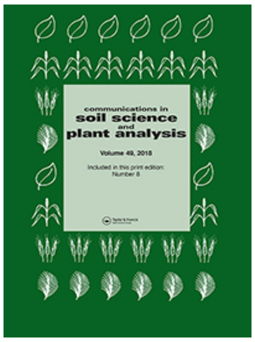

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Using Limestone to Improve Soil Fertility and Growth of Mango (*Mangifera Indica* L.)

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ABSTRACT
Soil acidity is one of the most important factors limiting crop production. The objective of this work was to evaluate the effects of limestone application on the soil chemical properties, nutrition and yield of mango plants in an orchard under implementation. The design was randomized blocks, with five limestone doses (0; 2; 4; 6 and 8 t ha^{-1}) and four replications. Soil chemical analyses were performed (at 12, 24, 36 and 48 months after the experiment implementation) in the layers 0–20; 20–40 and 40–60 cm deep. Nutrition status and yield were assessed during the first and second crop seasons. The highest fruit yield was associated with the application of 3.9 and 3.8 t ha^{-1} of limestone in the 2008/09 and 2009/10 seasons, respectively, that is, the dose recommended by the literature for raising base saturation to 80%, as a function of the fertility conditions of the soil initially obtained.

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Liming; plant nutrition; residual effect

Introduction

Most Brazilian soils present limitations to the development of a large part of crops due to the effects of high acidity, which may also be associated with low calcium, magnesium and potassium contents (Sousa et al. 2016). The soil environmental factors linked to acidity (pH, base saturation, potential acidity and nutrient availability) are the ones that most interfere with crop yield, especially in tropical regions (Natale et al. 2012). Under these conditions, calcium deficiency and aluminum toxicity are the main chemical limitations to root growth, with the roots elongating more slowly and subsequently thickening and not branching normally (Araújo, Salviano, and Coelho Filho 2009; Raij 2008). As a result, there is a limitation to the absorption of water and nutrients, making the plants more prone to yield loss, especially in regions with prolonged droughts during the rainy season (Sousa et al. 2016).

In acid soils with high aluminum saturation, liming raises soil pH, neutralizes toxic aluminum (Al^{3+}) and adds calcium (Ca^{2+}) and magnesium (Mg^{2+}), providing conditions favorable to the root system growth and the water and nutrient uptake by plants (Zandoná et al. 2015). However, according to Natale et al. (2012), even though it is a recognized beneficial practice in acid soils, it is not always carried out properly, being therefore ineffective.

In perennial crops, the inefficiency is accentuated, since the incorporation of the correctives is complex, due to the intrinsic characteristics of these crops and the lack of scientific and technological information (Quaggio 2000). Notwithstanding, the application of limestone without subsequent incorporation into the soil may result in an inadequate acidity correction in the deeper layers of the soil, explored by the roots of perennial crops.

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Among the perennial crops cultivated in Brazil, mango (*Mangifera indica* L.) is one of the most important tropical fruits produced (Almeida et al. 2012), growing in an estimated area (2014) of 70,315 hectares, with a fruit yield of 1.13 million tons, the northeast and southeast regions being responsible for 69% and 29% of the total produced, respectively (IBGE 2015).

Despite being considered a fruit tree that tolerates low-fertility soils, studies show that fertile soils favor the development of plants and consequent increase in yield (Castro and Kluge 1998). This is due, on the one hand, to the widespread poverty of tropical soils in nutrients and to the high acidity and, on the other hand, to the genetic improvement of the mango tree, with the development of plants that are more productive but more demanding in nutritional terms.

The knowledge of the chemical properties in tropical soils and the relationships between the acidity of these soils and the growth of plants is fundamental for the development of adequate practices of soil correction, aiming at the efficient use of water and fertilizers. In this sense, the objective of this work was to evaluate the effects of the application of limestone doses on the soil chemical properties, nutrition and yield of mango plants in an orchard under implementation.

Material and methods

Analysis and experimental design

The experiment was carried out at the Citrus Experimental Station of Bebedouro (EECB), in the municipality of Bebedouro-SP (20º53′16″ S, 48º28′11′" W, an altitude of 601 m), in a soil classified as dystrophic Oxisol, medium texture (Embrapa 2013). Before the implementation of the experiment, 30 simple soil samples were collected to make a composite sample in the layer 0–20 cm deep, for fertility purposes, according to the methodology proposed by Raij et al. (2001), with the following results: pH in ($CaCl_2$) = 4.4; O.M. (Organic matter) = 19 g dm^{-3}; P = 4 mg dm^{-3}; K; Ca; Mg; (H+Al); SB (Sum of bases); CEC (Cation exchange capacity); 1.1; 10; 5; 42; 16.1; 58.1 $mmol_c$ dm^{-3}, respectively, and V(%) = 28%.

The experimental design was randomized blocks, with five treatments and four replications. The treatments were composed of limestone doses (CaO = 24.5%; MgO = 18.5%; PN (Power of neutralization) = 89.7%; RE (Power of reactivity) = 83.2%; RTNP (Relative Total Neutralization Power) = 74.7%), calculated from the base saturation method (Raij et al. 1997), using as reference the base saturation of 80%, indicated as suitable for the mango crop (Quaggio, Van Raij, and Piza Júnior 1997). The commercial dolomitic limestone was derived from mining, and chosen for presenting lower RNV (Relative Neutralizing Value), suitable for the cultivation of perennial fruit species due to the greater residual effect.

Thus, the following treatments were obtained: D0 = zero (control); D1 = half of the dose to raise V = 80%; D2 = dose to raise V = 80%; D3 = 1.5 times the dose to raise V = 80%; and D4 = 2 times the dose to raise V = 80%, which corresponded to: 0; 2; 4; 6 and 8 t ha^{-1} of limestone, respectively.

The limestone was divided into two applications: 50% before soil preparation, and the remainder (50%) after soil incorporation with the aid of a moldboard plow at a depth of 20 cm. Limestone application was done manually and four months before the orchard implantation (July 2005).

Each experimental plot was composed of five mango trees (cv. Palmer), with the three central plants being used for the evaluations. The basic planting fertilization in the hole for the fruit tree was made by mixing 200 g of P_2O_5 in the form of triple granulated superphosphate, 10 L of organic compound based on bovine manure and 5 g of Zn in the form of zinc sulfate, both applied 30 days before planting (Quaggio, Van Raij, and Piza Júnior 1997).

Treatments measured and nutritional indices

The planting of seedlings in the field was carried out in November 2005, using a spacing of 7 m between rows and 5 m between plants. At the time of planting, the seedlings were irrigated with 20 L of water per plant, in a watering period of 2–3 days, depending on the occurrence of rainfall in those intervals. At 30 days after planting, pruning was done at a height of 1 m from the soil for the uniformity and adequate formation of the canopy; the other prunings of formation and conduction of the plants followed the recommendations of (Albuquerque, Mouco, and Santos 2000).

The coverage fertilizations for the fruit tree were carried out during the rainy season, divided in three applications around the plants and in the canopy projection between the months of October and December, using as sources of nitrogen, phosphorus, and potassium: urea, triple superphosphate and potassium chloride, respectively, in the period from 2006 to 2009; the fertilizations followed the recommendations of (Quaggio, Van Raij, and Piza Júnior 1997).

To evaluate soil fertility, soil samples were collected at 12, 24, 36 and 48 months after planting of the seedlings. The evaluations were made in the layers 0–20, 20–40 and 40–60 cm deep. For this, four simple soil samples were collected per useful plant in the four cardinal positions, thus totaling 12 simple soil samples per plot for the formation of a composite sample. In the soil samples, the following were determined according to methods described by Raij et al. (2001): active acidity (pH in $CaCl_2$); total acidity (H+Al, in $mmol_c\ dm^{-3}$) with SMP buffer solution (pH 7.0); contents of calcium (Ca), magnesium (Mg), and potassium (K), extracted with ion exchange resin (in $mmol_c\ dm^{-3}$), with determination of calcium and magnesium by atomic absorption spectrophotometry, and potassium by atomic emission photometry. The sum of exchangeable bases (SB) was calculated by summing the contents of Ca, Mg and K (in $mmol_c\ dm^{-3}$); base saturation (V%) was obtained by the formula: V% = (SB (Ca+Mg+K) × 100)/T (Ca+Mg+K + H+Al).

The nutritional status of the plants was evaluated in September 2008 and 2009, at the beginning of the commercial production phase. Leaf collection followed the recommendation of (Quaggio, Van Raij, and Piza Júnior 1997), with the leaves being collected halfway through the last vegetation flow, in branches with flowers at the end, from four leaves per useful plant, in the four cardinal positions. The determinations of nutrient contents in the plant tissue followed the methodology described by (Bataglia et al. 1983). Then, the yield of the useful plants in each plot was evaluated, corresponding to the first (2008/09) and second (2009/10) crop seasons.

Statistical analysis

The results were submitted to analysis of variance and polynomial regression at 5% probability ($p \leq 0.05$) using the AGROESTAT software (Barbosa and Maldonado Júnior 2012).

Results and discussion

Effect of treatments on soil chemical attributes

The joint analysis of pH values in $CaCl_2$, sum of bases (SB) and base saturation (V%), as well as Ca, Mg and (H+Al) concentrations of the soil chemical analyses did not show a significant interaction between limestone doses and sampling times, in all the layers studied in the planting row of mango trees (Figure 1). This lack of interaction indicates that the changes in soil chemical properties related to acidity, as a function of the limestone doses used, were proportionally similar in the different sampling times.

Limestone application significantly altered the pH, potential acidity, sum of bases, base saturation and Ca and Mg concentrations at all depths evaluated (Figure 1). There was an increase, with linear adjustment, of pH, Ca, Mg, SB and V% and a decrease of (H+Al), as a function of the increase of limestone doses in the row of mango trees, in all depths sampled, with the most expressive changes being found in the region of incorporation of the corrective (0–20 cm), which can be confirmed by the significance of the F test of the regressions that decreases with the soil sampling depth.

The results indicate that there was acidity correction below the limestone incorporation layer. The changes in the soil chemical attributes analyzed in this study, below the incorporation layer of the corrective, can be explained in many ways, although the low solubility and the restricted movement of limestone in the soil profile are known (Gonzales-Érico et al. 1979). Among them, a physical

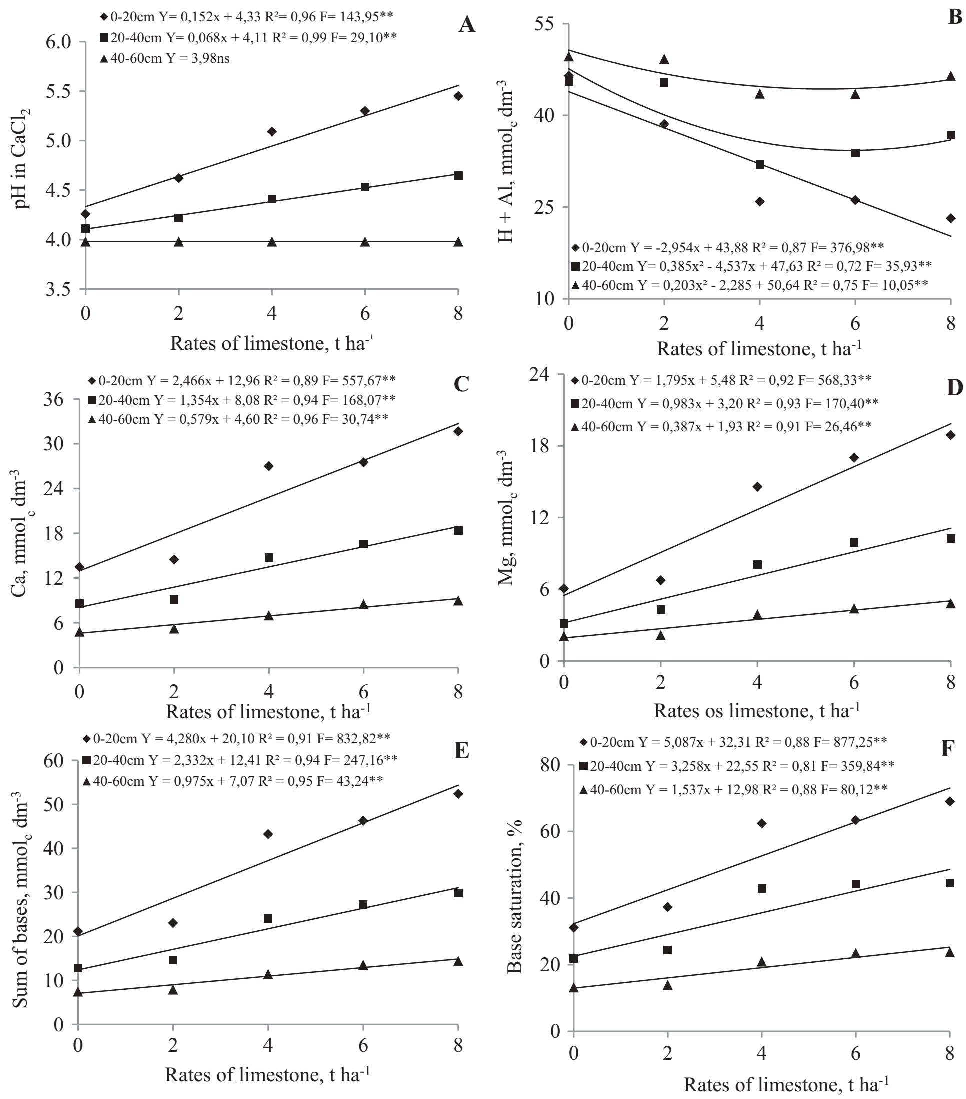

Figure 1. Effect of limestone application on pH in $CaCl_2$ (A); H + Al (B); Ca (C); Mg (D); Sum of bases (E); base saturation (F) of the soil. The dots are averages of three sampling times for the 0–20 layers, 20–40 and 40–60 cm deep, and four replications.

** - Significant at 1% probability by the F test.

contribution can be highlighted, i.e., the channels left by root decomposition (Pearson, Abruna, and Vice-Chances 1962), due to the activity of the micro- and macrofauna, contributing to the displacement of limestone particles to the subsurface layers.

Another contribution of the benefits of deep liming, highlighted in the literature, has a chemical nature, influencing the cation movement and the acidity correction in depth. According to (Aoyama 1996; Harter and Naidu 1995), the formation of base pairs (Ca^{2+} and Mg^{2+}) and organic acids (RO^- and $RCOO^-$) of high solubility and low molecular mass, which would allow the carrying of these pairs to the subsurface layers, would be another explanation. This reaction is explained by (Miyazawa, Pavan, and Santos 1996), by the formation of organic ligands, which complex the soil Ca, forming CaL° or CaL^- complexes. In addition to these compounds, there may be a formation of others, such as Ca $(HCO_3)_2$ and Mg $(HCO_3)_2$, according to (Oliveira and Pavan 1996).

Similar results in an Oxisol, in areas with perennial crops, corroborate those of this study, being presented by (Natale et al. 2007, 2008). The authors observed an increase in the Ca and Mg concentrations up to the depth of 60 cm, after 78 months of incorporation of the corrective material.

Regardless of the mechanism involved, it can be seen that the subsoil chemical environment is improved for the plants. This downward movement of the limestone in the soil profile, with consequent acidity correction below the incorporation layer, may have important practical implications, since perennial crops, especially the mango tree, have a deep and comprehensive root system, exploring these layers for many years. The time of implementation of the orchard is the most appropriate to perform acidity correction in the subsurface layers of the soil due to the incorporation of the corrective material, which facilitates the descent of this corrective material to the deeper layers of the soil, promoting acidity correction. Results of liming efficiency on chemical characteristics in the surface and subsurface layers, in areas with perennial crops, were also reported by other authors (Prado and Natale 2004; Silva et al. 2007).

It was observed that none of the doses applied increased the base saturation to 80%, a value described as suitable for the mango tree by (Quaggio, Van Raij, and Piza Júnior 1997). With the application of limestone to twice the 8 t ha-1 dose indicated to raise V to 80%, only 69% (mean of 3 soil samples in the surface layer) was obtained (Figure 1). There are reports in the literature that the base saturation values, determined after liming, were lower than those estimated by the method (Oliveira, Parra, and Costa 1997).

According to Tescaro (1998), this inefficiency in raising the V% to relatively high values can be linked to the potential of charges dependent on soil pH, usually high, for the displacement of the equilibrium reaction of the corrective solubilization and, still, to the formation of new minerals in the soil, as poorly soluble hydroxides, or even to a possible improper incorporation of the corrective to the layer and the desired soil volume.

Considering that base saturation generally reflects the benefits of liming on soil chemical attributes (increase of pH, Ca, Mg, SB and decrease of H+Al) and that, in a summary form, it may represent such modifications, it was chosen to present the V% in the layer where the limestone was incorporated 0–20 cm deep, during the 48 months of experimentation (Figure 2).

The results indicate that there was a positive effect of the liming action as a function of time on the soil base saturation index at 12 months after the experiment implementation (Figure 2). Despite the variation of the V% values in the 0–20 cm soil layer analyzed, a certain stability was observed up to 48 months, with a mean reduction of the 4% base saturation index between the evaluations at 12

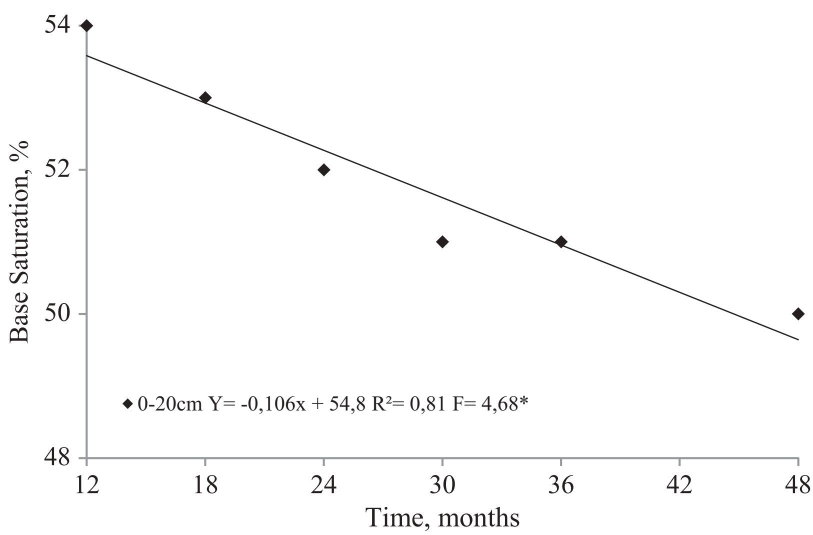

Figure 2. Effect of limestone application time on the base saturation of soil cultivated with hose, in samples collected at 0–20 cm depth. The points are averages of five doses of limestone and four replicates.

* - Significant at 5% probability by the F test.

and 48 months (Figure 2). Natale et al. (2008) in an experiment with liming in star fruit trees, observed stability of the base saturation index in the 0–20 cm layer until about 40 months, the period when the decrease of the limestone residual effect began.

In this sense, it was observed, in the literature, works mentioning divergence in the limestone reaction time, such as those of (Oliveira, Parra, and Costa 1997; Quaggio, Dechen, and Van Raij 1982), which indicate that the maximum limestone reaction in the soil occurred between 18 and 33 months after application. In addition, Natale et al. (2007) observed in a guava orchard that the maximum limestone reaction occurred at 12 months after the application of the corrective in the fruit tree row.

It should be noted that the limestone reaction time can be influenced by several factors related to corrective material, soil and environment. According to Weirich Neto et al. (2000), the soil buffer power and the homogeneity of the corrective incorporation are factors that can explain the differences in the limestone reaction time. In addition, it is highlighted that the local water regime can affect the rate of limestone reaction in the soil over time.

Natale and Coutinho (1994) observed that the reactivities of the granulometric fractions attributed by the legislation to limestone were only obtained about 18 months after its application to the soil. In this case, one of the aspects that may have influenced the corrective reaction time would be the reactivity indices currently used to calculate it, which are shown to be overestimated within the period stipulated by the Brazilian legislation, of 90 days.

In this sense, it is clear that the reaction time of the limestone in the soil is dependent on other factors already mentioned, justifying the divergence of the results observed in this work with those of the literature.

Effect of treatments on plant nutrition and yield

The application of the corrective doses did not significantly influence the leaf contents of the mango trees in the first evaluation of the nutritional status at 30 months after the implementation of the crop (Table 1). However, in the second evaluation period, at 42 months, the treatments significantly influenced the leaf contents of some nutrients: N, S, B, Fe, Mn, and Zn (Table 1).

Limestone application promoted an increase with quadratic adjustment in the foliar contents of Ca, with the dose of 4.63 t ha^{-1} of limestone being responsible for the maximum point of 13.7 g kg^{-1} leaf calcium in the mango tree; yet the leaf contents of Mg were explained by the linear regression model, showing increased leaf contents with increasing doses of the corrective material (Figure 3). This behavior may explain the reduction in mango yield and in foliar Ca contents, since the Mg

Table 1. Macronutrient and micronutrients foliar contents according to the application of limestone rates at 30 and 42 months after the orchard implantation.

Rates	N	P	K	S	B	Cu	Fe	Mn	Zn
t ha^{-1}	g kg^{-1}				mg kg^{-1}				
30 months after implantation of the orchard									
0	15	0.8	9	0.7	7	31	71	939	14
2	15	0.8	10	0.7	7	30	67	748	16
4	15	0.9	9	0.6	7	33	63	870	17
6	15	0.8	8	0.7	6	34	67	838	20
8	15	0.9	9	0.7	6	33	61	670	21
F	2.49^{ns}	0.59^{ns}	1.52^{ns}	1.61^{ns}	0.43^{ns}	0.33^{ns}	0.34^{ns}	1.73^{ns}	0.87^{ns}
CV (%)	3.1	14.9	11.1	6.0	26.4	20.2	19.6	19.6	36.0
42 months after implantation of the orchard									
0	14	0.9	8	1.1	14	35	69	954	19
2	12	0.7	7	0.9	17	38	59	777	19
4	12	0.7	7	1.0	12	47	60	912	30
6	12	0.8	7	0.9	12	37	50	683	19
8	13	0.9	8	1.1	14	41	75	714	40
F	4.54*	2.47^{ns}	1.12^{ns}	3.55*	16.51**	2.25^{ns}	9.13**	7.37**	46.04**
CV (%)	6.7	14.4	12.6	7.7	7.6	15.8	10.0	10.9	10.9

*, ** and ^{ns} – Significant at 5 and 1%, and non-significant at 5% probability, respectively, by the F test.

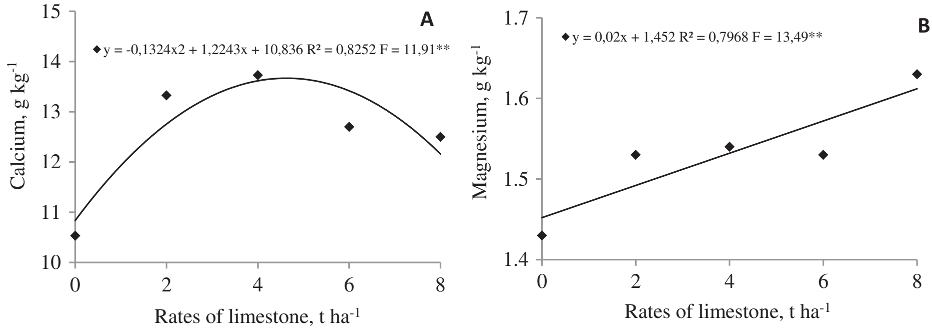

Figure 3. Effect of limestone application on Ca (A) and Mg (B) leaf contents in the mango orchard, evaluated in the 2009 agricultural year. The points are averages of four replications.

** - Significant at 1% probability by the F test.

competes for at least one Ca absorption site, to which it has a higher affinity; therefore, at a higher concentration, it may inhibit Ca absorption by the plant (Prado 2008). The leaf contents of N, S, B, Fe, Mn, and Zn were not explained by the regression models tested (linear and quadratic).

The nutrient contents considered appropriate for the mango tree are, for N, P, K, Ca, Mg and S: 12–14; 0.8–1.6; 5–10; 20–35; 2.5–5.0 and 0.8–1.8 g kg^{-1}, and for B, Cu, Fe, Mn and Zn: 50–100; 10–50; 50–200; 50–100; 20–40 mg kg^{-1}, respectively (Quaggio, Van Raij, and Piza Júnior 1997). It was verified that the Ca and Mg leaf contents in the first sampling varied between (12–16 and 1.6–1.8 g kg^{-1}), respectively, and B (6–7 mg kg^{-1}), being below that considered adequate by (Quaggio, Van Raij, and Piza Júnior 1997), that is (20–35 and 2.5–5.0 g kg^{-1}) for Ca and Mg and (50–100 mg kg^{-1}) for B. In the second leaf sampling, the Ca, Mg and B contents are also below the range considered suitable by (Quaggio, Van Raij, and Piza Júnior 1997) (Table 1). The other nutrients remained in the range considered appropriate by (Quaggio, Van Raij, and Piza Júnior 1997) during the experimental period, except the leaf contents of Mn, which were above the range in the two evaluation periods. In a study with phosphate fertilization in the mango crop, Prado (2010) also observed Mn levels up to five times above the levels considered adequate by the literature, agreeing with the results presented in this experiment.

Considering that the orchard under study is in the growth stage and that the chemical analysis carried out in the plant tissues refers to the first and second flowering of the plants, it can be inferred that the leaf contents are subject to this variation; nonetheless, it should be emphasized that the foliar contents considered adequate refer to orchards in production, in plants that have already stabilized the growth.

Nascimento et al. (1989) studied the variation in foliar contents of macronutrients in two mango varieties and found that the low Ca contents coincided with the low rainfall season, at which time the samples were collected for chemical analysis of plant tissues. Although the Mn contents were above the adequate range, no characteristic symptoms of excess of this micronutrient were observed in plant tissues; similar facts were verified by other authors (Silva and Lima 2001; Souza 2007).

Limestone application resulted in a significant increase in the yield of mango fruits in the first and second crops harvested (2008/09 and 2009/10), with a quadratic effect (Figure 4). The improvement of the plant root environment due to the acidity correction (Figure 1A), as well as the supply of Ca and Mg from limestone (Figure 1C and 1D), partially justify the increase in fruit yield (Figure 4). This is due, in particular, to the use of a more productive cultivar, which requires, nevertheless, liming management associated with adequate application of fertilizers and other recommended agricultural practices.

The corrective material doses that promoted the greatest increase in mango yield in the agricultural years 2008/09 and 2009/10 were 3.9 and 3.8 t ha^{-1}, respectively, providing a mango fruit yield of 8,197 and 11,274 kg ha^{-1}, respectively, in the 2008/09 and 2009/10 seasons. It is also important to highlight that the average yield of the last crop season, 2009/10 (Figure 4), was close to the average yield of the state of São Paulo, which was 12.8 t ha^{-1} (Agrianual 2010).

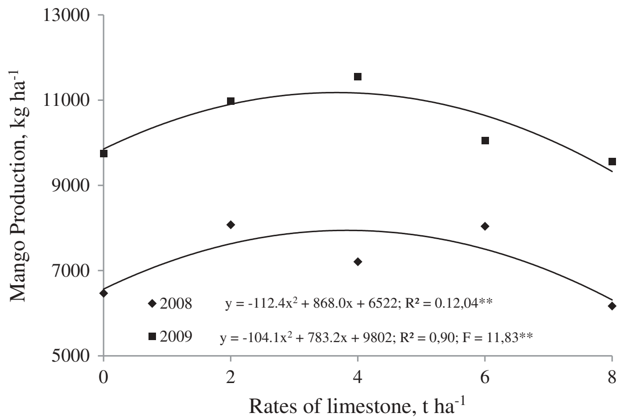

Figure 4. Effect of the application of limestone on the production of those fruits in the 2008 and 2009 harvests. The points are averages of four replications.

** - Significant at 1% probability by the F test.

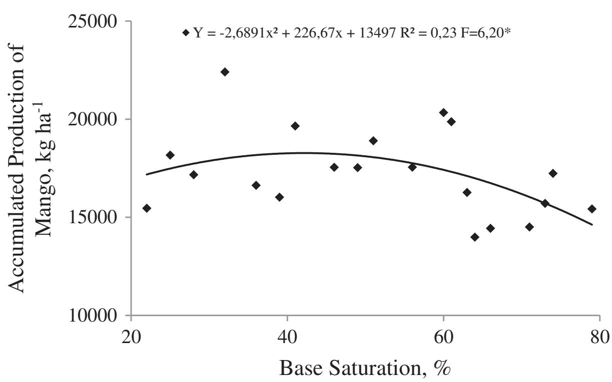

Figure 5. The relationship between soil base saturation in the 0–20 cm depth layer (mean of all samples) and the accumulated production of mango fruit in the 2008 and 2009 harvests.

* - Significant at 1% probability by the F test.

There was a significant increase in the accumulated fruit yield (2008/09 and 2009/10 seasons), as a function of the soil base saturation index in the layer 0–20 cm deep (Figure 5).

It is observed that the point of maximum accumulated fruit yield of the mango tree, 18,846 kg ha^{-1} crops (2008/09 and 2009/10) occurred when the soil base saturation index was 51% (Figure 5). This value is below that suggested by (Quaggio, Van Raij, and Piza Júnior 1997) for the mango crop in the state of São Paulo (V% = 80%) and below that found by (Almeida et al. 2008) (V% = 71%) in orchards in production. It should be noted that in the recommendation of (Quaggio, Van Raij, and Piza Júnior 1997), it is not indicated whether the V% refers to mango orchards under implementation or if this recommended value of V% refers to orchards in formation or production.

Conclusions

The liming improved the soil chemical characteristics, raising the pH and V% values and increasing the Ca^{2+} and Mg^{2+} concentrations, in addition to decreasing H+Al, up to 60 cm depth, during the 48 months of experimentation.

Liming promoted an increase in the calcium and magnesium contents in the leaves of mango trees in the second crop season.

The highest fruit yield was associated with the application of 3.9 and 3.8 t ha^{-1} of limestone in the 2008/09 and 2009/10 agricultural years, respectively. The highest accumulated fruit yield was associated with the soil base saturation (V%) index of 51%.

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