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Nitrogen and Potassium Fertilization in a Guava Orchard Evaluated for Five Cycles: Soil Cationic Balance

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ABSTRACT: Soil fertility evaluation through soil analysis traditionally does not consider interaction among elements. To include the interaction effect in interpretation of soil analyses, an experiment was conducted to evaluate the effect of nitrogen fertilization (0, 0.5, 1.0, and 2.0 kg N per plant per cycle) with urea (45 % N) and potassium fertilization (0, 0.55, 1.1, and 2.2 kg K_2O per plant per cycle) with potassium chloride (60 % K_2O) on soil cationic balance. The experiment was carried out in an irrigated commercial production area of 'Paluma' guava, for five consecutive cycles, 2009 through 2012, using the concept of isometric log ratio (*ilr*) to evaluate soil cationic balance through [K, Ca, Mg | H+Al], [K | Ca, Mg] and [Ca | Mg] balances. The compositional data analysis showed to be a suitable tool to interpret the soil cationic balance given that the soil cationic balances value was changed by nitrogen fertilization and potassium as well as the soil pH value and the concentration of K in the soil. The soil cationic balances also changed by the variations of in climate conditions at period of soil sample. An application rate of 0.55 kg K_2O per plant per cycle was considered sufficient to keep K soil concentration above 1.6 $mmol_c\ dm^{-3}$.

Keywords: compositional analysis of data, isometric log ratio (*ilr*), *Psidium guajava* L..

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INTRODUCTION

Guava (*Psidium guajava* L.) is a tropical plant, native to South and Central America. It is extensively cultivated in Brazil, especially the 'Paluma' variety, which is highly marketable due to its fine characteristics for *in natura* consumption and fruit industrialization. Moreover, 'Paluma' guava has also adapted well to intensive production (with pruning, irrigation, and adjusted nutrient management), ideally with eight-month output cycles, allowing scheduling of fruit output.

Average yield in Brazilian orchards is around 21 Mg ha^{-1} yr^{-1} (IBGE, 2011), although exclusive 'Paluma' guava orchards in an intensive system reach values above 60 Mg ha^{-1} per cycle (Natale, 2009). Low overall average yield in Brazil may be attributed to many factors, but nutrition and soil fertility certainly both play a key role in successful fruit growing (Natale et al., 2012).

Knowing the appropriate soil conditions for orchard development - especially acidity and nutrient availability - is of major importance for success in this agricultural undertaking. After all, these soil conditions determine development of the plant root system, which is closely related to shoot growth and, consequently, yield at harvest (Raij, 2011).

Chemical analysis is the method traditionally used to evaluate soil fertility. It can reveal the need for correction of soil acidity and crop fertilization. However, an adequate application rate of a soil conditioner and/or fertilizer is not so simple to establish. Soil is complex and heterogeneous, a site of numerous chemical, physical, and microbiological reactions, not to mention climate factors, which influence both the availability and the potential of nutrients necessary for healthy plant life. Despite the infinite interactions among soil nutrients (Ca, Mg, and K interactions for example), observing soil balance and interactions among nutrients is outside the scope of soil analysis procedures (Malavolta, 2006).

Seeking to know the effects of these interactions when interpreting the results of cationic soil balance in guava orchards, Hernandes et al. (2012) used the isometric log ratio (*ilr*) transformation, a compositional analytical technique proposed by Egozcue and Pawlowski-Glahn (2005) to evaluate the effects of fertilization with N, P, and K, as well as lime, in guava tree orchards. Through [K | Ca, Mg, H+Al], [Ca, Mg | H+Al] and [Ca | Mg] balances, Parent et al. (2012b) were able to study the effect of fertilization and lime on the balance of components of cation exchange capacity (CEC).

An *ilr* transformation is a special case of log transformation, preserving information contained in the new variable. This allows the ratio among nutrients to be studied (Parent et al., 2012a).

The *ilr* is regarded as the most adequate methodology for multivariate analyses (Filzmoser and Hron, 2011). Impartial and unbiased, it is well-suited for studying ratios among nutrients (Parent et al., 2012a). It is a three-stage methodology: representation of data in *ilr* coordinates; analysis of variance of coordinates as random real variables; and interpretation of results in terms of balances (Egozcue and Pawlowski-Glahn, 2011). However, they cannot be transformed back into their initial values. This concept has been successfully used in studies of plant nutrition (Parent, 2011; Hernandes et al., 2012), of decomposition of organic waste (Parent et al., 2011), and of soil aggregation (Parent et al., 2012a).

Assuming that there is a needed to understand better the relation between the nutrients to get a better a soil analysis interpretation, an experiment was carried out with nitrogen and potassium fertilization in a 'Paluma' guava orchard for the purpose of verifying the effect of fertilization on soil cationic balance.

MATERIALS AND METHODS

The treatments, experimental design, site locations, soil, and climate characteristics were reported in Montes et al. (2016).

Post-harvest soils were sampled at each cycle in the 0.00-0.20 and 0.20-0.40 m soil layers, the samples from both depths being taken in the orchard rows. The methods described by Raij et al. (2001) were used for assessment of soil fertility, including assessment of K, Ca, Mg, and H+Al chemical properties and pH in $CaCl_2$.

The method suggested by Egozcue et al. (2003) was used for the study of soil cationic balance. The compositional space for analysis was defined as:

$S^D = C$ (K, Ca, Mg, and H+Al)

in which $D = 4$ components, and C is the function-closing operator, signaling compositional space closure.

Balances were then secured using *ilr* (isometric log ratio) coordinates, and the sequential binary partition (SBP) was arranged following the recommendations of Parent (2011) and Rozane et al. (2012) (Table 1).

The SBP can be organized in such a way as to facilitate balance interpretation in relation to the goal of the study. Hence, our study started by contrasting anions (N, S, and P) with cations (K, Ca, and Mg), in order to separate the physiological effects of N and K fertilization. The second and third balances, contrasting N and P with S, and N with P, respectively, also sought to ascertain the effects of N fertilization. The final two balances were organized to evaluate the effect of K fertilization - the former (next to last) contrasting the monovalent cation (K) with the two bivalent cations (Ca and Mg); and, finally, the latter contrasting Ca and Mg.

Isometric Log Ratio (*ilr*) calculations followed the recommendations of Egozcue and Pawlowsky-Glahn (2005), and were expressed by the following equation:

$$ilr_j = \sqrt{\frac{rs}{r+s}} \ln \frac{g\ (c+)}{g\ (c-)} \quad j = [1,2,...,D\text{-}1]$$

in which **r** and **s** represent the number of positive and negative components, respectively; g (c+) is the geometric average of the positive components, and g (c-) is the geometric average of the negative components. The square root is the balance between the number of positive and negative components.

The *ilr* balances underwent analysis of variance through application of the F test at 5 % probability. Whenever called for (significant), polynomial regression analysis was carried out. Pearson correlation analysis was carried out between the balance [K, Ca, Mg | H+Al] and soil pH, and between the balance [K | Ca, Mg] and the concentration of K^+ in the soil, at 5 % probability. The statistical procedure used was PROC MIXED (SAS program 9.2).

Table 1. Sequential binary partition of soil cation exchange capacity components

ilr	K^+	Ca^{2+}	Mg^{2+}	H+Al	Balance	r	s
	Sequential binary partition						
1	1	1	1	-1	[K, Ca, Mg | H+Al]	3	1
2	1	-1	-1	0	[K | Ca, Mg]	1	2
3	0	1	-1	0	[Ca | Mg]	1	1

r: number of positive signals, and s: number of negative signals.

RESULTS AND DISCUSSION

Nitrogen fertilization significantly influenced ($p<0.05$) nutrient balance [K, Ca, Mg | H+Al] in the 0.00-0.20 and 0.20-0.40 m soil layers in the 'Paluma' guava tree orchard (Figures 1a and 1b). Decreased balance values are an outcome of the nitrification process, transformation of ammonium N into nitric form, triggering release of H^+ (Natale et al., 2012) and root uptake of nitrate, thus fostering plant development and consequent nutrient uptake, leading to reduced K, Ca, and Mg in the soil (Table 2).

Despite relative scarcity of information on soil cationic balance in the literature, similar results were verified by Teixeira et al. (2005). Such results indicated reduced base saturation when an N treatment protocol was applied to coconut palm trees, affecting the 0.20-0.40 m layer. Banana crops likewise exhibited reduction in pH values as a result of increasing N application rates, namely 0, 200, 400, and 800 kg ha^{-1} yr^{-1} of N). The pH level declined by around one unit, from 5.1 to 4.1, following two years of cropping on the surface layer of a *Latossolo Vermelho Eutroférrico típico* (Teixeira et al., 2001). This effect suggests that areas receiving continuous N applications (in amidic form or as ammonium) must be monitored, especially as regards soil acidity (Teixeira et al., 2011). Furthermore, agricultural practice indicates that acidification is more intensive under tree canopies as result of N fertilization, organic waste and accumulated pruned plant material (Natale et al., 2012).

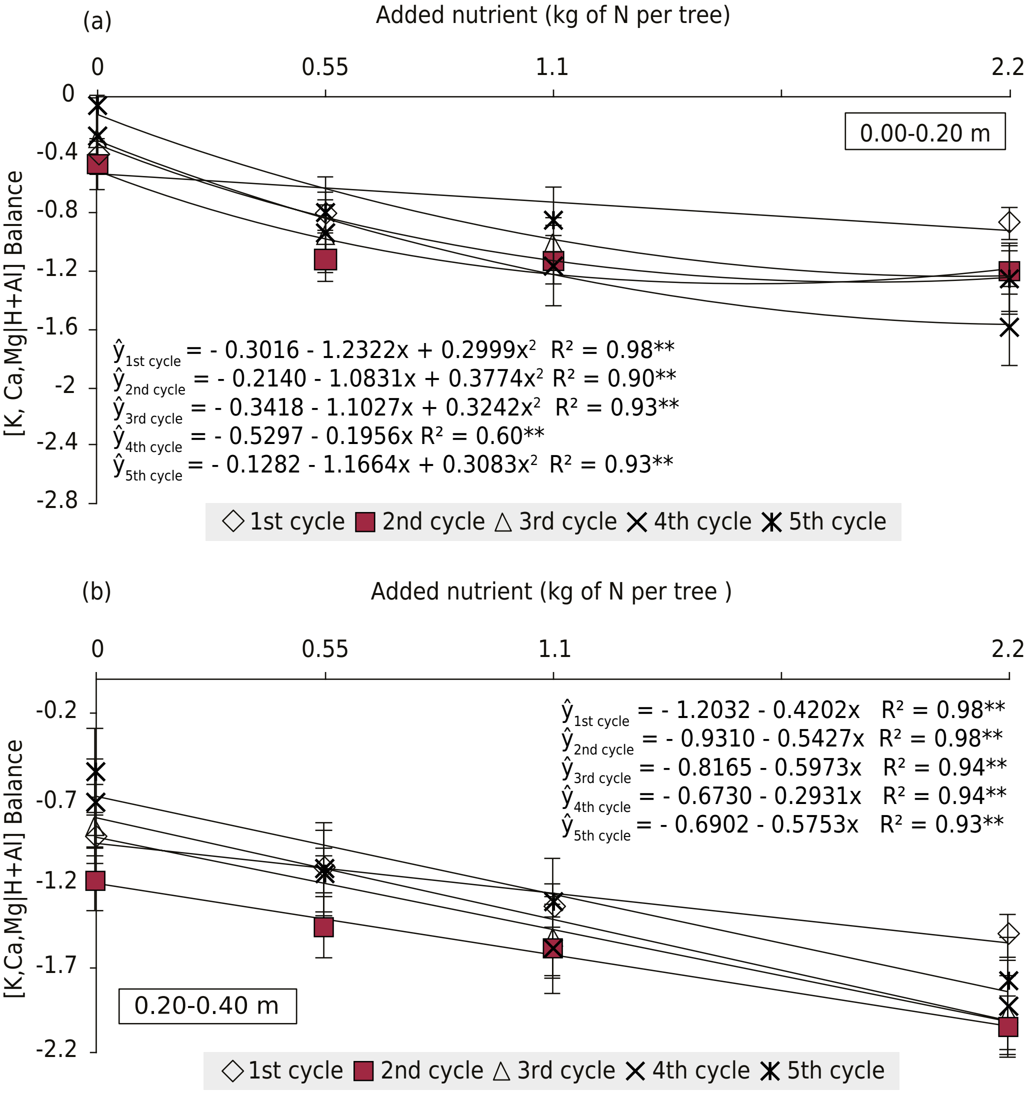

Figure 1. [K, Ca, Mg | H+Al] balances in the 0.00-0.20 m (a) and 0.20-0.40 m (b) layers in response to nitrogen fertilization in 'Paluma' guava trees. Vertical bars at each point represent standard deviations of the mean (2009 - 2012).

Table 2. Seasonal change in median values of soil chemical properties in two soil layers (0.00-0.20 and 0.20-0.40 m) in a ‘Paluma’ guava orchard in response to nitrogen fertilization (2009 - 2012)

Cycle	N rate	0.00-0.20 m					0.20-0.40 m				
		pH($CaCl_2$)	K^+	Ca^{2+}	Mg^{2+}	H+Al	pH($CaCl_2$)	K^+	Ca^{2+}	Mg^{2+}	H+Al
	kg per plant		mmol$_c$ dm^{-3}					mmol$_c$ dm^{-3}			
1	0.0	5.6	4.2	25.0	10.9	15.1	5.1	4.1	13.2	6.0	19.3
	0.5	5.3	3.6	21.4	7.8	19.4	4.9	3.5	13.3	6.3	22.8
	1.0	5.5	3.2	21.3	8.5	18.4	4.8	3.1	10.3	4.9	23.8
	2.0	5.3	2.8	23.4	8.5	19.8	4.5	3.4	10.2	4.2	28.2
2	0.0	5.4	5.3	25.0	9.2	16.0	4.8	4.7	11.5	5.3	23.9
	0.5	5.0	4.0	18.7	5.3	24.2	4.6	3.6	10.3	4.6	26.6
	1.0	5.0	3.7	20.8	5.1	25.3	4.5	3.3	10.3	4.1	28.4
	2.0	4.8	3.6	18.2	6.4	28.0	4.2	3.0	7.3	2.5	35.8
3	0.0	5.7	4.0	30.1	8.7	13.3	5.2	5.0	12.5	6.0	17.7
	0.5	5.2	3.0	22.4	6.8	21.5	4.8	3.8	12.1	4.7	23.7
	1.0	5.1	2.8	21.0	6.8	22.8	4.7	3.1	9.6	3.8	26.2
	2.0	4.9	2.5	17.3	5.9	25.2	4.2	2.7	6.3	2.5	31.6
4	0.0	5.8	3.6	29.3	10.2	13.2	5.3	3.9	16.1	6.8	16.0
	0.5	5.1	2.9	19.2	6.6	20.2	5.0	2.9	11.9	5.3	19.2
	1.0	5.1	2.1	17.5	6.0	22.6	4.7	2.2	9.7	3.4	24.2
	2.0	4.7	1.8	12.2	4.4	27.6	4.4	1.9	7.0	2.8	28.3
5	0.0	5.9	4.9	34.3	11.5	12.4	5.5	5.0	20.5	7.4	16.0
	0.5	5.4	3.6	23.3	7.4	20.7	5.0	3.3	15.0	5.7	22.9
	1.0	5.3	3.4	22.3	8.1	21.3	4.9	3.1	13.4	4.9	24.5
	2.0	4.9	2.4	18.1	6.3	26.5	4.5	2.2	8.9	3.5	30.3

The [K | Ca, Mg] balance varied as a result of K fertilization in the 0.00-0.20 and 0.20-0.40 m layers (Figures 2a and 2b). Addition of P-based fertilizer did not change soil H+Al values, but increased K concentration and reduced Ca and Mg concentration in the soil, particularly in the 0.20-0.40 m layer. Similar results were reported by Büll et al. (1998), who observed higher K /(Ca+Mg) ratios with an increase in K application in growing garlic in a greenhouse, using the surface layer (0.00-0.20 m) of a *Latossolo Vermelho-Escuro*.

A significant increase in soil K concentration was also observed in a banana tree orchard fertilized at rates of 0, 300, 600, and 900 kg ha^{-1} yr^{-1} of K_2O in a *Latossolo Vermelho Eutroférrico típico* (Teixeira et al., 2001). In 2005, the same authors noticed linear increases in K soil concentrations in the 0.00-0.20 and 0.20-0.40 m layers in ‘Anão verde’ coconut due to increased P-based fertilization. These authors pointed out a striking effect of P fertilization on K leaching, due to increased nutrient concentration in the 0.20-0.40 m layer.

The average [K | Ca, Mg] balance in the 0.20-0.40 m layer varied according to N fertilization, and is represented by the equation $\hat{y}_{[K \mid Ca,\ Mg]\ average} = -0.7579 - 0.1369\ x + 0.0991\ x^2$ ($R^2 = 0.89^{**}$). In derivation of the equation, the minimum value of the average [K | Ca, Mg] balance was found at the N application rate of 0.7 kg per plant. Reduction in the value of the balance is a result of the stimulus of N in nutrient uptake due to higher consumption of K in relation to Ca and Mg up to the minimum dose obtained. The trend of the balance changes after this point.

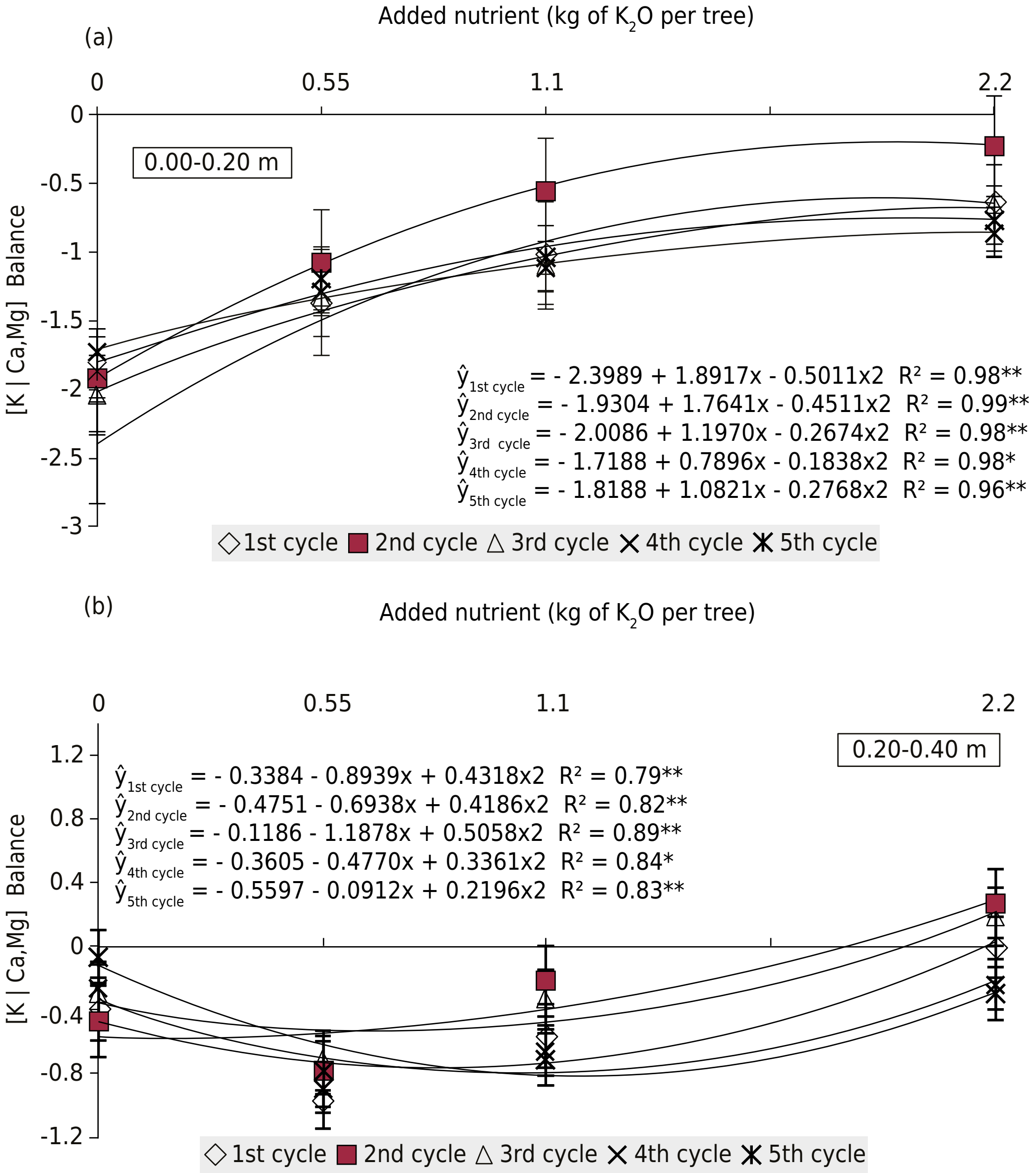

Figure 2. [K | Ca, Mg] balance in the 0.00-0.20 m (a) and 0.20-0.40 m (b) layers in response to potassium fertilization in 'Paluma' guava trees. Vertical bars at each point represent standard deviations of the mean (2009 - 2012).

The average [Ca | Mg] balance significantly affected ($p<0.05$) the 0.20-0.40 m layer in response to N and K fertilization. Best fit was found in the linear equations: $\hat{y} = 0.5978 + 0.0377\,x$ ($R^2 = 0.99^{*}$) and $\hat{y} = 0.5965 + 0.0356\,x$ ($R^2 = 0.82^{**}$), for N and K application rates, respectively. Nitrogen fertilization induces nutrient uptake, thereby reducing Ca, Mg, and K in the soil (Table 2). A similar result was obtained by Hernandes et al. (2012), who detected a significant effect on the average [Ca | Mg] balance in response to N fertilization, although no significant result was found for K fertilization. However, P fertilization increased K content and reduced exchangeable Ca and Mg (Table 3), likely due to competition among soil cations for various uptake sites, suggesting probable interference of K in the Ca and Mg balance. A similar result was observed by Cretton (2006), using increasing application rates of KCl (100, 300, and 600 g per plant), also verifying reduction in Ca and Mg content in a guava orchard.

The concept of Isometric Log Ratio (*ilr*) was used to study the effect of N and K soil fertilization in a 'Rica' guava orchard in an *Argissolo Vermelho-Amarelo Eutrófico abruptico* in low-activity clay with a moderate A horizon and sandy/clayish texture (Parent et al., 2012b). Though using a configuration unlike the ones used in this study for soil balances, the authors detected that N fertilization reduces the [K | Ca, Mg, H+Al] and [Ca, Mg | H+Al] soil balances, while increasing the [Ca | Mg] balance. These same authors verified, in a 'Paluma' guava orchard, that N-based treatments decreased [Ca, Mg | H+Al] and [Ca | Mg] soil balances in both layers of a *Latossolo Vermelho-Amarelo, epieutrófico, endodistrófico* and average soil texture in the area of greatest concentration of the plant root system.

In contrast, K treatments increased the [K | Ca, Mg, H+Al] soil balance in both soil layers (Rica and 'Paluma' guava orchards). In another study, Parent et al. (2012b) explained that N fertilization reduced soil pH since NH_4^+-N acidifies the rhizosphere due to nitrification or ammonium uptake by plant roots, but also fosters plant growth and, consequently, nutrient uptake, causing a decrease in K, Ca, and Mg in the soil. However, K-based protocol treatments did not change soil pH, but did increase soil concentration of K, while not changing Ca and Mg concentrations.

Pearson's linear correlation revealed a high direct correlation between [K, Ca, Mg | H+Al] balance and soil pH (Figure 3a), demonstrating that reduction in the values of the balance lead to a reduction in soil pH. The correlation index was high (0.98 and 0.97 for the 0.00-0.20 and 0.20-0.40 m layers, respectively), showing a close relation between [K, Ca, Mg | H+Al] balance and soil pH.

Table 3. Seasonal changes in median values of soil chemical properties in two soil layers (0.00-0.20 and 0.20-0.40 m) in a 'Paluma' guava orchard in response to potassium fertilization (2009 - 2012)

Cycle	K rate	0.00-0.20 m					0.20-0.40 m				
		pH($CaCl_2$)	K^+	Ca^{2+}	Mg^{2+}	H+Al	pH($CaCl_2$)	K^+	Ca^{2+}	Mg^{2+}	H+Al
	kg per plant			mmol$_c$ dm^{-3}					mmol$_c$ dm^{-3}		
1	0.00	5.3	0.8	22.7	9.7	19.1	4.9	1.4	13.8	6.4	23.7
	0.55	5.5	2.7	22.1	9.1	18.0	4.8	2.5	11.2	5.6	22.2
	1.10	5.4	4.0	22.8	8.4	18.7	4.8	3.9	11.7	5.3	24.5
	2.20	5.5	6.2	23.6	8.6	16.9	4.7	6.3	10.3	4.1	23.7
2	0.00	5.0	1.2	23.6	7.1	25.7	4.6	0.9	11.5	5.0	28.2
	0.55	5.1	3.5	24.1	8.2	22.1	4.6	2.5	1.0	4.4	27.3
	1.10	5.0	4.9	17.3	5.3	23.8	4.5	4.4	9.2	3.9	29.3
	2.20	5.1	7.2	17.7	5.5	21.8	4.5	6.9	8.7	3.2	30.0
3	0.00	5.2	1.1	24.4	7.3	21.3	4.8	1.0	11.6	5.3	23.6
	0.55	5.2	2.5	22.9	6.8	21.7	4.8	2.9	10.8	4.3	24.5
	1.10	5.3	3.3	23.2	7.0	19.6	4.6	4.1	9.3	4.1	25.9
	2.20	5.2	5.4	20.3	7.2	20.1	4.7	6.6	8.8	3.3	25.1
4	0.00	5.0	1.2	19.3	6.2	23.1	4.8	0.9	11.8	5.5	22.5
	0.55	5.1	2.3	20.2	7.2	20.8	4.9	2.2	11.8	4.3	19.8
	1.10	5.2	2.7	18.3	6.7	20.2	4.8	3.0	10.4	4.4	23.3
	2.20	5.3	4.2	20.4	7.2	19.5	4.9	4.8	10.6	4.2	22.0
5	0.00	5.4	1.4	24.8	8.7	20.2	5.0	1.3	15.8	6.4	21.4
	0.55	5.4	3.4	28.2	8.4	21.3	5.0	3.2	15.1	5.2	23.3
	1.10	5.4	3.9	22.2	7.8	19.4	5.0	3.7	14.6	5.1	24.1
	2.20	5.4	5.6	22.9	8.4	20.0	4.9	5.5	12.4	4.8	24.8

The [K | Ca, Mg] balance had a high direct correlation with K concentration in the soil (Figure 3b), indicating that the increase in the balance in response to K fertilization corresponds also to increased K concentration in the soil. An application rate of 0.55 kg K_2O per plant per cycle was enough to maintain values of [K| Ca, Mg] balance in all cycles evaluated above -1.4 and -1.8 in the 0.00-0.20 and 0.20-0.40 m layers, respectively, corresponding to K values above 1.6 mmol$_c$ dm^{-3} in the soil (Figure 3). Fertility standards proposed by Raij et al. (1997) call for maintaining soils within classes of average concentration (1.6 to 3.0 mmol$_c$ dm^{-3} of K in the soil), thus avoiding deficiencies and excesses, both of which can hamper and jeopardize crop yield and quality.

The study of soil cationic balance in ‘Paluma’ guava orchards also showed high correlation between [Ca, Mg | H+Al] balance and K concentration in the soil at 0.90 for the Pearson linear correlation coefficient (Parent et al., 2012b). However, this value was still lower than those in this study for correlation between the [K | Ca, Mg] balance and K concentration in the soil (0.96 and 0.94 for the 0.00-0.20 and 0.20-0.40 m layers, respectively).

Analyzing the effect of different soil collection times for purposes of soil analysis revealed a significant difference ($p<0.05$) in the [K | Ca, Mg] balance in the 0.00-0.20 and 0.20-0.40 m layers fertilized with K, and the [K, Ca, Mg| H+Al] balance in the 0.00-0.20 and 0.20-0.40 m layers that received N fertilization (Table 4), as well as average [Ca | Mg] balances in the 0.00-0.20 and 0.20-0.40 m layers (Table 5). Variation in balances could be associated with differences in maximum and minimum temperature and accumulated rainfall at the time at which data were collected. Variations in soil chemical properties (pH, Ca, Mg, K, and H+Al)

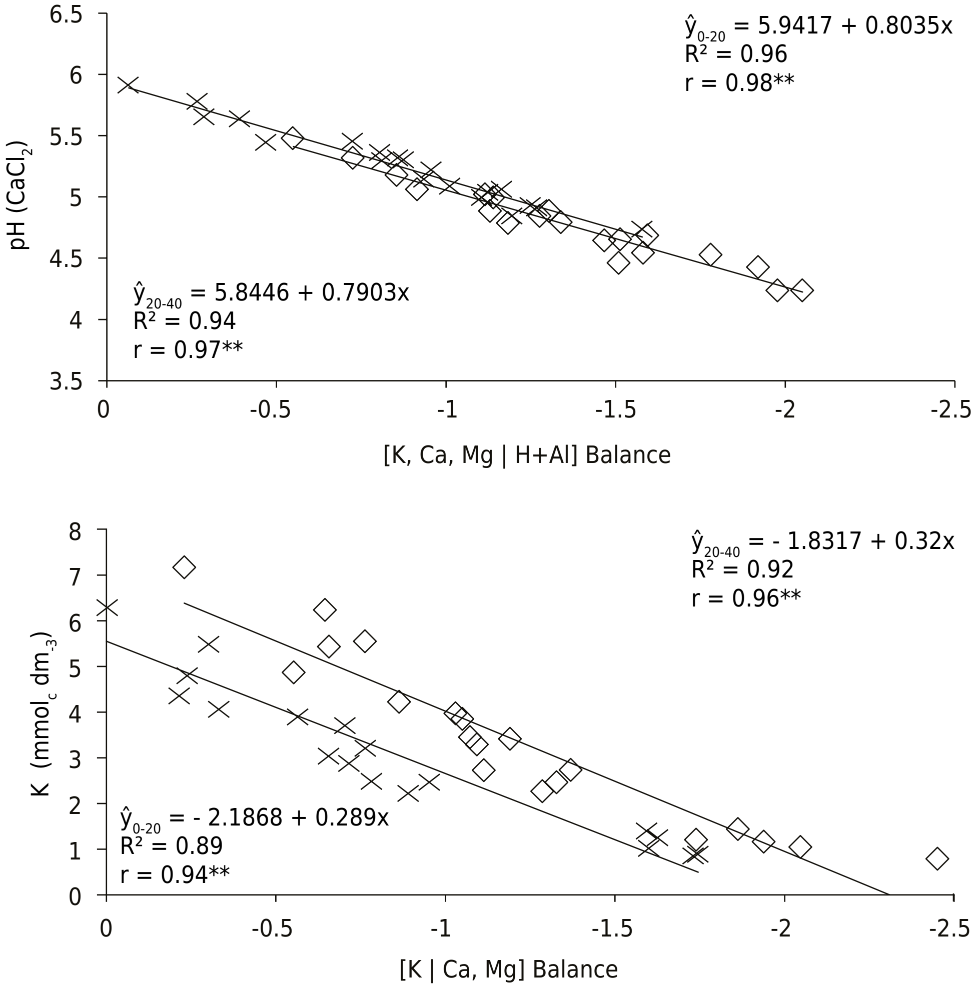

Figure 3. Correlation between [K, Ca, Mg | H+Al] balance and pH ($CaCl_2$), and correlation between [K | Ca, Mg] balance and concentration of exchangeable K in a ‘Paluma’ guava tree orchard (2009 - 2012).

Table 4. Seasonality of [K | Ca, Mg] balance in response to potassium fertilization, and [K, Ca, Mg | H+Al] balance in response to nitrogen fertilization, in the 0.00-0.20 and 0.20-0.40 m layers, in a ‘Paluma’ guava tree orchard (2009 - 2012)

Cycle	[K | Ca, Mg] balance (0.00-0.20 m)				[K, Ca, Mg | H+Al] balance (0.00-0.20 m)			
	kg K_2O per tree				kg N per tree			
	0	0.55	1.1	2.2	0	0.5	1.0	2.0
1	-2.452 c	-1.369 b	-1.030 b	-0.645 b	-0.392 bc	-0.812 a	-0.725 a	-0,875 a
2	-1.939 ab	-1.073 a	-0.553 a	-0.230 a	-0.470 c	-1.106 c	-1.124 c	-1,195 b
3	-2.048 b	-1.328 b	-1.093 b	-0.657 b	-0.288 bc	-0.957 b	-1.012 bc	-1,268 b
4	-1.739 a	-1.286 ab	-1.113 b	-0.864 b	-0.267 ab	-0.936 bc	-1.164 c	-1,578 c
5	-1.863 ab	-1.191 ab	-1.051 b	-0.763 b	-0.064 a	-0.805 a	-0.858 ab	-1,249 b
	[K | Ca, Mg] balance (0.20-0.40 m)				[K, Ca, Mg | H+Al] balance (0.20-0.40 m)			
1	-1.593 a	-0.953 b	-0.565 b	-0.003 b	-0.916 b	-1.130 a	-1.339 a	-1.510 a
2	-1.745 a	-0.783 ab	-0.215 a	0.273 a	-1.183 c	-1.468 b	-1.582 b	-2.051 c
3	-1.600 a	-0.716 a	-0.333 a	0.193 ab	-0.855 b	-1.277 a	-1.514 ab	-1.978 bc
4	-1.731 a	-0.891 ab	-0.656 b	-0.239 c	-0.726 b	-1.116 a	-1.59 4b	-1.921 bc
5	-1.626 a	-0.764 ab	-0.704 b	-0.302 c	-0.549 a	-1.140 a	-1.304 a	-1.781 b

Mean values followed by the same letters in the column do not differ from each other by the LSD test ($p<0.05$).

Table 5. Seasonality of the average [Ca | Mg] balance, in the 0.00-0.20 and 0.20-0.40 m layers, in a ‘Paluma’ guava orchard (2009 - 2012)

Cycle	[Ca | Mg] balance	
	0.00-0.20 m	0.20-0.40 m
1	0.6679 c	0.5746 b
2	0.8404 a	0.6385 ab
3	0.8169 a	0.6331 ab
4	0.7406 b	0.6304 ab
5	0.7531 b	0.6769 a

Mean values followed by the same letters in the column do not differ from each other by the LSD test ($p<0.05$).

were shown by Orlando Filho et al. (1977). They collected samples from an Oxisol and observed differences in values at different periods of collection within one year. These authors indicate that pH and K determinations were most affected by the moisture content of the soil samples, but this influence bears no practical importance for K in accordance with the standard contents used.

Seasonal influence on soil chemical composition was also detected during the heaviest annual rainfalls and most intense flooding of marshland in a Molisol on the banks of the Guamá River in Belém, in northern Brazil. Sample collected in February increased pH and reduced Mg, while Al remained exchangeable. At the time of year of lowest soil moisture (May through August), base saturation and CEC were both higher (Abreu et al., 2007). Similar results were also reported by Childs and Jencks (1967), demonstrating that chemical soil properties (pH, K, Ca, Mg) varied according to different soil collection times. The results of the present study likewise show variations in accordance with soil collection times. These same variations were reported by Orlando Filho et al. (1997) and by Childs and Jencks (1967), indicating temperature and moisture as major causes of these changes.

CONCLUSIONS

The compositional data analysis showed to be a suitable tool to interpret the soil nutrient concentration and soil cationic balance.

The soil cationic balance was changed by nitrogen fertilization and potassium as well as the soil pH value and the concentration of K in the soil. The soil cationic balances also changed by the variations of the climate conditions in function of soil sample period.

An application rate of 0.55 kg of K_2O per plant per cycle is indicated sufficient to keep K soil concentration above 1.6 $mmol_c$ dm^{-3}.

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