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Surface Application of Lime on a Guava Orchard in Production

Márcio Cleber de Medeiros Corrêa(1)*, William Natale(1), Renato de Mello Prado(2), David Ariovaldo Banzatto(3), Ronialison Fernandes Queiroz(4) and Marcos Antonio Camacho da Silva(5)

(1) Universidade Federal do Ceará, *Campus* do Pici, Departamento de Fitotecnia, Fortaleza, Ceará, Brasil.
(2) Universidade Estadual Paulista, Faculdade de Ciências Agrárias e Veterinárias, *Campus* de Jaboticabal, Departamento de Solos e Adubos, Jaboticabal, São Paulo, Brasil.
(3) Universidade Estadual Paulista, Faculdade de Ciências Agrárias e Veterinárias, *Campus* de Jaboticabal, Departamento de Ciências Exatas, Jaboticabal, São Paulo, Brasil.
(4) Universidade Federal do Ceará, *Campus* do Pici, Departamento de Fitotecnia, Programa de Pós-Graduação em Agronomia/Fitotecnia, Fortaleza, Ceará, Brasil.
(5) Universidade Estadual de Mato Grosso do Sul, Unidade Universitária de Aquidauana, Aquidauana, Mato Grosso do Sul, Brasil.

ABSTRACT: Several complications can arise, either directly or indirectly, from implementation of measures to correct soil acidity in established fruit orchards, such as impaired roots, lower root volume, risk of plant infection, propagation of diseases, promotion of pest development (especially nematodes), and soil disaggregation and compaction. These factors can have a negative effect on crop yield. Therefore, it becomes critical to implement an effective method of neutralizing soil acidity, especially at the level of the tree roots. To assess the effect that the rates and forms of limestone applied on the soil surface have on soil fertility and on nutrition and yield of guava, an experiment was conducted in a commercial orchard. A randomized block experimental design was implemented with three replicates consisting of two forms of limestone [common limestone with relative neutralizing value (RNV) = 80 % and calcined limestone with RNV = 131 %], which were applied at five different rates (0, 0.5, 1, 1.5, and 2 times the recommended rate to raise the V value to 70 %), without incorporation. Liming with common or calcined limestone caused a drop in soil acidity in the 0.00-0.10 m layer at 6, 12, and 24 months after application. Soil acidity decreased in the 0.10-0.20 m layer at 6 and 12 months after use of calcined limestone, and at 24 months after liming with the common form of limestone. The chemical composition (N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, Zn) of leaves was not affected at 14 months after surface liming treatments, nor the chemical composition of fruit at 20 months after the treatments. Guava yield was not affected by surface liming.

Keywords: soil acidity, limestone, perennial crop, fruticulture, *Psidium guajava.*

*** Corresponding author:**
E-mail: mcleber@ufc.br

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INTRODUCTION

The guava (*Psidium guajava* L.) plant, typical of the tropics and subtropics, grows in soils where acidic reactions are predominant, and the plant is considered to be tolerant to low fertility soils. However, to obtain high yields, the nutritional requirements of this fruit must be adequately met, requiring correct fertilization management and, especially, soil acidity correction.

The solubility of most acidity corrective materials is limited; so, to achieve a maximum reaction in the soil volume compatible with the area used by the plant root system, limestone is applied the deepest possible. For perennial crops, like guava, the time of establishing the orchard is the only opportunity for deep incorporation of the soil corrective through plowing.

In general, in established orchards in Brazil, shallow incorporation of limestone between the rows is the procedure most used (Raij et al., 1996). The recommendation might be different if there were greater assistance from research, considering a variety of issues that may directly or indirectly arise from the practice of incorporating the corrective, such as root injuries and a decrease in root volume, along with the risk of infection, the propagation of diseases that favor development of pests such as mites and cochineals (Gravena, 1993) and, currently, above all, nematodes (Silva, 2009), and soil disaggregation and compaction, which clearly affect crop yield.

An alternative to incorporation of limestone in established orchards would be to utilize correctives with fine particle size or calcined limestone. When fine limestone is used, the physical nature of the particles contributes to their displacement in the soil profile through the channels left by root decomposition (Pearson et al., 1962; Oliveira and Pavan, 1996) and/or through transport of non-dissociated particles (Alves and Lopes, 1981). Calcined limestone, obtained industrially through partial calcination of limestone, contains $CaCO_3$ and $MgCO_3$ not decomposed from the limestone and CaO and MgO, as well as $Ca(OH)_2$ and $Mg(OH)_2$ produced by hydration of the oxides by humidity. It comes in the form of fine powder, and its neutralizing action arises from its strong base OH^- and weak base CO_3^{-2} (Alcarde, 2005). Due to their fine particle size and the bases of which they are composed, calcined limestones move more easily through the soil profile.

Another possible mechanism by which correctives move through the soil profile is through the plant residues on the soil surface, which promote accelerated transport of Ca^{2+} and Mg^{2+} (Miyazawa et al., 2002). However, it should be emphasized that movement of the particles is contingent on the application rate of the corrective, time since application, soil type, fertilization practices in the orchard, soil slope, and kind of plant cover (Natale et al., 2012).

Moreover, it must be remembered that fruit orchards are, in fact, long-term agricultural production units in which plant roots remain limited to a specific soil volume over several years. The Ca^{2+} present in the soil solution in contact with the roots is critical for root survival, as Ca^{2+} is not translocated from the shoots to new regions of growing roots (Caires et al., 2001). Thus, adequate liming will have a positive effect on plant development and nutritional status and, consequently, rational use of fertilizers and improved cost/benefit ratio through an increase in yield. In orchards in production, high N fertilizer rates applied over a limited area (fruit tree canopy projection) and for repeated crop cycles have worsened the soil acidity problem, which requires continuous monitoring through chemical analysis to verify fertility (Natale et al., 2012).

Therefore, effective practices must be developed to neutralize soil acidity in the regions where tree roots occur. The limestones have different behavior over time and in the soil profile of the orchard. Thus, the aim of this study was to evaluate the effect of surface application of different rates and forms of limestone on soil fertility and on guava nutrition and yield.

MATERIALS AND METHODS

The experiment was conducted in a commercial orchard with 9-year-old guava trees (*Psidium guajava* L.), cv. Paluma, propagated through cuttings, in the municipality of Taquaritinga (21° 24’ S, 48° 29’ W, at 521 m a.s.l.), São Paulo, Brazil. Climate type in the region is Cwa (according to the Köppen classification system), with annual rainfall of about 1,350 mm.

Soil in this area is an *Argissolo Vermelho Amarelo* (Santos et al., 2013), which corresponds to Ultisols (Soil Survey Staff, 2014), of medium texture, with the following chemical properties prior to application of the treatments under canopy projection: pH($CaCl_2$) 4.6; OM 10 g dm^{-3}; P (resin) 56 mg dm^{-3}; K^+, Ca^{2+}, Mg^{2+}, H+Al, SB, and T of 1.0, 9.0, 7.0, 31.0, 17.0, and 48.0 mmol$_c$ dm^{-3} respectively; and V = 35 % in the 0.00-0.10 m layer. Properties in the 0.10-0.20 m layer were pH($CaCl_2$) 4.4; OM 10 g dm^{-3}; P (resin) 54 mg dm^{-3}; K^+, Ca^{2+}, Mg^{2+}, H+Al, SB, and T of 0.9, 8.0, 6.0, 38.0, 14.9, and 52.9 mmol$_c$ dm^{-3}, respectively; and V = 28 %. In the area between the rows, soil acidity was roughly 20 % less than the acidity below the canopy.

A randomized complete block design was adopted for the experiment in a 2 × 5 factorial arrangement, with three replications. Two correctives were tested – common limestone taken from rock that was ground without heat treatment [CaO = 27 %; MgO = 20 %; neutralizing power (PN) = 97; 1, 8, and 27 % of the material being retained in the ABNT (Brazilian National Standards Organization) No. 10, 20, and 50 sieves, respectively, and 64 % passing through ABNT No. 50 sieve; reactivity (RE) = 81.9 %, relative neutralizing value (RNV) = 80 %]; and calcined limestone, obtained from rock that was ground after heat treatment (CaO = 42 %; MgO = 25 %; PN = 137; 0, 1, and 9 % of the material being retained in the ABNT No. 10, 20, and 50 sieves, respectively; and 90 % passing through the ABNT No. 50 sieve; RE = 95.6 %, RNV = 131 %). Five rates of limestone were applied: 0, 0.5, 1.0, 1.5, and 2.0 times the amount recommended to increase the base saturation to 70 %, which is considered ideal for the crop (Raij et al., 1996) and which corresponded to 0, 1.2, 2.4, 3.6, and 4.8 Mg ha^{-1} of common limestone and, 0, 0.75, 1.5, 2.25, and 3.0 Mg ha^{-1} of the calcined limestone. To calculate the limestone application rates, the mean CEC and V values of the 0.00-0.10 and 0.10-0.20 m soil layers were used.

Each plot contained five plants, spaced 7 × 5 m apart, of which three were considered useful. There was always a border row between the useful rows. The limestone was always broadcast without incorporation on both sides of the plant, in a 5 × 5 m area, based on the center of the guava tree trunk, in a continuous manner for each plot (this covered a total of 25 m^2 per plant and 125 m^2 per plot) to ensure that the corrective was uniformly distributed. The quantity of limestone applied was adjusted for the area to receive limestone application. Therefore, only a continuous 2 m strip running between the crop rows did not receive liming.

The orchard received periodic phytosanitary management to keep it free of pests, diseases, and weeds, all without soil tillage. Fertilization with N and K^+ was uniformly applied in all plots according to the measures adopted by Natale et al. (1996). A total of 480 g of N and 480 g of K_2O were added per plant per year, which was applied in four portions from August to January. The fertilizer was manually applied around the plant in a 0.60-m wide strip under the canopy projection. A single application of 200 g of P_2O_5 per plant per year was also made. In addition to annual soil fertilization, boric acid (0.06 %) plus zinc sulfate (0.5 %) were applied at the beginning of fruit development. Fruit-bearing plants were pruned and cleaned every year, based on the recommendations of Piza Júnior (1994), and the biomass from this operation was placed on the ground in that area.

To monitor the chemical changes occurring in the soil, samples were taken from the layers of 0.00-0.10, 0.10-0.20, and 0.20-0.40 m at six months after liming, and from the layers of 0.00-0.10, 0.10-0.20, 0.20-0.40, and 0.40-0.60 m at 12 and 24 months. Below the canopy, within the fertilized area, four subsamples were collected per plant, for a total of 12 per plot, to make up a composite sample for each layer. A total of 20 subsamples were collected from between the rows of the orchard to constitute a composite sample.

The nutritional status of the plants was evaluated and monitored annually by leaf samplings according to the procedure of Natale et al. (1996), during the full flowering phase of the guava trees. Thirty leaf pairs per plot, 10 from each useful plant, were collected. The leaves collected, together with the petiole, were the third pair (newly mature) from the tip of the branch around the entire plant, about 1.5 m above the ground.

The mineral composition of the fruit was evaluated annually at peak production. First, four pieces of fruit from each useful plant were harvested, for a total of 12 per plot. Each piece of fruit was separated into four symmetrical parts, one of which was used for chemical analysis. Yield was assessed by harvest from the useful area of each plot over the whole period of production.

The soil samples were subjected to chemical analyses according to the method recommended by Raij et al. (2001), whereas the leaves and fruit were assessed based on the methodology of Bataglia et al. (1983).

The data were statistically analyzed in a manner individualized by soil layer (depth), considering the combinations of limestone types and application rates as plots, and the sampling times as split-plots.

RESULTS AND DISCUSSION

Effect of treatments on the soil

In the 0.00-0.10 m layer, significant effects were observed for the forms of limestone and application rates on pH, potential acidity (H+Al), Ca^{2+}, Mg^{2+}, sum of bases (SB), and base saturation (V%). Although there was no limestone type × application rate interaction, the findings are presented to facilitate a clear understanding of the treatments effects (Figures 1 and 2). This statistical procedure was advocated by Little and Hills (1978).

Both forms of limestone used for liming led to changes in the properties connected with acidity in the uppermost soil layer (0.00-0.10 m). The pH, Ca^{2+}, Mg^{2+}, SB, and V% values increased, whereas the exchangeable ion (H+Al) value decreased, in accordance with the different rates applied in the three time periods evaluated, i.e., at 6, 12, and 24 months after liming (Figures 1 and 2). However, calcined limestone initially proved to be more effective than common limestone in neutralizing soil acidity in this soil layer at 6 and 12 months after liming, as observed from the angular coefficients of the equations. After 24 months, the effect from calcined limestone had already begun to decline, whereas the common limestone corrective peaked in practically all the variables analyzed (Figures 1 and 2). The highest limestone application rate (4.8 t ha^{-1}) achieved base saturation values of almost 60 % at 24 months, whereas for the calcined limestone, V% values of almost 70 % were observed, also at the highest application rate (3.0 t ha^{-1}), already at 6 months. Base saturation of 70 % is recommended by Santos and Quaggio (1996) for the guava crop.

Effects of decline in soil acidity from both forms of limestone were also observed in the 0.10-0.20 m soil layer (Figures 3 and 4). However, whereas common limestone had this effect only at 24 months after liming (Figure 3), the calcined limestone produced this reduction in acidity at six months after liming, and became more evident from the 12th month after its application for the other properties assessed (Figure 4). Both cases led to an increase in pH, Ca^{2+}, Mg^{2+}, SB, and V%, and a decline in exchangeable H+Al, in a linear relationship with the rates applied. Similar to the findings in the 0.00-0.10 m layer,

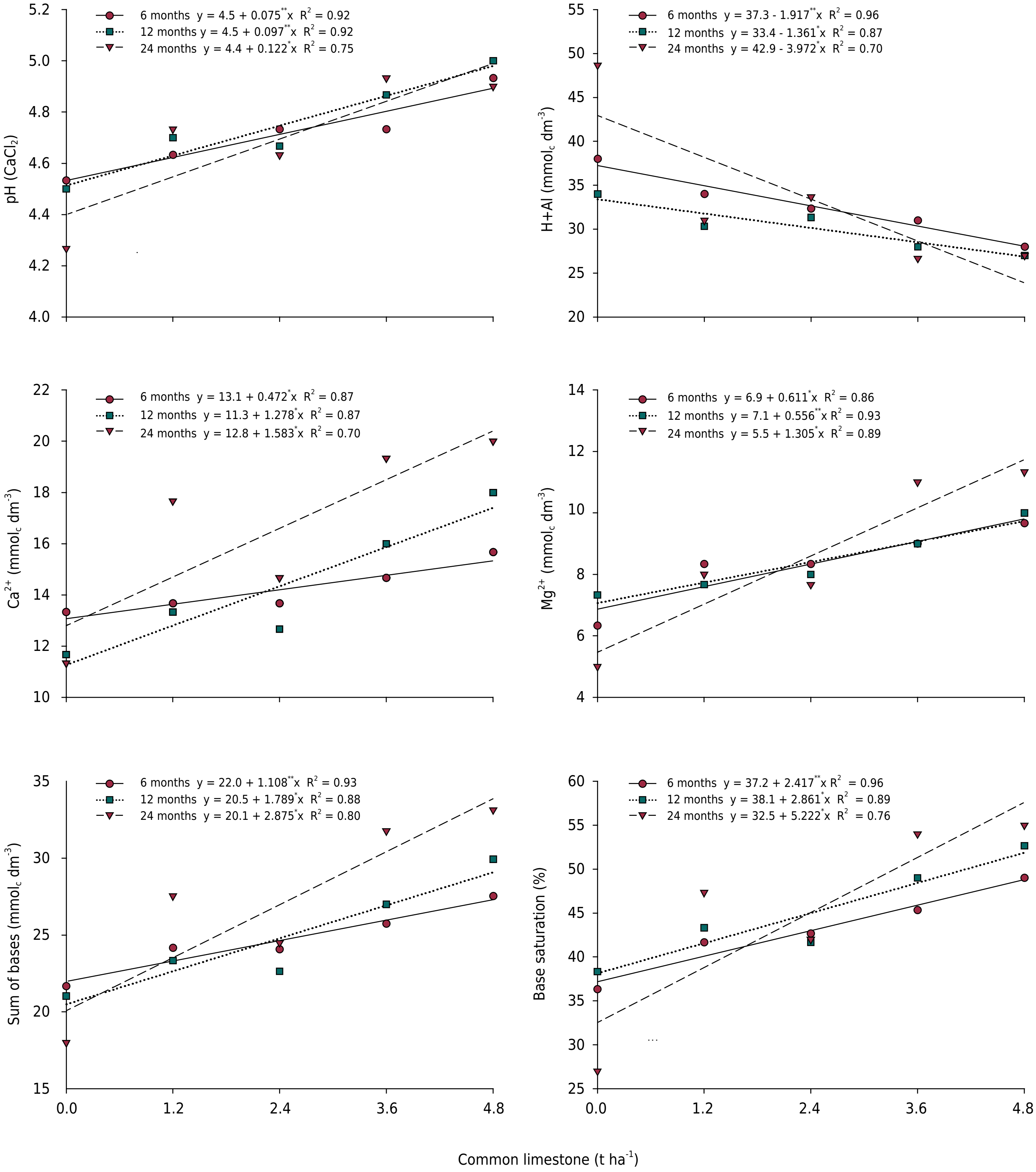

Figure 1. The pH value, potential acidity, Ca^{2+}, Mg^{2+}, sum of bases, and base saturation in the 0.00-0.10 m layer of an *Argissolo Vermelho Amarelo* [Ultisols (Soil Survey Staff, 2014)] in response to the rates of common limestone applied, without incorporation. The dots represent the averages of three replicates. ** and * indicate significance at 1 and 5 % probability, respectively.

calcined limestone proved to be more effective and faster in reducing soil acidity than common limestone. It is notable that, beginning with an initial base saturation of 28 % in the 0.10-0.20 m layer, 24 months after liming, the values rose to more than 40 % for the highest application rate of common limestone (Figure 3) and achieved values of almost

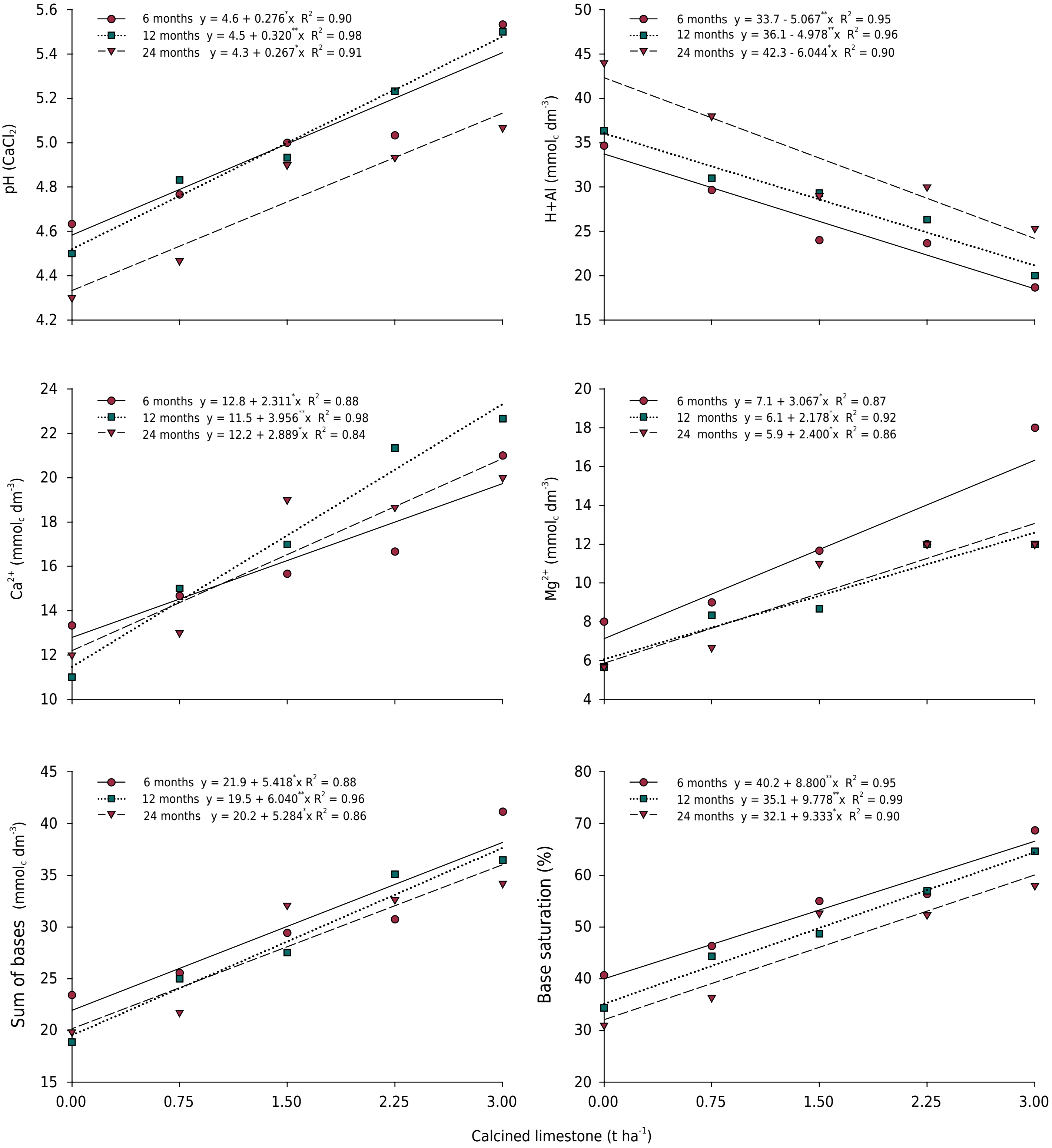

Figure 2. The pH value, potential acidity Ca^{2+}, Mg^{2+}, sum of bases, and base saturation in the 0.00-0.10 m layer of an *Argissolo Vermelho Amarelo* [Ultisols (Soil Survey Staff, 2014)] in response to the rates of calcined limestone applied, without incorporation. The dots represent the averages of three replicates. ** and * indicate significance at 1 and 5 % probability, respectively.

50 % for the highest application rate of calcined limestone (Figure 4), even though the correctives were only applied on the surface, without incorporation.

In general, the correctives have low solubility and move slowly through the soil profile; thus, contact between the corrective and the acid sources is necessary to achieve adequate results from liming. Improvement in the chemical properties of the subsurface soil layers

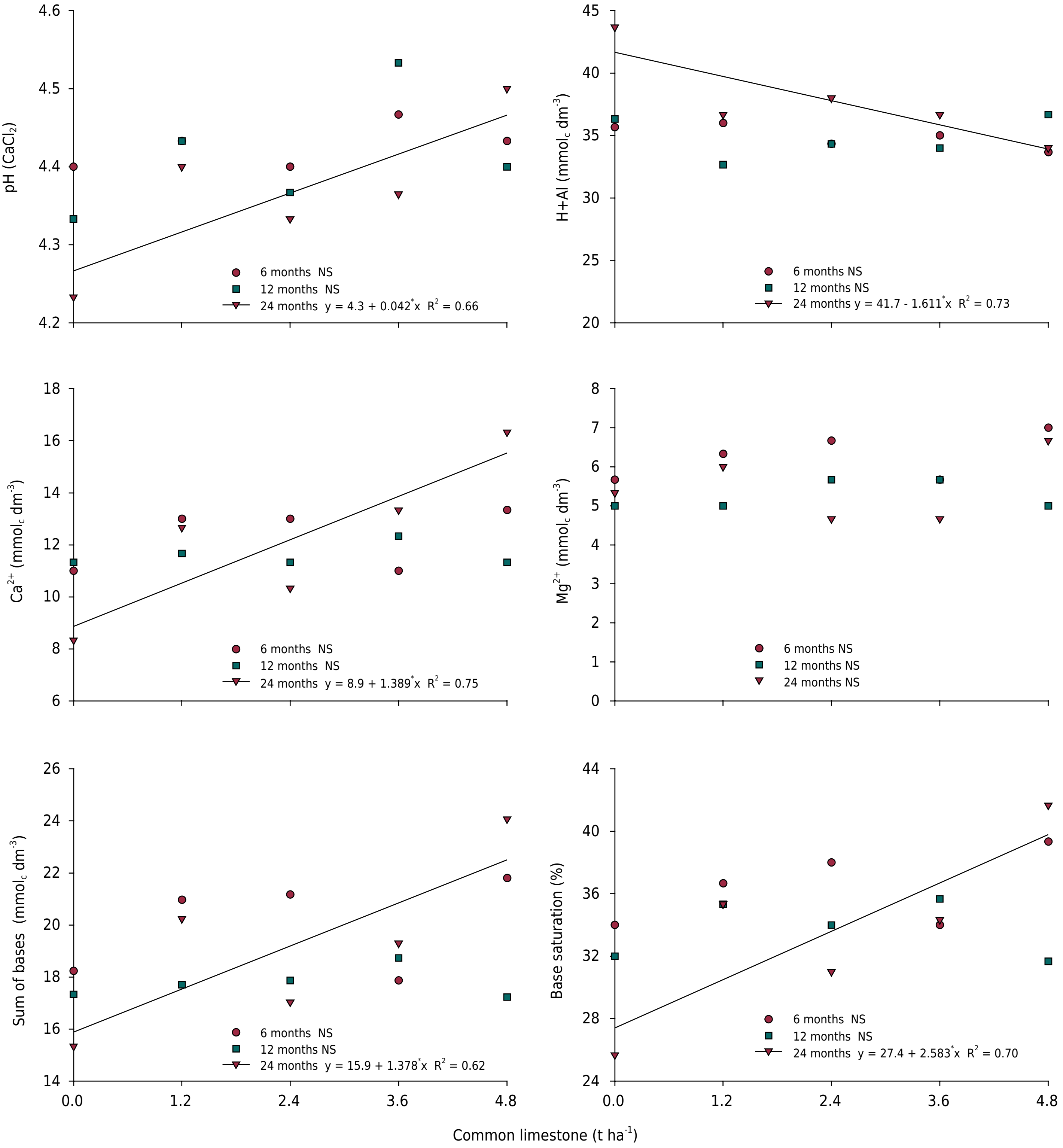

Figure 3. The pH value, potential acidity, Ca^{2+}, Mg^{2+}, sum of bases, and base saturation in the 0.10-0.20 m layer of an *Argissolo Vermelho Amarelo* [Ultisols (Soil Survey Staff, 2014)] in response to the rates of common limestone applied, without incorporation. The dots represent the averages of three replicates. ** and * indicate significance at 1 and 5 % probability, respectively.

after the addition of the correctives demands time and occurs gradually because of the nature of the carbonates that form the neutralizing bases that constitute common correctives (Quaggio, 2000). Their vertical movement through the soil profile depends on variables such as rainfall, soil texture and porosity, particle size, and limestone reactivity, as well as on the plant material present in the soil or on its surface.

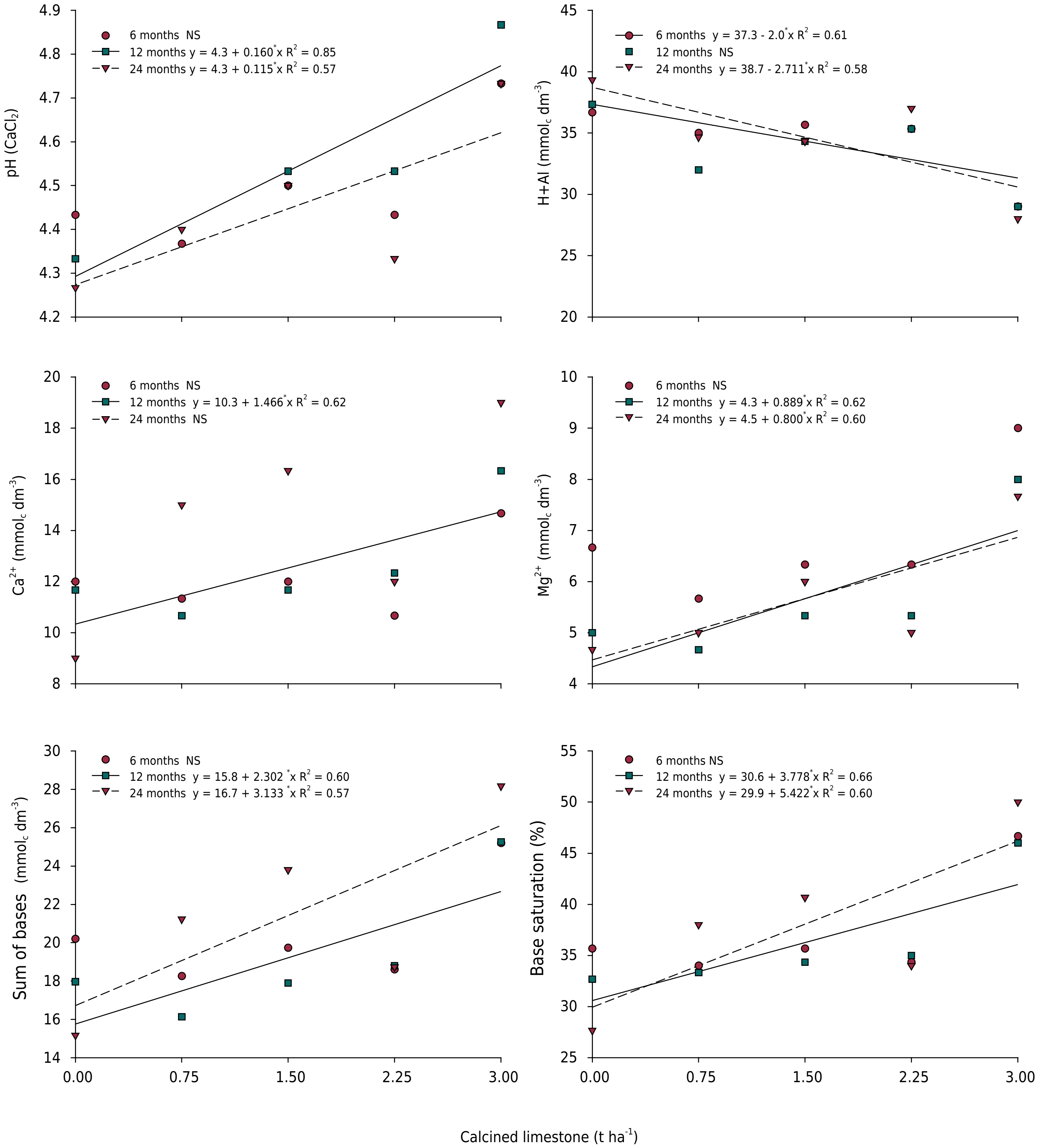

Figure 4. The pH value, potential acidity, Ca^{2+}, Mg^{2+}, sum of bases, and base saturation in the 0.10-0.20 m layer of an *Argissolo Vermelho Amarelo* [Ultisols (Soil Survey Staff, 2014)] in response to the rates of calcined limestone applied, without incorporation. The dots represent the averages of three replicates. ** and * indicate significance at 1 and 5 % probability, respectively.

The formation of pairs between the bases (Ca^{2+} and Mg^{2+}) and organic acids (RO$^-$ and RCOO$^-$) high in solubility and low in molecular weight, promoting the movement of these pairs to the subsurface layers, is another explanation of movement of correctives in the profile (Harter and Naidu, 1995; Aoyama, 1996). Miyazawa et al. (1996) explained this reaction as the formation of organic ligands, which complex soil Ca^{2+}, forming CaL^0 or

CaL^- complexes. Oliveira and Pavan (1996) indicated that other compounds may form, such as $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$. When there is nitrogen fertilization, soluble salts may be formed, such as $CaNO_3$, which percolate downward with water movement through the soil profile (Blevins et al., 1977).

In long-established guava orchards, besides the natural dropping of leaves, branches, flowers, and fruit during the crop cycle, large quantities of plant material fall at the time of annual pruning for cleaning and future fruit bearing after every production cycle. Natale et al. (2009) estimated that in this operation between 40 and 60 % of the entire aboveground part of the trees falls to the ground. However, this material apparently does not affect soil cation dynamics or subsurface reaction (Corrêa et al., 2002). The mechanisms of vertical displacement particles of corrective proposed for no-tillage soils normally involve large quantities of organic residues on the soil surface (Caires et al., 2000).

In perennial crop systems without soil tillage, as is the case of guava in this experiment, vertical displacement of smaller particles of the soil corrective by water infiltration through the soil pores and biological channels formed by dead roots of cut weeds or by soil macrofauna (Pavan, 1994) may contribute to limestone descending through the soil profile, especially calcined limestone, with its smaller particle size.

Another mechanism that is certainly involved in the subsurface action of limestone is the formation of an alkaline front, described by Rheinheimer et al. (2000). These authors suggest that the effects of liming only penetrate deeper after the $pH(H_2O)$ in the limestone dissolution zone has reached values from 5.2 to 5.5. This is attributed to the dissociation of the limestone in the acidic soil, promoting the release of the OH- and HCO^{3-} anions, which react with the acid solution cations of the soil solution (H^+, Al^{3+}, Fe^{2+}, Mn^{2+}). This reaction continues until $pH(H_2O)$ is approximately 5.5. While these acidic cations are present, the neutralization reaction of the acidity will be limited to the surface layer, delaying the effect at greater depths. For neutralization of acidity to occur at greater soil depths, the products of dissociation of limestone must be drawn along to lower layers. Natale et al. (2008) observed liming effects up to a depth of about 0.60 m in the carambola crop.

The results shown in figures 1 and 2 are quite consistent with what was proposed earlier because they confirm that the limestone effect only went beyond soil layers when these layers had $pH(CaCl_2)$ above 4.8-4.9, corresponding to $pH(H_2O)$ of approximately 5.4-5.5. These effects are clearly observable in figures 3 and 4, in which the pH in the 0.10-0.20 m layer is maintained or increases in response to the higher limestone application rates, especially the application of calcined limestone. At the same time, lower pH in this layer is related to lack of liming or lime applied at lower rates.

Therefore, one can reasonably assume that the sum of the contributions of all the processes mentioned above is more important than each one of them individually in order for the effects of surface limestone application to be observed in lower soil layers.

Regardless of the mechanism involved, correction of subsoil acidity may have important practical implications because guava is a large perennial fruit tree and has a deep and extensive root system. This root system may be restricted if there is a chemical impediment (acidity and/or Al-toxicity) at depth.

As liming with either form of limestone had no effect on the chemical properties of the soil at the 0.20-0.40 and 0.40-0.60 m depths 24 months after application, we present no data in this regard.

Silva et al. (2007), working with the same kind of calcined limestone used in the present experiment, found a corrective effect up to the depths of 0.20-0.40 and 0.40-0.60 m in a medium-textured *Latossolo Vermelho típico* in an orange tree grove at 12 to 24 months after surface liming. The more limited depth range confirmed in the current study is mainly attributed to the intense fertilization, especially urea nitrogen fertilization, performed in the guava orchard, as well as to the low initial pH in the tilled layer, as previously mentioned. The soil type (*Latossolo*), and the high initial pH($CaCl_2$) in the 0.00-0.10, 0.10-0.20, and 0.20-0.40 m layers (5.4, 5.3, and 4.8, respectively) in the orange grove examined by Silva et al. (2007) most likely strengthened the liming effect in the 0.20-0.40 and 0.40-0.60 m layers.

Evaluation of the effect of the correctives over time shows that reduction in acidity in the soil in the 0.00-0.10 m layer occurred in a slower and more constant way in the plots treated with common limestone (Figure 5). Calcined limestone led to a more rapid reduction in soil acidity; however, this reduction lasted for a shorter time, as can be seen in figure 5, for practically all the properties evaluated.

The common limestone treatment induced a maximum reaction in the 0.00-0.10 m soil layer at 24 months, whereas the calcined limestone showed its maximum effect at 6-12 months from the date of liming. During these periods, the highest pH, Ca^{2+}, Mg^{2+}, SB, and V% values, as well as the lowest H+Al contents, were recorded. However, a longer evaluation time is certainly required to more clearly define the point of maximum reaction from common limestone. In the case of calcined limestone, progressive decline in the soil properties related to acidity are clearly evident from the 12th month on, showing the decline in the corrective effect and confirming the lower residual power of this form of limestone, as reported by Silva et al. (2007). It is also noteworthy that the plots that did not receive soil correction underwent soil acidification over time, which was mainly attributed to nitrogen fertilization (urea), as well as to leaching of bases, uptake of basic cations by the plants, and exudation of H^+ (Figure 5).

In regard to the subsurface of the soil, although normally surface application of common limestone led to only slightly perceptible changes in soil acidity in the 0.10-0.20 m layer, it proved to be effective in blocking the acidification process in this layer, a process similar to that observed in the plots that did not receive limestone (Figure 3). For its part, the calcined limestone not only blocked the acidification process, but also led to a slight drop in soil acidity at the same depth (Figure 4).

Soil fertility between the rows remained nearly unchanged throughout the two years of experimentation (data not shown). This was expected since both treatments and fertilizations were limited to the area below the guava tree canopy.

Effect of treatments on the plants

No significant effect was found from surface liming on the chemical composition of the guava leaves and fruit, regardless of the type or application rate of the corrective; thus, the data are not shown. The lack of an effect from application of limestone must be related to the perennial growth habit of the crop because the response of perennial plants to change in management practices requires time to be effective. It may be that the 14-month period and 20-month period from the time of application of the treatments to the last leaf sampling and fruit sampling, respectively, were insufficient to bring about change in these plant organs.

Fruit production likewise did not exhibit any significant effect from the corrective application rates until about 20 months after the treatments, probably because of the lack of an effect on the chemical composition of leaves and fruits. It is noteworthy, however, that the average guava yield in this study far exceeded the average yield of adult commercial orchards in Brazil, which was 22 t ha^{-1} in 2015 (Treichel et al., 2016). Although they did not receive the limestone corrective, the control plots produced 82.6 t ha^{-1} of fresh guavas, on average, while areas under the limestone treatments (common or calcined) produced around 92.3 t ha^{-1} (data not shown). This is especially due to the use of a high-yielding guava cultivar (Paluma).

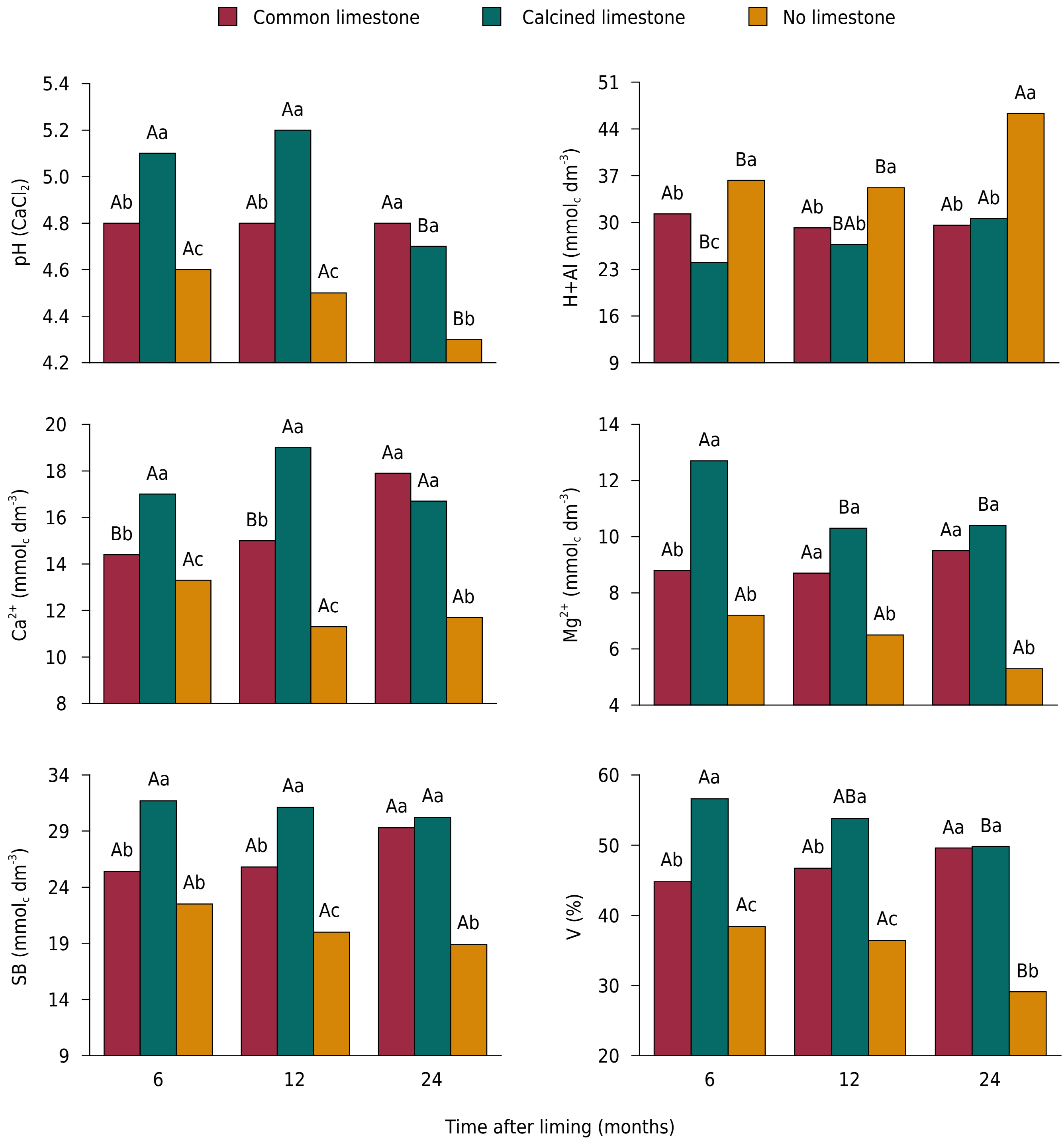

Figure 5. The values of pH, H+Al, Ca^{2+}, Mg^{2+}, SB, and V % in the 0.00-010 m soil layer in response to time after surface liming with common limestone, calcined limestone, and no limestone. Means followed by the same lowercase letter within the time periods (6, 12, and 24 months) and uppercase letter between the seasons for each form of limestone do not differ by Tukey's test ($p<0.05$). The values represent the averages of all the application rates for each form of limestone (common lime, calcined lime) and no limestone.

CONCLUSIONS

In the established guava orchards, the use of common or calcined limestone decreased soil acidity in the 0.00-0.10 and 0.10-0.20 m layers, in accordance with the rates applied. The 0.20-0.40 and 0.40-0.60 m soil layers remained unaffected by liming, 24 months after surface application of the correctives.

Common limestone reduced soil acidity in the 0.10-0.20 m soil layer at 24 months after liming, whereas the calcined limestone caused a similar effect from 6 to 12 months after surface liming.

Surface liming did not affect the chemical composition of the leaves and fruit up to 14 months after application, or guava yield up to 20 months after application. This is because guava is a perennial plant, which requires a long period to manifest changes due to management practices.

Surface liming without incorporation can be a successful technique in established guava orchards to correct surface and subsurface soil acidity. However, further studies are required to identify the soil sampling criteria (layers), application rates necessary in accordance with the layer to be corrected, and the frequency of application, which are specific for each crop. Further studies are also necessary to adapt the method of base saturation to this liming modality.

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