

Response of physalis (*Physalis peruviana* L.) to liming in acidic soils

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Abstract

Physalis is an herbaceous plant that produces edible fruits with a bittersweet flavor. This species has a high cropping potential attracting attention of farmers, traders and consumers. The effects of soil acidity indices on nutrient uptake, optimal growth, yield and fruit quality of physalis in acidic soils were evaluated. The study was conducted in a greenhouse with four lime requirements in completely randomized design and five replications. Dolomitic limestone was applied to the soils at rates of 0, 0.6, 1.4, and 2.3 t ha⁻¹ (Typic Quartzipsamment) and 0, 0.8, 1.8, and 2.8 t ha⁻¹ (Rhodic Hapludox). Plant height, stem diameter, shoot and root dry weight, longitudinal and transverse diameters of the fruits, macro and micronutrient concentrations in leaves, and soil chemical properties were evaluated. Liming is an essential practice for the cultivation of *Physalis peruviana* L. in the acidic soils, where it is aimed to achieve higher yields and quality fruit. The results highlighted the high demands of physalis for Ca, Mg, and base saturation, and low tolerance to aluminum in the soil. Maximum growth, yield and fruit quality was obtained with the application of 1.8 t lime ha⁻¹ for both soils. The determined standards for pH in water, tolerated aluminum saturation, desired base saturation and calcium and magnesium requirements were 6.4, 5.0 %, 67 % and 25,8 mmol_c dm⁻³, respectively.

Keywords: Aluminum; base saturation; fruit quality; *Physalis peruviana*; soil pH.

Abbreviations: CEC_cation exchange capacity, CV_canonical variable, LR_lime requirement, RH_Rhodic Hapludox, TQ_Typic Quartzipsamment.

Introduction

Physalis or cape gooseberry or goldenberry (*Physalis peruviana* L.) is a species native to the Andes Mountains (Puente et al., 2011). This decumbent shrub has very dense branches and belongs to family Solanaceae and genus *Physalis* (Puente et al., 2011, Mares et al., 2016). This plant has high added value and its roots and leaves have medicinal and pharmacological properties (Muniz et al., 2014). The fruit is a berry enveloped by a calyx and has a variety of flavors and sweetness being rich in vitamins A and C and is commonly used to make jellies, jams, juices, and sorbets (Muniz et al., 2014).

Acidic soils occupy approximately one-third of the soils worldwide (Sikiric et al., 2011) and occur in some of the world's most important food producing regions (Takasu et al., 2006). Soil acidity is one of the main limiting factors of agricultural activities (Li et al., 2016, Santos et al., 2016). Liming is an essential practice in agricultural systems (Fageria et al., 2007, Sikiric et al., 2011, Anikwe et al., 2016, Silva et al., 2016) and is widely used to increase yield in acidic soils (Caires et al., 2006, Fageria et al., 2008, Bhat et al., 2010, Kostic et al., 2015). The application of lime

decreases toxic concentrations of aluminum (Al) (Steiner et al., 2012, Li et al., 2016, Raboin et al., 2016), manganese (Mn), and iron (Fe) in the soils (Sikiric et al., 2011). It is one of the most efficient and common strategies to correct the high acidity of the soil (Nelson and Su, 2010, Steiner et al., 2012). Moreover, the addition of dolomitic limestone increases Ca and Mg concentrations in the soil (Li et al., 2016, Rietra et al., 2017) and improves the cation balance in the soil (Rietra et al., 2017).

The soil pH values for optimum crop production should be between pH 6.0 and 7.0 (Caires et al., 2006, Fageria et al., 2008), with base saturation values ranging from 60 to 80% (Fageria et al., 2008), and for physic nut crop, a pH above to 6.0 and base saturation of 52% provided maximum plant growth (Silva et al., 2016). Adequate Ca and Mg levels for the common bean grown on Oxisol soils were found to be approximately 20 and 10 mmol_c kg⁻¹ for Ca and Mg, respectively, for conventional planting (Fageria et al., 2008), and 17.0 mmol_c kg⁻¹ for Ca and 5.7 mmol_c kg⁻¹ for Mg to maximum growth of the physic nut plants in Brazilian soils (Silva et al., 2016). The ideal saturation ratios for Cation-

exchange capacity were 65 to 86% Ca, 6 to 12% Mg, and 2 to 5% K, with wide variations in Ca/Mg/K ratios in the soil (Rietra et al., 2017), and for the growth of physic nut, optimal Ca, Mg and K saturation was 36.0, 12.0 and 3.8 %, respectively, in two Brazilian soils (Silva et al., 2016).

However, to date, few studies have evaluated soil chemical attributes and optimization conditions for physalis farming. Cropping parameters and specific management practices responsible for higher yields are necessary to increase the acceptance of plant species in the agribusiness productive chain. The objectives of this study were to evaluate the response of soil's acidity indices to liming, nutrient uptake for optimal growth, yield and fruit quality of physalis, grown on acidic soils.

Results and Discussion

Growth, yield and fruit quality response

The results of the MANOVA indicated a significant interaction between soil types and lime requirement (LR) ($p < 0.01$) (Table 2). The interaction of the canonical variable (CV) using the multivariate model revealed a total variation of 93% (Table 2). This value was shown to be adequate using this technique (Hair et al., 2009).

The analysis of variance was performed for each experimental unit and all evaluated parameter indicating significant interaction between the two soil types and LR (F-test; $p < 0.01$) (Table 2). The regression equations were adjusted for LR and CV scores for each soil type. The quadratic equation best explained the variation in CV as a function of the LR in each soil type (Figure 1). The LRs for maximum growth, yield and fruit quality were obtained with the application of dolomite limestone at 1.6 t ha^{-1} (Typic Quartzipsamment, TQ) and 2.0 t ha^{-1} (Rhodic Hapludox, RH). These results indicate that the growth, yield and fruit quality of physalis depends on the lime requirement, which is applied to the soil and the soil type.

Liming promoted better development of fisalis in both soils (TQ and RH) (Figure 1). In addition to the low soil pH, particularly in TQ (5.1) (Table 1), the response to liming may also be correlated with low base saturation (TQ = 26%; RH = 25%) and exchangeable Al concentration (Table 1). Liming caused the decrease or elimination of toxic concentrations of Al (Raboin et al., 2016, Li et al., 2016) and an increase in the availability of Ca and Mg, improving the balance of cations and increasing the base saturation of the soil (Rietra et al., 2017).

The physalis responded more strongly to liming in the TQ than the RH, as estimated by the CV (Table 2). It was observed that amount of liming for maximum growth, yield and fruit quality is similar in both soils, corresponding to 1.6 and 2.0 t ha^{-1} for TQ and RH, respectively. Although similar, the optimum amount of limestone may be affected by the buffering capacity of each soil. Soil buffering capacity is affected by many factors, including cation exchange capacity, soil pH, clay concentration, and soil organic matter (Nelson and Su, 2010). All these variables, particularly the clay concentration, were higher in the RH than TQ (Table 1). The amount of limestone promoting a maximum development of physalis was higher in RH because of the higher clay concentration. As the clay concentration increases, a higher concentration of limestone is required to

achieve maximum growth and crop yield (Fageria et al., 2008).

Liming is widely used to increase crop yield in acidic soils (Bhat et al., 2010), being positively correlated with improvements in growth, productivity and quality of many crops, such as raspberry (Sikiric et al., 2011), wheat (Kostic et al., 2015), physic nut (Silva et al., 2016), and cassava (Anikwe et al., 2016). Other studies on soil correction using limestone in other crops have stated the importance of other variables, limestone application method, target depth, soil texture, organic matter concentration, soil pH, application time and frequency, feedstock, and costs of soil correction (Takasu et al., 2006, Bhat et al., 2010, Kostic et al., 2015).

Soil acidity affected growth, yield and fruit quality of physalis and; therefore, should be corrected with the addition of limestone to improve crop yield. The response curve of physalis crops with increased LR indicates liming as an essential practice, regardless the soil type.

Effect of liming on soil chemical attributes

A significant interaction between soil type and LR ($p < 0.01$) was found for all soil chemical attributes evaluated ($p < 0.01$). The linear regression equations were adjusted for soil chemical attributes as a function of LR in both soils (Table 3). The liming increased soil pH, concentration and saturation of Ca and Mg, and base saturation (Table 3). In contrast, liming decreased the concentration and saturation of K and Al in both soils (Table 3). After adjusting the linear regression coefficient, limestone application had a weaker effect on the pH of RH compared to TQ (Table 3). Liming caused a stronger decrease in exchangeable Al concentrations and Al saturation in TQ compared to RH (Table 3). The saturation of Ca and Mg was increased slightly higher in TQ than RH, but with no significant difference (Table 3). In turn, the decrease in K saturation was greater in TQ than RH (Table 3).

The rise in LR increased Ca and Mg concentration in both soils, resulting in cation competition with K. This competition, along with the constant humidity of the soils, favored the leaching of K and led to the accumulation of K at the bottom of the pot. Therefore, K concentration reduction in both soils due to LR increase is justified by the used sampling method, which precluded the sampling of K concentration present in the soil and its subsequent quantification during the analyses.

In TQ, liming acted as an acidity buffer and better results were observed for the neutralization of Al. Limestone neutralizes soil acidity, and acid cations are substituted for Ca^{2+} and Mg^{2+} in the soil (Santos et al., 2016). Al is precipitated as oxyhydroxide and carbon dioxide is released (Steiner et al., 2012, Li et al., 2016, Raboin et al., 2016). With regard to macronutrient supply (Ca and Mg), liming had similar performance in both soils. However, the increase in Ca was higher in TQ, whereas the increase in Mg was higher in RH. Dolomitic limestone effectively supplies Ca and Mg (Li et al., 2016, Rietra et al., 2017). Compared to baseline values, the use of limestone improved pH and the supply of Ca and Mg in the soil (Li et al., 2016, Rietra et al., 2017).

Optimum soil acidity indices

The optimum acidity indices for maximum growth, yield and fruit quality of physalis were pH 6.2-6.6, base saturation

65.0-68.7%, Ca saturation 42.6-42.2%, Mg saturation 14.1-14.4%, and K saturation 8.0-13.7% (Table 3). Soil K, Ca, and Mg concentrations for the highest growth, yield and fruit quality of physalis were 4.0-5.0, 17.3-21.3, and 5.9-7.1 mmol_c kg⁻¹, respectively. The Al saturation tolerated by physalis was 1.6 and 7.6% (Table 3).

The knowledge of the optimum acidity indices for liming and soil fertilization for the cultivation of physalis is essential. Increased productivity is achieved after the establishment of these chemical standards in different soils. Fertilization and management practices improve the responses of physalis. Furthermore, liming increases the availability of nutrients such as P, which plays an essential role in initial plant growth.

The soil acidity values for maximum growth, yield and fruit quality of physalis were higher for TQ than for RH, except for pH and Ca and Mg concentrations (Table 3). The lower pH of TQ was due to the lower initial pH of this soil type and the lower amount of limestone required for maximum growth, yield and fruit quality of physalis compared to RH. The highest concentrations of Ca and Mg in RH can be attributed to a higher requirement of basic cations (Ca and Mg) in the development of physalis in this soil compared to those in TQ (Table 2).

The optimum pH values for growth, yield and fruit quality of physalis and base saturation found in this study were 6.4 and 67%, respectively. A soil pH of 6.7 and base saturation of 60-80% was reported as being adequate for the growth of common bean (Fageria et al., 2007). In physic nut crop, a pH above to 6.0 and base saturation of 52% provided maximum plant growth (Silva et al., 2016). In general, pH values between 6.0 and 7.0 are considered ideal for crop yield (Caires et al., 2006).

The concentrations of 19.3 and 6.5 mmol_c kg⁻¹ for Ca and Mg, respectively, were considered adequate for growth, yield and fruit quality of physalis. Ca and Mg concentration were 20 and 10 mmol_c kg⁻¹, respectively, for the maximum growth of common beans in Oxisol (Fageria et al., 2008). The average Ca and Mg concentration was 17.0 and 5.7 mmol_c kg⁻¹, respectively, in acidic soils used for the growth of physic nut (Silva et al., 2016). Optimal calcium saturation value for maximum growth, yield and fruit quality of physalis was 42%, optimal Mg saturation was 14%, and optimal K saturation was 11% being averaged across the two soils. The ideal saturation ratios for CEC were 65-86% Ca, 6-12% Mg, and 2-5% K, with wide variations in Ca/Mg/K ratios in the soil (Rietra et al., 2017). The optimal Ca, Mg and K saturation was 36.0, 12.0 and 3.8 %, respectively, in Entisol e Oxisol used for the growth of physic nut (Silva et al., 2016).

Physalis can tolerate Al concentrations of 1.25 mmol_c kg⁻¹, and an Al saturation of 5.0% (Table 3). A mean soil tolerance of 1.9 mmol_c kg⁻¹ of Al and Al saturation of 10.3% was reported in physic nut crops (Silva et al., 2016). Acid solids have high levels of aluminum that have been linked to decreased shoot and root growth, and plants have shown morphological abnormalities typical of the toxicity caused by this metal (Steiner et al., 2012).

Effects of liming on plant nutrition

The effects of liming on nutrient concentrations in shoot dry matter are known for some crops, including soybean (Caires et al., 2006), common bean (Fageria et al., 2008), physic nut

(Silva et al., 2016), and other crops. Conversely, to date, these parameters are still undefined for physalis. Therefore, aiming to obtain this information, nutrient concentrations in the diagnostic leaf were determined.

A significant interaction ($p < 0.01$) was observed between the soil type and LR for all the analyzed nutrients, except for copper (Cu) ($p > 0.05$). The linear regression equations were adjusted to the LR with nutrient concentrations in each soil (Table 4). For macronutrients, the concentrations of P, Ca, Mg, and S were increased and the concentrations of N and K were decreased in the diagnostic leaves of physalis as the amount of limestone was increased (Table 4). Based on the linear regression coefficient (Table 4), the increment in P, Ca, and Mg was highest in RH, whereas the increment in S was highest in TH. The reduction in N and K concentration was stronger in TQ (Table 4). For micronutrients, the concentrations of B, Fe, Mn, and Zn were decreased in diagnostic leaves relative to the increase for limestone applied to the soil (Table 4). The decrease in the concentrations of B, Fe, and Zn was higher in TQ, whereas the decrease in Mn concentration was higher in RH (Table 4). The concentration of macronutrients in the diagnostic leaf was higher in plants grown in the RH, except for S, which was higher in TQ (Table 4). All micronutrients, except B, presented higher concentrations in plants cultivated in LVd (Table 4). There was a lack of data on nutrient concentrations of physalis. However, the study by Raviv and Lieth (2008) on different plant was used for comparison.

The increase in LR had a positive linear effect on P concentrations and a negative effect on N and K concentrations in physalis (Table 4). However, the concentrations of N and P were within the range of 10-56 g kg⁻¹ for N and 1.2-5.0 g kg⁻¹ for P, which is considered suitable for plant development (Raviv and Lieth, 2008). By contrast, K concentration was below the range of 14-64 g kg⁻¹ (Raviv and Lieth, 2008). The negative effect was proportional to the increase in Ca and Mg levels, which is related to the greater availability of Ca and Mg in the soil from dolomitic limestone applications (Caires et al., 2006). The Ca²⁺ concentration is increased, K⁺ uptake is decreased until antagonism between these cations occurs (Rietra et al., 2017).

The Ca and Mg concentrations were higher with limestone application (Table 4), being above the level considered adequate for plant development, which were 2.0-9.4 g kg⁻¹ for Ca and 1.0-2.1 g kg⁻¹ for Mg (Raviv and Lieth, 2008). Although S levels were higher after the application of limestone, S concentration was below the level considered optimum for plant development (2.8 and 9.8 g kg⁻¹) (Raviv and Lieth, 2008). Liming increased Ca and Mg concentrations in raspberry leaves from 14.9 to 19.2 g kg⁻¹ and 3.5 to 5.8 g kg⁻¹, respectively (Sikiric et al., 2011). The mean S concentration in the shoot (3.1 g kg⁻¹) was considered adequate for physic nut cultivated at different limestone doses in soil acidic (Silva et al., 2016).

The concentrations of B, Fe, Mn, and Zn were decreased in response to increase after the application of limestone (Table 4). The B levels remained above the range considered adequate for plant development (1.0 to 35.0 mg kg⁻¹) (Raviv and Lieth, 2008). The Mn concentrations remained below the range considered suitable for plant development (50 to 250 mg kg⁻¹) (Raviv and Lieth, 2008).

Table 1. Chemical and textural characterization of the soils before applying treatments.

Attribute	Unit	Typic Quartzipsamment (TQ)	Rhodic Hapludox (RH)
pH ^a _{water}	-	5.1	5.5
p ^b	mg kg ⁻¹	0.2	0.2
K ^b	mmol _c kg ⁻¹	0.4	0.2
Ca ^c	mmol _c kg ⁻¹	6.7	8.1
Mg ^c	mmol _c kg ⁻¹	3.5	3.9
Al ^c	mmol _c kg ⁻¹	7.8	1.6
CEC ^d	mmol _c kg ⁻¹	40.6	49.2
m ^e	%	42.0	12.0
V ^f	%	26.0	25.0
MPAC ^g	mg kg ⁻¹	120	250
Organic carbon	g kg ⁻¹	3.5	5.2
Sand	g kg ⁻¹	830	310
Loam	g kg ⁻¹	110	180
Clay	g kg ⁻¹	60	510

^aSoil:water 1:2.5; ^bMehlich 1 extractor; ^cKCl 1 mol L⁻¹ extractor; ^dCation-exchange capacity; ^eAl saturation; ^fBases saturation; ^g Maximum phosphate adsorption capacity

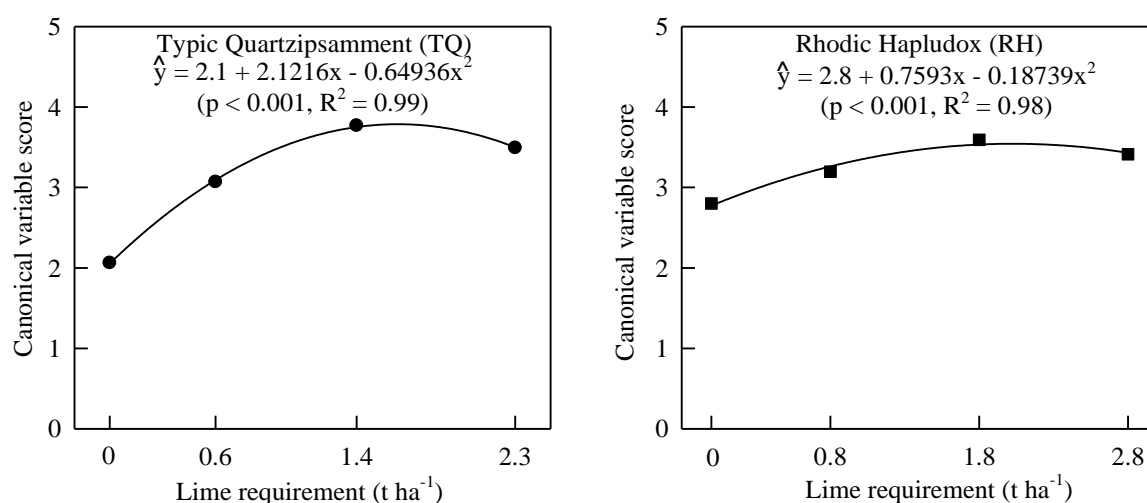


Fig 1. Canonical variable score from multivariate analysis for physalis depend on lime requirement applied to acidic soils.

Table 2. Mean values of plant height, stem diameter, shoot dry matter (SDM), root dry matter (SDR), fruit yield, longitudinal diameter (LD), and transverse diameter (TD) of fruits for physalis and the results of a canonical variable (CV) analysis and analysis of variance for lime requirements (LR) for acidic soils.

LR	Height	Diameter	SDM	SDR	Yield	LD	TD	CV ^a
t ha ⁻¹	--cm--	--mm--	-----g plot ⁻¹ -----			-----cm-----		
Typic Quartzipsamment (TQ)								
0	36.50	7.78	13.97	9.70	28.77	1.15	1.10	2.06
0.6	47.24	9.94	21.78	17.85	56.95	1.45	1.44	3.07
1.4	52.88	11.22	26.77	31.75	78.44	1.50	1.51	3.77
2.3	51.18	10.80	25.34	26.83	71.20	1.45	1.45	3.49
Rhodic Hapludox (RH)								
0	52.74	7.36	22.24	36.14	60.09	1.31	1.38	2.80
0.8	56.60	10.10	19.30	34.08	65.55	1.56	1.53	3.20
1.8	58.90	10.96	23.64	37.07	69.23	1.61	1.65	3.59
2.8	41.30	9.64	17.40	26.01	64.67	1.54	1.51	3.41
LSD (p ≤ 0.05)	9.41	1.47	3.85	9.10	21.58	0.16	0.13	0.30
F-Wilks' lambda test								F-value
Soil (S)				4.56**				46.03**
LR				20.21**				34.12**
S * LR				3.52**				45.56**

^a Canonical variable: CV = -0,034638 × Height + 0,15057 × Diameter + 0,02998 × SDM + 0,01938 × SDR + 0,01003 × Yield + 0,18854 × LD + 0,94572 × TD with eigenvalue = 93%.

** Significant at 0.01.

Table 3. Regression equation and determination coefficients (R^2) for soil chemical attributes (\hat{y}) at varying lime requirements (x , t ha⁻¹) for two acidic soils, resulting optimal values for maximum growth, yield and fruit quality of physalis.

Chemical attribute	Regression equation	R^2	F-value	Value
Typic Quartzipsamment (TQ)				
pH _{water}	$\hat{y} = 5.1 + 0.6583x$	0.91	29.4**	6.2
K (mmol _c kg ⁻¹)	$\hat{y} = 5.3 - 0.1878x$	0.89	25.5**	5.0
Ca (mmol _c kg ⁻¹)	$\hat{y} = 6.7 + 6.6117x$	0.99	526.7**	17.3
Mg (mmol _c kg ⁻¹)	$\hat{y} = 3.1 + 1.7212x$	0.94	30.3**	5.9
Al (mmol _c kg ⁻¹)	$\hat{y} = 8.2 - 3.8987x$	0.85	21.6**	2.0
Al saturation (%)	$\hat{y} = 33.1 - 15.9473x$	0.86	22.7**	7.6
Base saturation (%)	$\hat{y} = 36.7 + 20.0001x$	0.99	113.9**	68.7
Ca saturation (%)	$\hat{y} = 16.4 + 16.1261x$	0.99	428.6**	42.2
Mg saturation (%)	$\hat{y} = 7.4 + 4.2127x$	0.97	41.5**	14.1
K saturation (%)	$\hat{y} = 13.0 - 0.4581x$	0.89	23.5**	13.7
Rhodic Hapludox (RH)				
pH _{water}	$\hat{y} = 5.9 + 0.3507x$	0.96	42.8**	6.6
K (mmol _c kg ⁻¹)	$\hat{y} = 4.2 - 0.0867x$	0.99	32.5**	4.0
Ca (mmol _c kg ⁻¹)	$\hat{y} = 8.5 + 6.4086x$	0.99	712.8**	21.3
Mg (mmol _c kg ⁻¹)	$\hat{y} = 3.6 + 1.7664x$	0.98	112.5**	7.1
Al (mmol _c kg ⁻¹)	$\hat{y} = 0.9 - 0.2077x$	0.80	27.6**	0.5
Al saturation (%)	$\hat{y} = 4.9 - 1.6284x$	0.80	28.0**	1.6
Base saturation (%)	$\hat{y} = 32.6 + 16.1766x$	0.99	304.5**	65.0
Ca saturation (%)	$\hat{y} = 17.0 + 12.8172x$	0.99	712.0**	42.6
Mg saturation (%)	$\hat{y} = 7.3 + 3.5327x$	0.98	122.3**	14.4
K saturation (%)	$\hat{y} = 8.3 - 0.1733x$	0.99	210.2**	8.0

** Significant at 0.01.

Table 4. Regression equation and determination of coefficients (R^2) for nutrient concentrations (\hat{y}) in diagnostic leaf of physalis at varying lime requirements (x , t ha⁻¹) for two acidic soils, resulting optimal values for nutrient concentration for maximum growth, yield and fruit quality of physalis.

Nutrient	Regression equation	R^2	F-value	Value
Typic Quartzipsamment (TQ)				
N	$\hat{y} = 29.8 - 6.4208x$	0.85	21.8**	19.5
P	$\hat{y} = 2.7 + 0.1881x$	0.91	31.2**	3.0
K	$\hat{y} = 14.1 - 4.9403x$	0.87	33.5**	6.2
Ca	$\hat{y} = 4.0 + 3.0793x$	0.97	62.2**	8.9
Mg	$\hat{y} = 2.2 + 0.6928x$	0.84	39.8**	3.3
S	$\hat{y} = 1.2 + 1.0294x$	0.94	32.1**	2.8
B	$\hat{y} = 112.2 - 28.4296x$	0.87	25.7**	66.7
Cu	$\hat{y} = \bar{y} = 14.4$	-	2.8	14.4
Fe	$\hat{y} = 369.4 - 122.4384x$	0.99	78.4**	173.5
Mn	$\hat{y} = 36.2 - 5.3439x$	0.97	75.4**	27.6
Zn	$\hat{y} = 42.4 - 9.6917x$	0.85	36.5**	26.9
Rhodic Hapludox (RH)				
N	$\hat{y} = 34.5 - 2.0052x$	0.92	32.8**	30.5
P	$\hat{y} = 2.5 + 0.6210x$	0.98	36.2**	3.7
K	$\hat{y} = 15.0 - 0.6696x$	0.99	80.5**	13.7
Ca	$\hat{y} = 11.0 + 3.8532x$	0.99	95.3**	18.7
Mg	$\hat{y} = 2.9 + 1.1378x$	0.93	45.7**	5.2
S	$\hat{y} = 1.4 + 0.5550x$	0.97	66.2**	2.5
B	$\hat{y} = 80.1 - 10.8450x$	0.86	22.4**	58.4
Cu	$\hat{y} = \bar{y} = 14.4$	-	2.8	14.4
Fe	$\hat{y} = 276.1 - 21.9613x$	0.98	117.1**	232.2
Mn	$\hat{y} = 71.9 - 18.1447x$	0.99	108.6**	35.6
Zn	$\hat{y} = 51.7 - 9.0409x$	0.83	39.8**	33.6

^o Concentration values for macronutrients are in g kg⁻¹ and micronutrients in mg kg⁻¹.

** Significant at 0.01.

Fe and Zn concentrations were within the levels considered optimum for plant development between 50 to 550 mg kg⁻¹ and 10 to 100 mg kg⁻¹, respectively (Raviv and Lieth 2008). Leaf concentrations of Cu were poorly affected by increases in liming in both soils (Table 4). Nonetheless, Cu concentration was more than two-fold higher than the one proposed by Raviv and Lieth (2008) (2.3-7.0 mg kg⁻¹) which is considered adequate for plant development. This result indicates a poor response to Cu accumulation, as reported in *Lupinus albus* cv. Estoril crops (Mourato et al., 2009). These results indicate the importance of liming in increasing nutrient availability, particularly Ca and Mg; however, high concentrations of limestone may impair nutrient uptake, especially micronutrients.

Materials and methods

Plant material and growing conditions

The study was conducted in a greenhouse in Diamantina state of Minas Gerais, Brazil (18°15'S, 43°36'W, 1,250 m a.s.l.). Samples were collected from the 0-0.2 m layer of two soil: a Typic Quartzipsamment (Entisol) and a Rhodic Hapludox (Oxisol). A subsample was air-dried, sieved (2.0 mm) for chemical analysis and soil texture (Teixeira et al., 2017) (Table 1).

A completely randomized design was used for the experiment, with four lime requirements and five replications. Lime requirements were based on increase the base saturation by 40, 60, and 80%, combined with a control treatment in each soil. Lime requirement (LR) was calculated as $LR (t ha^{-1}) = (V_2 - V_1) \times CEC / 100$, where V_2 is the established base saturation (40, 60 and 80%) and V_1 is the current base saturation (soil analysis) (Table 1). Dolomitic limestone (380 g kg⁻¹ of calcium oxide (CaO), 125 g kg⁻¹ of magnesium oxide (MgO), and 90% total neutralizing power) was applied to the soils at rates of 0, 0.6, 1.4, and 2.3 t ha⁻¹ (Typic Quartzipsamment) and 0, 0.8, 1.8, and 2.8 t ha⁻¹ (Rhodic Hapludox). The soils were incubated for 15 days, with humidity of 60% of field capacity, which was controlled by weighing the soil samples daily.

The basal fertilization rates of nitrogen (N), potassium (K), sulfur (S), boron (B), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) were 150 mg N (ammonium nitrate (NH₄NO₃)), potassium nitrate (KNO₃) and ammonium sulfate ((NH₄)₂SO₄), 150 mg K (KNO₃), 50 mg S ((NH₄)₂SO₄), 1.0 mg B (boric acid (H₃BO₃)), 1.5 mg Cu (copper chloride (CuCl₂)), 5.0 mg Fe (iron(II) sulfate heptahydrate-ethylenediaminetetraacetic acid (FeSO₄·7H₂O-EDTA)), 4.0 mg Mn (MnCl₂·H₂O), and 5.0 mg Zn (zinc chloride (ZnCl₂)) per kg of soil. Phosphate fertilization was estimated by the maximum phosphorus adsorption capacity of each soil (Table 1) using data from the second region of the Langmuir isotherm (Pinto et al. 2013). Therefore, the rate of P (phosphoric acid) was 120 mg kg⁻¹ for Typic Quartzipsamment and 250 mg kg⁻¹ for Rhodic Hapludox. The soil samples were incubated for 15 days, with moisture at 60% of the field capacity. The experimental unit consisted of a 5 kg pot; and 4 kg of air-dried soil (sieved to 5.0 mm) added to each pot. After the treatments and before transplantation of the *Physalis* seedlings, a new soil sampling was performed from each treatment. Sampling was carried

out with a polyvinyl chloride pipe of half inch with 0.40 m of length, being made four holes throughout the length of the plot with soil. Soil chemical analyzes were pH in water; K (Mehlich-1 extractor); Ca, Mg, and Al (potassium chloride (KCl) 1 mol L⁻¹ extractor), and hydrogen (H) + Al (calcium acetate 0.5 mol L⁻¹ extractor) according to the methods described by Teixeira et al. (2017). Al, base, Ca, Mg, and K saturation were calculated using the following equations: Al saturation (m%) = $(Al)/(\sum K, Ca, Mg, Al) \times 100$; base saturation (V%) = $(\sum Ca, Mg, K)/(cation\ exchange\ capacity\ (CEC)) \times 100$ and saturation of Ca, Mg, or K (%) = $(Ca)/(CEC) \times 100$, $(Mg)/(CEC) \times 100$ and $(K)/(CEC) \times 100$. The values of K, Ca, Mg, H + Al, and cation exchange capacity at pH 7.0 (CEC = $\sum K, Ca, Mg, H + Al$) were expressed in mmol_c kg⁻¹.

Physalis was grown from seeds of a population provided by Agricultural Research Company of Minas Gerais (Epamig) in Maria da Fé state of Minas Gerais, Brazil (22°17'S, 45°23'W, 1,285 m a.s.l.). Seeds were sown in styrofoam trays with 128 cells using a commercial 'Bioplant' substrate and irrigated daily for 10 minutes three times a day until transplantation to the pots, which occurred when the seedlings presented a mean height of 0.04 m and a stem diameter of 2.4 mm, 90 days after seedling emergence. Beginning 15 days after transplanting *Physalis* seedlings to plots, three applications of 50 mg N (urea) per kg of soil were applied at 15 days intervals. Pots were irrigated daily with distilled water to maintain soil moisture at 60% of the field capacity with checked daily by weighing the plots.

Measurements

Plant height, measure from the stem to the apical bud and stem diameter at the root collar were evaluated after 75 days of planting, when the plants of *Physalis* began to bloom. At the same time, leaves were collected to determine nutrient concentration. The leaves to be collected were defined using criteria established in an unpublished study. One whole leaf located in the middle third of the plant and composed of petiole and limbus was used and was designated diagnostic leaf. Leaf samples were packed in paper bags and dried in an oven with forced air circulation at a temperature of 65°C for 72 hours. Total concentrations of N (sulfuric acid digestion/Kjeldahl method), P, K, Ca, Mg, S, Cu, Fe, Mn, and Zn (nitric-perchloric acid digestion) and B-incineration (muffle) in diagnostic leaf were determined.

The fruits were harvested as they matured, i.e., turned orange and the calyx dried. The fruits were weighed together with the calyx to comply with trade standards. The longitudinal and transverse diameters of the fruits were measured without the calyx. Shoots and roots of *Physalis* were harvested after 120 days. Roots were removed from the soil and washed in running water. Shoot and root tissues were packed in paper bags and dried in an oven with forced air circulation at a temperature of 65°C for 72 hours. After drying, the plant material was weighed on an analytical balance, and dry weight of shoots and roots were obtained.

Calculations and statistics

A multivariate analysis of variance (MANOVA) was used to test for significant differences in *Physalis* plant height, stem diameter, dry matters of shoots and roots, fruit yield,

longitudinal and transverse diameter of the fruits by the soil type and lime requirement. The effects of soil type and lime requirement on each variable were tested using Wilks' lambda test. After the MANOVA was completed, a canonical variable process (Hair et al., 2009) was used to determine the lime requirement for maximum growth, yield and fruit quality of physalis. A single canonical variable with the highest eigenvalue was obtained using the scores from the observation vector of each experimental unit for each variable of the MANOVA. Individual univariate variance analyses and regression analyses were performed on these scores. Using the resulting equations, the lime requirement to achieve maximum growth, yield and fruit quality of physalis were determined. The data for soil attributes and nutrient concentrations in diagnostic leaf of physalis were subjected to univariate variance analyses. The regression equations were adjusted for each variable using varying lime requirement. Optimal values for maximum growth, yield and fruit quality of physalis for soil acidity indices, nutrient concentration in diagnostic leaf of physalis were estimated by replacing the lime requirement for each soil into the equations expressing the relationship between lime requirement and each variable. SAS for Windows program, including the PROG GLM and REG procedures were used for the statistical analyses.

Conclusion

Liming is an essential practice for the cultivation of physalis in acidic soils and is used to achieve higher growth, yield and fruit quality. Maximum development was obtained with the application of 1.8 t lime ha⁻¹ to a Brazilian soil. The soil acidity indexes were recommended to obtain maximum growth, yield and fruit quality of physalis as follows: pH_{water} = 6.4, Ca²⁺ = 19.3 mmol_c kg⁻¹, Mg²⁺ = 6.5 mmol_c kg⁻¹, acidity saturation = 5%, base saturation = 67%, Ca saturation = 42%, Mg saturation = 14.0% and K saturation = 11%. These results highlight the high demands of physalis to Ca, Mg, and base saturation, and low tolerance to aluminum in the soil.

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References

Anikwe MAN, Eze JC, Ibudialo, AN (2016) Influence of lime and gypsum application on soil properties and yield of cassava (*Manihot esculenta* Crantz.) in a degraded Ultisol in Agbani, Enugu Southeastern Nigeria. *Soil Tillage Res.* 158:32-38.

Bhat JA, Kundu MC, Hazra GC, Santra GH, Mandal B (2010) Rehabilitating acid soils for increasing crop productivity through low-cost liming material. *Sci Total Environ.* 408:4346-4353.

Caires EF, Churka S, Garbuio FJ, Ferrari RA, Morgano MA (2006) Soybean yield and quality as a function of lime and gypsum applications. *Sci Agric.* 63:370-379.

Fageria NK, Baligar C, Zobel W (2007) Yield, nutrient uptake, and soil chemical properties as influenced by liming and boron application in common bean in a no-tillage system. *Commun Soil Sci Plant Anal.* 38:1637-1653.

Fageria NK, Stone LF, Moreira A (2008) Liming and manganese influence on common bean yield, nutrient uptake, and changes in soil chemical properties of an Oxisol under no-tillage system. *J Plant Nutr.* 31:1723-1735.

Hair JFJ, Black WC, Babin BJ, Anderson RE (2009) *Multivariate data analysis.* 7th edn, Prentice Hall, New Jersey, EUA.

Kostic L, Nikolic N, Samardzic J, Milisavljevic M, Maksimović V, Cakmak D, Manojlovic D, Nikolic M (2015) Liming of anthropogenically acidified soil promotes phosphorus acquisition in the rhizosphere of wheat. *Biol Fertil Soils.* 51:289-298.

Li Z., Dai P, Yanhui W, Li T, Webb AA, Wang Y, Li Z, Kou T, Shi G, Zhang B (2016) Effects of liming on health and growth of young *Schima superba* trees under canopy of a *Pinus massoniana* stand damaged by soil acidification in Chongqing, China. *New Forest.* 47:801-813.

Mares LEV, Zaragoza FAR, González JJSV, Vargas-Ponce O (2016) Phenology, agronomic and nutritional potential of three wild husktomato species (*Physalis*, Solanaceae) from Mexico. *Sci Hort.* 200:83-94.

Mourato MP, Martins LL, Cuypers A (2009) Effect of copper on antioxidant enzyme activities and mineral nutrition of white lupin plants grown in nutrient solution. *J Plant Nutr.* 32:1882-1900.

Muniz J, Kretzschmar AA, Rufato L, Pelizza TR, Rufato AR, Macedo TA (2014) General aspects of physalis cultivation. *Ciência Rural.* 44:964-970.

Nelson PN, Su N (2010) Soil pH buffering capacity: a descriptive function and its application to some acidic tropical soils. *Aust J Soil Res.* 48:201-207.

Pinto FA, Souza ED, Paulino HB, Curi N, Carneiro MAC (2013) P-sorption and desorption in Savanna Brazilian soils as a support for phosphorus fertilizer management. *Ciênc Agrotec.* 37:521-530.

Puente L, Pinto C, Castro E, Cortés M (2011) *Physalis peruviana* Linnaeus, themultiple properties of a highly functional fruit: a review. *Food Res.* 44:1733-1740.

Raboin LM, Azafimahafaly AHD, Rabenjarisoa MB, Rabary B, Dusserre J, Becquer T (2016) Improving the fertility of tropical acid soils: Liming versus biocharapplication? A long-term comparison in the highlands of Madagascar. *Field Crops Res.* 199:99-108.

Raviv M, Lieth h (2008) *Soilless culture: theory and practice.* Elsevier Science, Amsterdam, EUA.

Rietra RPJJ, Heinen M, Dimkpa C, Bindraban PS (2017) Effects of nutrient antagonism and synergism on yield and fertilizer use efficiency. *Commun Soil Sci Plant Anal.* 48:1895-1920.

Santos JA, Fonseca AF, Zocco D, Vieira I (2016) Special liming materials for acidity control of soils with variable charge. *Afr J Agric Res.* 11:2920-2936.

- Sikiric B, Cakmak D, Saljnikov E, Mrvic V, Jakovljevic M, Stajkovic O, Bogdanovic D (2011) Optimization of macrolelement contents in raspberry leaves by liming in an extremely acid soil. *Span J Agric Res.* 9:329-337.
- Silva EB, Alleoni LRF, Santos SR, Magalhães SC, Farnezi MMM (2016) Response of physic nut trees to liming of acidic soils. *Commun Soil Sci Plant Anal.* 47:1023-1032.
- Steiner F, Zoz T, Pinto Junior AS, Castagnara DD, Dranski JAL (2012) Effects of aluminum on plant growth and nutrient uptake in young physic nut plants. *Semina: Ciênc Agrár.* 33:1779-1788.
- Takasu E, Yamada F, Shimada N, Kumagai N, Hirabayashi T, Saigusa M (2006) Effect of phosphogypsum application on the chemical properties of Andosols, and the growth and Ca uptake of melon seedlings. *Soil Sci Plant Nutr.* 52:760-768.
- Teixeira PC, Donagemma GK, Fontana A, Teixeira WG (2017) *Manual for methods of soil analysis.* 3rd ed, Embrapa. Brasília, Brazil.