da adubação fosfatada no crescimento, na composição mineral das folhas, na produção de frutos e na colonização micorrízica de plantas jovens de goiabeira serrana (*Acca sellowiana*). Os tratamentos consistiram de quatro níveis de calagem – 0, 25, 50 e 100% da dose necessária para elevar o pH do solo a 6,5 – e de cinco níveis de fósforo – 0, 60, 120, 180 e 240 kg ha^{-1} de P_2O_5 –, dispostos em delineamento de blocos ao acaso, em arranjo de parcelas subdivididas, com três repetições. O pomar foi implantado em 2010 com a cultivar Helena. Em 2012, 2013 e 2014, o crescimento das plantas foi avaliado por meio da medição do perímetro do tronco, da altura das plantas e do diâmetro das copas. A composição mineral das folhas, quanto aos teores de P, N, K, Ca e Mg, foi avaliada anualmente. A colonização micorrízica foi avaliada em 2012, e a produção de frutos foi determinada em 2014. Não houve interação entre os fatores estudados. Os níveis de P não tiveram efeito sobre as variáveis avaliadas. A calagem, no entanto, aumenta o crescimento das plantas, a colonização micorrízica, a produção de frutos e os teores foliares de Ca e Mg, além de ter reduzido o teor foliar de K.

Termos para indexação: *Acca sellowiana*, nutrição mineral, colonização micorrízica, estado nutricional, adubação fosfatada, acidez do solo.

Introduction

Feijoa [*Acca sellowiana* (Berg.) Burret (Syn. *Feijoa sellowiana* Berg.)] is a plant species of the family Myrtaceae, native to the southern Brazilian plateau, northeastern Uruguay (Mattos, 1986), and Argentina (Keller & Tressens, 2007). Its fruits have excellent organoleptic potential for sale in natura (Barni et al., 2004) and they can be processed as juices, jellies, ice cream, and liqueurs (Thorp & Bieleski, 2002), besides having pharmacological properties (Vuotto et al., 2000).

New Zealand and Colombia are the major producers and exporters of the fruit. Although the largest natural

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concentration of this species occurs in Brazil, the country imports most fruits from Colombia, where local population considers the species native.

The lack of proper cultural practices for the management of this culture, such as the absence of a fertilization recommendation system adjusted to the soil and climatic conditions where feijoa adapts to in Brazil, are factors that limit the culture's productivity and expansion in the country. Moreover, research on the nutritional management of this culture is scarce, which makes recommendations for fertilizing and liming more difficult, either before or after the planting of seedlings.

In Brazil, soils where the species occurs are usually acidic, with high contents of exchangeable Al and low contents of extractable P. However, the best results for commercial production of the fruit are obtained in fertile, well-drained, slightly acidic (pH 6.0–6.5) soils, with high organic matter (OM) contents (Thorp & Bieleski, 2002; Fisher et al., 2003). Studies on plants grown in pots showed positive effects of liming and phosphate fertilization on feijoa growth (Dal Bó & Ducroquet, 1992). However, works carried out under field conditions are still essential for a better adjustment of fertilization recommendations.

The objective of this work was to investigate the effect of liming and phosphorus fertilization on the growth, mineral composition of the leaves, fruit yield, and mycorrhizal colonization of young feijoa (*Acca sellowiana*) plants.

Materials and Methods

The experiment was conducted at the experimental station of Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina (Epagri), in the municipality of São Joaquim, in the state of Santa Catarina, Brazil (28°17'25"S, 49°56'56"W, at an altitude of 1,415 m). The orchard was planted in 2010, with the cultivar Helena, obtained from the breeding program of Epagri.

The soil of the experimental area is classified as a Cambissolo Húmico (Santos et al., 2013), i.e., an Inceptisol, with the following physicochemical attributes: pH in H_2O of 5.1; 4.2 mg dm^{-3} P; 2.51 mmol$_c$ dm^{-3} K; 17 mmol$_c$ dm^{-3} Ca; 8 mmol$_c$ dm^{-3} Mg; 69 g dm^{-3} OM; and 250 g dm^{-3} clay.

The treatments were placed in a randomized complete block design, in a split-plot arrangement, with three replicates. The main plots (30x4.0 m) received four liming doses: 0, 25, 50, and 100% of the dose required to raise the pH in H_2O to 6.5, which corresponded to 0, 12, 24, and 36 Mg ha^{-1}, respectively; and the split-plots (6.0x4.0 m) received five doses of P: 0, 60, 120, 180, and 240 kg ha^{-1} P_2O_5. Dolomitic lime was applied in two equal doses and incorporated into the soil through a sequence of plowing and harrowing operations, up to about 0.40-m depth. P doses, in the form of triple superphosphate, were incorporated into the soil along with the second lime application.

To favor the early development of the plant, the flowers developed until the 2012/2013 crop season were removed. Annually, in November and January, surface N fertilization (30 kg ha^{-1} N) was performed. In 2012, 2013, and 2014, plant growth was evaluated by measuring trunk perimeter, plant height, and canopy width. Additionally, the first fruit yield was assessed in 2014.

Also annually, in the second fortnight of March, 40 leaf samples were sampled from the median portion of the branches grown during the year, at the median height of the plant. The leaves were dried at 65°C and ground afterward. Subsamples of 0.5 g of the ground material were subjected to nitric-perchloric acid digestion with 1.0 mL $HClO_4$ + 6.0 mL HNO_3, at 190°C, in a digester block. In the extract, P contents were determined by UV spectrophotometry through the vanadate-molybdate method; and K, Ca, and Mg contents, by flame atomic absorption spectrometry. N was obtained by the micro-Kjeldahl method after digestion of 0.2 g with 2.0 mL H_2O_2 + 5.0 mL H_2SO_4 and catalyst salts at 380°C.

In March 2012, samples of the root system, i.e., root fragments of approximately 1.0 g, were randomly collected in the canopy projection area. The intensity of the mycorrhizal colonization in the root system and the arbuscule abundance in mycorrhizal parts of root fragments were determined and calculated as described by Trouvelot et al. (1986). For this analysis, root fragments were: preserved in alcohol 50%; subjected to discoloration with KOH 10% for 24 hours, at room temperature, and for 35 min, at 121°C; and then subjected to coloration with glycerol acid solution containing 0.05% trypan blue, at 121°C, for 10 min (Koske & Gemma, 1989).

The results were subjected to the analysis of variance, at 5% probability, and to the regression analysis to determine the effects of P and lime doses.

Results and Discussion

The effects of lime and P doses did not interact with each other. Phosphorus application had no effect on any of the evaluated variables, except canopy width. However, lime had a significant effect on all of them, increasing trunk perimeter, plant height, and canopy width (Table 1). These results indicate that, although feijoa is adapted to acidic soils, liming improves plant growth in the period preceding production, as reported by Dal Bó & Ducroquet (1992) for plants grown in pots.

Table 1. Plant growth parameters of feijoa (*Acca sellowiana*) in response to the application of different lime doses to the soil in 2012, 2013, and 2014.

Lime dose ($Mg\ ha^{-1}$)[1]	Trunk perimeter	Plant height	Canopy width
	------------------------------(cm)--------------------------------		
		2012[2]	
0	6.8*	100*	42*
12	8.2	109	52
24	8.2	107	52
36	9.1	112	57
CV (%)	16.0	10.2	27.5
		2013[3]	
0	24.8*	123*	96*
12	31.6	148	121
24	31.6	144	119
36	33.0	142	123
CV (%)	16.0	16.9	16.1
		2014[4]	
0	37.3*	136*	136*
12	46.8	166	164
24	45.3	153	155
36	46.7	166	160
CV (%)	13.2	13.5	11.2

[1]Lime doses respectively associated with 0, 25, 50, and 100% of the required dose necessary to increase soil pH to 6.5. [2]Significant regressions associated with: trunk perimeter, $y = 7.04 + 0.0575x$ ($R^2 = 0.88$); plant height, $y = 100.9 + 0.533x - 0.0069x^2$ ($R^2 = 0.79$); and canopy width, $y = 42.75 + 0.687x - 0.0087x^2$ ($R^2 = 0.90$). [3]Significant regressions associated with: trunk perimeter, $y = 25.21 + 0.542x - 0.0094x^2$ ($R^2 = 0.92$); plant height, $y = 124.55 + 2.129x - 0.0468x^2$ ($R^2 = 0.87$); and canopy width, $y = 97.65 + 1.9708x - 0.0365x^2$ ($R^2 = 0.86$). [4]Significant regressions associated with: trunk perimeter, $y = 37.99 + 0.7287x - 0.0141x^2$ ($R^2 = 0.84$); plant height, $y = 139.45 + 1.7042x - 0.02951x^2$ ($R^2 = 0.61$); and canopy width, $y = 138.55 + 1.9625x - 0.0399x^2$ ($R^2 = 0.72$). CV, coefficient of variation. *Significant regressions at 5% probability.

The positive effect of liming for plants, in general, has been known for a long time. The application of lime to acidic soils promotes greater development of the plant root system, consequently improving water and nutrient absorption. Besides neutralizing the toxic forms of Al (Kochian et al., 2005), liming also supplies Ca, which has a preponderant role in root growth. Ca uptake occurs only in newer parts of the roots, not yet suberized (Marschner, 2012); therefore, it requires continuous absorption to ensure the adequate development of the root system (Tagliavini & Scandellari, 2013), since new roots are only formed when the nutrient is present in the soil (Taiz & Zeiger, 2013).

As previously mentioned, phosphorus P fertilization did not affect any of the evaluated variables, except canopy width in 2013 (Table 2). This result may be related to the fact that fruit trees generally show little response to this nutrient, whose absorption is relatively lower than that of other macronutrients, such as N and

Table 2. Growth parameters of feijoa (*Acca sellowiana*) in response to the application of different phosphorous doses to the soil in 2012, 2013, and 2014.

P_2O_5 ($kg\ ha^{-1}$)	Trunk perimeter	Height	Canopy width
	---------------------------------(cm)---------------------------------		
		2012	
0	7.87	106	46
60	8.12	110	50
120	7.96	108	51
180	8.42	107	52
240	8.00	104	55
CV (%)	16.0	10.2	27.5
		2013[1]	
0	30.5	143	115.0*
60	30.4	142	114.2
120	29.7	130	112.2
180	30.3	138	113.6
240	31.8	149	125.5
CV (%)	16.0	16.9	16.1
		2014	
0	43.7	157	155
60	43.0	149	148
120	43.0	154	156
180	44.1	154	153
240	46.3	160	155
CV (%)	13.2	13.5	11.2

[1]Significant regression associated with canopy width: $y = 115.23 - 0.1892x + 0.0038x^2$ ($R^2 = 0.75$). CV, coefficient of variation. *Significant regression at 5% probability.

K (Neilsen et al., 2008). Furthermore, compared with annual crops, fruit trees have greater time for nutrient uptake, which favors the accumulation of reserves, requiring lower amounts of available P. In addition, the high OM content in the soils of the studied region probably contributed to significantly increase P availability for feijoa. Another factor that greatly contributes to increase P uptake is the association of roots with arbuscular mycorrhizal fungi (Cardoso & Kuyper, 2006), which may also be related to the efficiency of P use by the trees. In the present study, water stresses may also have limited the response to P, since the experimental area was not irrigated and the main supply route of P to the roots, i.e., diffusion, is a mechanism highly dependent on soil moisture content (Santos et al., 2008).

In another study, however Dal Bó & Ducroquet (1992) observed that feijoa growth responded to phosphate fertilization. This positive response was probably linked to the different P availability in the evaluated soils and the smaller soil volume for exploration by the plants, which were grown in pots in their experiment.

With respect to the mineral composition of the leaves, the greater plant growth promoted by liming was accompanied by increased Ca and Mg leaf contents, which approximately doubled with the application of any of the lime doses (Table 3). Because dolomitic lime contains Ca and Mg in its composition, it increases the availability of these nutrients in the soil solution, favoring their uptake by the plants. Lime application also affects indirectly N availability, since it promotes increased microbial activity and, consequently, greater OM mineralization rate, which is a major N source to plants. This effect can explain the increased foliar N content in the first year when liming was used.

Regardless of the year, K leaf contents were reduced with lime application (Table 3). The lower K contents in the leaves can be associated with the nutrient dilution effect in response to increased plant growth in the presence of lime. Liming also increases the number of negative charges (CEC) in the soils (Havlin et al., 2013), which favors K adsorption in the new charges generated by liming (Ernani, 2008), reducing K activity in the soil solution.

Beyhan et al. (2011) evaluated nutrient contents in feijoa leaves and found significant variations between the genotypes studied. According to the authors, the N, P, K, Ca, and Mg contents ranged from 14.2–22.2 for N, 0.86–1.34 for P, 3.6–6.6 for K, 1.7–3.4 for Ca, and 0.19–3.20 mg kg^{-1} for Mg, depending on the genotype. These results contrast with those obtained in the present study, especially in terms of K and Ca contents, which were lower and higher, respectively (Table 3). These discrepant contents can be attributed to the different soil types, climate, and genotypes analyzed in each experiment.

Regardless of the crop, none of the leaf nutrient contents, not even that of P, changed in response to phosphate fertilization (Table 4). These results show that, in similar soils with high OM content, P is not a limiting nutrient for plant growth. However, further studies may indicate the need or not to use phosphate fertilizers during the full production cycle of this crop.

Since fruit yield did not respond to phosphate fertilization, it was not possible to establish the critical value of P between relative fruit yield and soil P content

Table 3. Leaf contents of N, P, K, Ca, and Mg in feijoa (*Acca sellowiana*) in response to the application of different lime doses to the soil in 2012, 2013, and 2014.

Lime dose [(1)] (Mg ha^{-1})	Mineral composition of the leaves				
	N	P	K	Ca	Mg
	-----	-----	($g\ kg^{-1}$)	-----	-----
			2012[(2)]		
0	15.3*	1.48	16.5*	2.99*	1.18*
12	15.7	1.28	10.7	6.08	2.18
24	16.4	1.34	11.0	6.61	2.35
36	16.8	1.30	10.5	6.61	2.32
			2013[(3)]		
0	18.8	1.45*	10.9*	4.15*	1.27*
12	19.2	1.56	9.0	7.78	2.51
24	19.5	1.70	8.8	8.09	2.75
36	19.2	1.55	8.1	9.15	2.90
			2014[(4)]		
0	23.5	1.99	11.3*	5.00*	1.50*
12	22.5	2.06	8.9	7.95	3.00
24	23.1	2.24	8.8	8.45	3.00
36	21.8	2.00	7.0	9.14	3.10

[(1)]Lime doses respectively associated with 0, 25, 50, and 100% of the required dose necessary to increase soil pH to 6.5. [(2)]Significant regressions associated with: N, $y = 15.27 + 0.0433x$ ($R^2 = 0.98$); K, $y = 16.155 - 0.4788x + 0.0092x^2$ ($R^2 = 0.90$); Ca, $y = 3.0915 + 0.288x - 0.0054x^2$ ($R^2 = 0.97$); and Mg, $1.2115 + 0.0943x - 0.0018x^2$ ($R^2 = 0.98$). [(3)]Significant regressions associated with: P, $y = 1.434 + 0.0199x - 0.0005x^2$ ($R^2 = 0.84$); K, $y = 10.79 - 0.1467x + 0.0021x^2$ ($R^2 = 0.94$); Ca, $y = 4.3535 + 0.2882x - 0.0045x^2$ ($R^2 = 0.94$); and Mg, $y = 1.3155 + 0.1109x - 0.0019x^2$ ($R^2 = 0.97$). [(4)]Significant regressions associated with: K, $y=10.959-0.1083x$ ($R^2=0.90$); Ca, $y = 5.132 + 0.2489x - 0.0039x^2$ ($R^2 = 0.96$); and Mg, $y = 1.58 + 0.1275x - 0.0024x^2$ ($R^2 = 0.93$). *Significant regression at 5% probability.

in the 0.00–0.20-m layer, nor between the relative fruit yield and total P content in the leaves (Figure 1).

Lime application promoted significant increases in fruit yield and in the number of fruits per plant, in the first crop yield assessed (Figure 2). The application of 25% of the lime dose necessary for soil pH to reach 6.5, in the 0.00–0.20-m layer, increased it to 5.58 in 2013. This dose approximately doubled fruit yield compared with the plots that did not receive lime. The average mass of fruits (103 g) was similar between the treatments, indicating that the increase in yield can be attributed to the larger number of fruits per plant in the plots that had received lime, mainly in response to the increased availability of Ca, which favors root and canopy growth. Critical values of Ca in the soil and in plant tissues related to the first fruit yield are shown in Figure 3. To reach 90% of the maximum yield, soil critical values should be 4.8 mg dm^{-3} of exchangeable Ca, and 5.9 g kg^{-1} of total Ca in the leaves were obtained.

Since lime has low mobility in the soil when applied on soil surface (Ernani, 2008), in commercial crops, it should be applied and incorporated to the soil, prior to the planting of seedlings. This would enable greater initial plant growth, with positive effects on the productive capacity in subsequent years.

Table 4. Leaf contents of N, P, K, Ca, and Mg in feijoa (*Acca sellowiana*) in response to the application of different phosphorus doses to the soil in 2012, 2013, and 2014.

Lime dose ($Mg\ ha^{-1}$)(1)	Mineral composition of the leaves				
	N	P	K	Ca	Mg
	($g\ kg^{-1}$)				
			2012		
0	16.6	1.39	12.6	5.58	2.01
12	15.6	1.34	11.4	5.64	1.97
24	15.7	1.34	12.1	5.78	2.04
36	16.4	1.32	12.3	5.22	1.97
			2013		
0	19.3	1.58	9.4	7.39	2.35
12	19.6	1.58	9.5	7.26	2.34
24	18.6	1.59	9.1	7.48	2.44
36	19.1	1.52	8.9	7.10	2.34
			2014		
0	21.5	2.08	9.2	8.05	2.88
12	23.6	2.17	9.0	8.25	2.94
24	23.1	2.20	9.0	8.30	2.94
36	21.8	2.00	7.0	9.14	3.10

The mycorrhizal colonization showed typical structures of arbuscular mycorrhizal fungi, as reported for *A. sellowiana* (Andrade et al., 2000), with intracellular hyphae and vesicles, and only arbuscules of the *Arum*-type (Berbara et al., 2006). Phosphorus doses had no effect on the colonization intensity of the root cortex, nor on the content of arbuscules (Figure 4). Although not confirmed in the present study, increased P availability in the soil commonly leads to decreased mycorrhizal colonization (Nogueira & Cardoso, 2006; Balota et al., 2011; Smith et al., 2011). However, some tree species native to Brazil showed no decrease in mycorrhizal colonization due to increased P availability

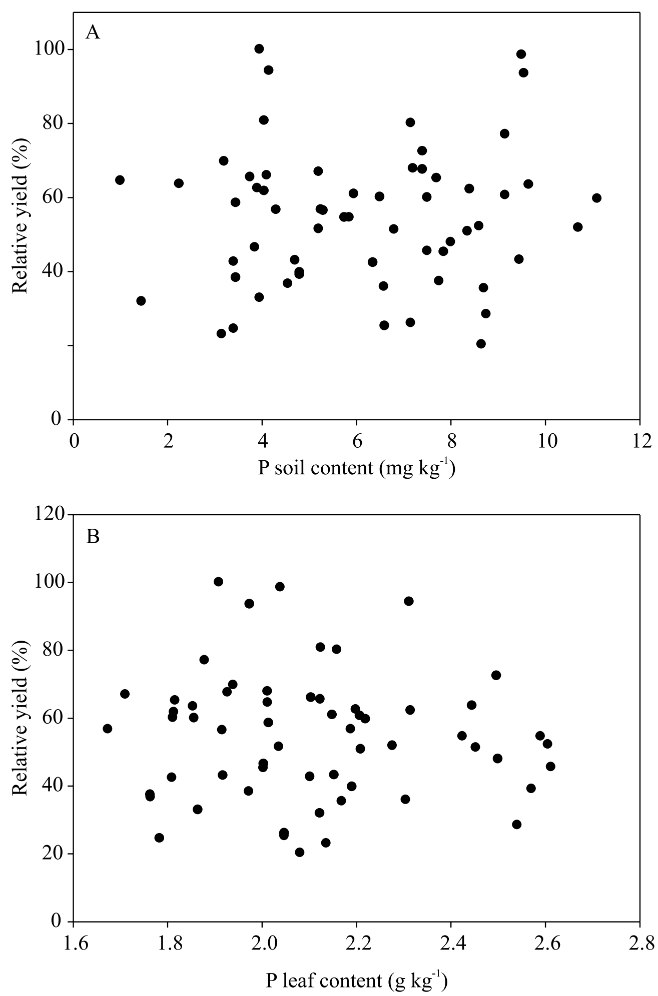

Figure 1. Relationship between: A, relative yield and available P content in the 0.00–0.20-m layer; and B, relative yield and total P content in the leaves of feijoa (*Acca sellowiana*). Assessment performed in 2014.

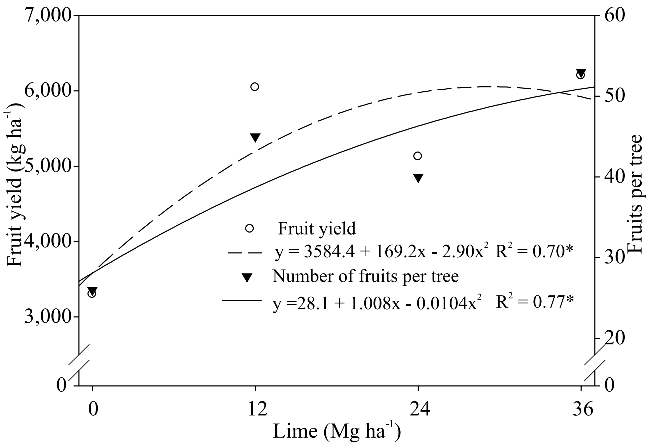

Figure 2. Yield and number of fruits of feijoa (*Acca sellowiana*) in response to the application of increasing lime doses to the soil. Assessment performed in 2014. *Significant at 5% probability.

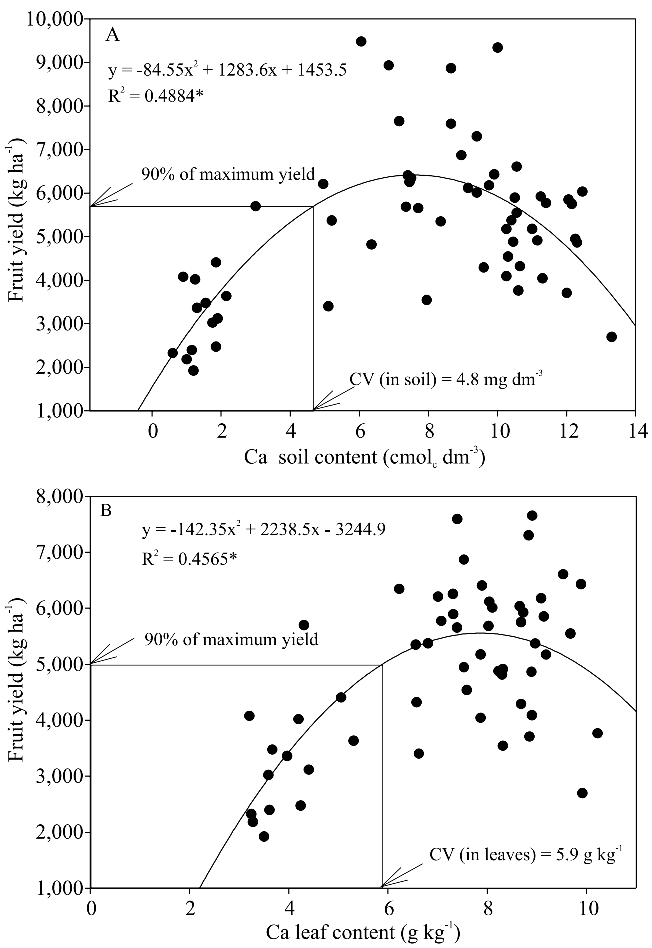

Figure 3. Relationship between: A, yield and exchangeable Ca content in the 0.00–0.20-m layer; and B, yield and total Ca content in the leaves of feijoa (*Acca sellowiana*). Assessment performed in 2014. *Significant at 5% probability. CV, critical value.

in the soil (Siqueira & Saggin-Junior, 2001), which may be the case of *A. sellowiana*.

Similarly to the variables related to plant growth, mycorrhizal colonization was positively affected by lime application (Figure 4). Compared with the control, the application of the lowest lime dose increased colonization intensity by 60%. Tolerance and sensitivity to acidity and to high levels of exchangeable Al in the soil vary between species and ecotypes of arbuscular mycorrhizal fungi, as well as between the stages of colonization (Seguel et al., 2013). Therefore, benefits to plant growth associated with mycorrhizal colonization can occur regardless of soil pH, varying according to the species of mycorrhizal fungi (Cavallazzi et al., 2007). Other studies have also shown that lime application in the field can increase mycorrhizal colonization rates (Aliasgharzad et al., 2010; Schneider et al., 2011; Guo et al., 2012).

Increased availability of soil nutrients by raising soil pH and, at the same time, by supplying Ca and Mg through lime, provided improved plant nutrition, which may be related to increased mycorrhizal colonization rates in feijoa trees. Therefore, soil acidity should be corrected at the establishment of the orchard, and soil pH should be raised to at least 5.5, in order to ensure the elimination of the toxic effects of Al to the root system.

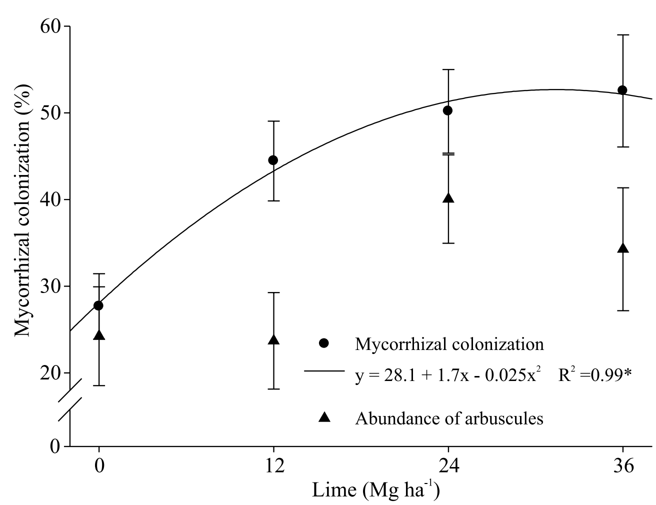

Figure 4. Intensity of the mycorrhizal colonization and arbuscule abundance in the mycorrhizal fraction (%), in response to the application of increasing lime doses to the soil. Assessment performed in 2012. *Significant at 5% probability.

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Conclusions

1. Phosphate fertilization does not affect the mineral composition, growth, or fruit yield of feijoa (*Acca sellowiana*), which indicates that this culture is little responsive to the nutrient application in the early years of cultivation.
2. Soil liming improves the nutritional status, growth, fruit yield, and mycorrhizal colonization of feijoa.

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