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Precision agriculture tools for liming management in mango orchards in the Brazilian semi-arid region

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Abstract

Optimizing the recommendation for the management of Liming Requirement (LR) is essential for cost reduction and increased yield of mango. Therefore, the objective of this study was to delimit management zones for the limestone recommendation in areas of irrigated mango in the Brazilian semi-arid region using precision agriculture techniques. The experiment was carried out in three commercial mango orchards located in the region of the São Francisco River Valley, Brazil. Soil samples were collected in the 0.0-0.2 m and 0.2-0.4 m layers following regular grids where the number of samples varied from 50 to 56. Soil analyses were performed. The kriging and inverse distance weighting methods were used to interpolate the maps. The LR map was created from the potential cation exchange capacity (T) and base saturation (BS) maps. It was verified that the Mandacaru area obtained 63.42% of the field requiring liming, being subdivided into four management zones. The Sempre Verde area obtained 1.20% of the area requiring liming and the Barreiro de Santa Fé area showed no need for the LR map. The use of precision farming techniques to delineate management zones was adequate to separate the areas into smaller and more homogeneous zones, for a more precise recommendation of liming.

Keywords: fruit crop, *Mangifera indica* L., semivariance, spatial distribution

Introduction

The São Francisco River Valley is the most important fruit production region of Brazil, in addition to being the greatest Brazilian mango exporter region (Sampaio et al., 2017). Despite its potential, techniques which can reduce cost and increase crop yield are indispensable for the activity's sustainability. Among these techniques, the optimization of the use of fertilizers and soil conditioners can be highlighted, since these are responsible for approximately 30% of the total cost of irrigated mango production (Almeida & Gomes, 2016).

The most widely used soil conditioner, dolomitic limestone, when applied correctly, increases pH to the ideal values for crops (5.5-6.0) (Ribeiro et al., 1999), causing the reduction exchangeable aluminum contents, increasing the availability of nutrients such as calcium and magnesium (Sousa et al., 2007), and improving the development of the root system of plants (Raij, 2011). These beneficial effects make dolomitic limestone commonly used by mango farmers in the São Francisco River Valley region.

Calcium and magnesium deficiency can be induced as a result of competition between them or other cations, decreasing their uptake rate (Salvador et al., 2011). This reinforces the need for a correct recommendation so that the solubilization of these nutrients is not affected by errors in liming management. In addition, an error that causes over-liming, in which pH increases out of the ideal values, can negatively affect the availability of micronutrients in general, reducing their uptake by the crop (Hansel & Oliveira, 2016), especially zinc and boron in the mango crop (Bhatt et al., 2012).

The liming requirement (LR) in agricultural areas is often calculated using the average values of soil properties, assuming that the crop field is homogeneous. However, this recommendation may cause under

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or overestimation of the amount of limestone, since heterogeneity of fruit fields located in the São Francisco River Valley has been verified in previous works (Rodrigues et al., 2018; Rodrigues et al., 2019) and has been ignored.

Thus, the use of tools that enable the study of spatial variability and the division of agricultural fields into smaller and more homogeneous management zones is essential to avoid errors in soil management (Tagarakis et al., 2013). Although it is possible to find works which divide the area into more homogeneous zones successfully, using geostatistics, deterministic interpolators, clustering method, etc. (Behera et al., 2018), there are no reports in the literature about site-specific management of liming in mango fields under the semi-arid condition in the São Francisco River Valley region.

Therefore, the objective of this study was to delimit management zones for limestone recommendation in areas of irrigated mango in the Brazilian semi-arid region using precision agriculture techniques.

Materials and Methods

The experiments were carried out in 2017 and 2018, in three commercial mango orchards in the São Francisco River Valley region, Brazil. The areas were considered homogeneous by the farmers, cultivated with mango cv. Tommy Atkins under localized irrigation by micro-sprinkler (two micro-sprinklers per plant). N, P, and K were supplied by fertigation, and Ca and Mg by manual application of liming under the canopy region of the trees. A description of the areas can be found in Table 1.

According to Köppen's classification, the local climate is BSh, which is semi-arid, with annual precipitation of less than 500 mm concentrated only in three to four months of the year and annual averages of temperature varying between 18.7 and 33.6 °C.

Soil samples were collected under the canopy region after harvest (before application of any product), in the layers of 0.0-0.2 and 0.2-0.4 m, following regular grids containing 56 georeferenced points (56 × 30 m) in the Barreiro de Santa Fé area (Figure 1a), 50 points (32 × 25 m) in the Mandacaru area (Figure 1b), and 53 points (42 × 35 m) in the Sempre Verde area (Figure 1c).

Table 1. Location, soil type, texture, area size, age, and spacing of the crop of the Barreiro de Santa Fé, Mandacaru, and Sempre Verde areas cultivated with irrigated mango cv. Tommy Atkins in the São Francisco River Valley region, Brazil.

	Barreiro de Santa Fé area	Mandacaru area	Sempre Verde area
Location	Petrolina, Pernambuco (9°23'39.37" S and 40°44'32.91" W)	Petrolina, Pernambuco (9°20'50.58" S and 40°33'04.51" W)	Juazeiro, Bahia (9°14'59.38" S and 40°16'58.40" W)
Soil type	Oxisol	Ultisol	Ultisol
Sand (g kg^{-1})	767 A; 705 B	869 A; 797 B	758 A; 470 B
Clay (g kg^{-1})	160 A; 210 B	101 A; 165 B	95 A; 362 B
Area size	9 ha (797 x 114 m)	4.5 ha (353 x 125 m)	9.5 ha (411 x 232 m)
Crop age	25 years old	26 years old	25 years old
Crop spacing	8 x 5 m	8 x 5 m	7 x 6 m

A: A horizon; B: B horizon.

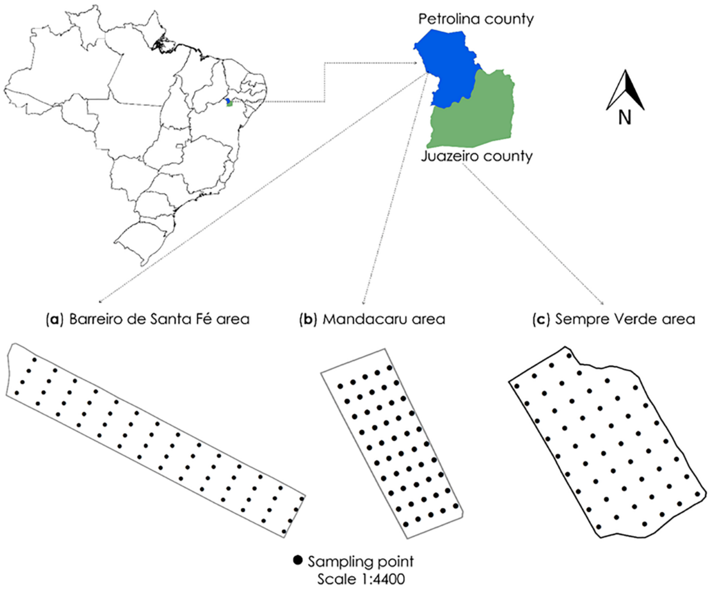

Figure 1. Sampling design in the mango fields located in the São Francisco River Valley region, semi-arid region, Brazil. a) 56 georeferenced points in the Barreiro de Santa Fé area, b) 50 points in the Mandacaru area, and c) 53 points in the Sempre Verde area.

The number of samples was defined according to two criteria: 1) obtaining at least 30 pairs of points for calculation of the semivariance in the first lag (Arétouyap et al., 2016) following Yamamoto and Landim's (2013) recommendation of at least 30 to 40 points, and 2) the geometric shape of each area.

The disturbed soil samples were obtained using a Dutch auger. Each soil sample was analyzed for particle size (pipette method), pH (1:2 soil/water mixture), Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, potential acidity (H+Al), and Al^{3+} content according to Teixeira et al. (2017). From the analytical determinations, the sum of basis (SB), potential cation exchange capacity (T), and base saturation (BS) were calculated.

Descriptive analysis of the data (mean, minimum, maximum values, and coefficient of variation) was performed. Data normality was checked by the Shapiro-Wilk's test at 5% probability using R statistical software (version 3.2.2). The coefficient of variation (CV) was classified according to Pimentel-Gomes and Garcia (2002), who define $CV \leq 10\%$ as low, $10\% < CV \leq 20\%$ as medium, $20\% < CV \leq 30\%$ as high, and $CV > 30\%$ as very high variability.

The Ca^{2+} and Mg^{2+} contents were classified according to the availability range suggested by Malavolta (2001) and the pH and T were classified according to Ribeiro et al. (1999) classification.

The spatial dependence between the samples was checked with geostatistics, using semivariogram models. The three most used models for each semivariogram are spherical, exponential, and Gaussian (Oliver & Webster, 2014).

The data that showed spatial dependence were interpolated using ordinary Kriging method and those that showed pure nugget effect (PNE)were interpolated using the inverse distance weighting (IDW) for obtaining the pH, T and BS maps of both soil layers evaluated (Oliver & Webster, 2014). Map Algebra was used to obtain the mean maps between the two study layers for the pH, T, and BS variables. This method consists of calculating the mean value for each pixel overlapping the maps from the two evaluated soil layers. Based on the T and BS mean maps, the liming requirement (LR) was calculated using also map algebra, by means of the base saturation method (Ribeiro et al., 1999), as shown in equation 1:

$$LR = \frac{T \times (BS_e - BS_c)}{100} \qquad (1)$$

where: T is the potential cation exchange capacity ($cmol_c\ dm^{-3}$); BS_e is the base saturation value expected for the mango crop (BS_e = 80%) (Correia et al., 2018) and BS_c is the current base saturation value (%).

Results and Discussion

Table 2 shows the descriptive analysis of the data, in which most of the soil properties showed minimum and maximum values that were far from the mean, indicating high dispersion, mainly of base saturation (BS) and potential cation exchange capacity (T), which are used for calculating the liming requirement (LR).

The Barreiro de Santa Fé and Sempre Verde areas showed Ca^{2+} and Mg^{2+} mean values (Table 2) greater than the optimum levels for mango cultivation according to Malavolta (2001) classification in the 0.0-0.2 (Ca^{2+} = 3.0 $cmol_c\ dm^{-3}$; Mg^{2+} = 1.2 $cmol_c\ dm^{-3}$) and 0.2-0.4 m (Ca^{2+} = 2.5 $cmol_c\ dm^{-3}$; Mg^{2+} = 0.9 $cmol_c\ dm^{-3}$) layers. In the Mandacaru area, the Ca^{2+} and Mg^{2+} mean values (Table 2) were below the optimum values in both layers according to the Malavolta (2001) classification, and the T values were classified as medium for the 0.0-0.2 m depth (T = 4.31-8.60 $cmol_c\ dm^{-3}$) and low for the 0.2-0.4 m layer (T = 1.61-4.63 $cmol_c\ dm^{-3}$) according to the Ribeiro et al. (1999) classification. This probably occurred because the low clay content (Table 1), resulting in low T values, favor the leaching of Ca^{2+} and Mg^{2+} (Raij, 2011).

It is important to correct the Ca^{2+} level, which is above the optimum values since its highest content is found in mango leaves (Silva et al., 2014), and calcium deficiency can depreciate the quality of the fruit, as low concentration of leaf Ca is associated with the incidence of internal collapse in mango (Almeida et al., 2015). Therefore, higher calcium content in the fruit slows ripening and senescence, by reducing respiration, ethylene evolution and loss of fresh weight, extending post-harvest life and fruit quality of mango (Aular & Natale, 2013; Hojo et al., 2009).

The high variability of soil chemical properties, based on the CV and minimum and maximum values (Table 2), may be a consequence of the interaction processes of soil formation, plant and soil management practices, caused by successive and non-homogeneous fertilization and liming, impacting, mainly, the topsoil (Dalchiavon et al., 2017).

The greatest variability (CV values), common to the three areas in both layers, was observed for the K^{+} content (Table 2). Other authors have also found high variability for K^{+} content (Oliveira et al., 2015; Rodrigues & Corá, 2015). This can be due to some factors such as: 1) frequent application of fertilizers (Richart et al., 2016): as in the São Francisco River Valley, fertilization with this nutrient is performed by fertigation, using the most soluble forms (Silva et al., 2014), which favors the leaching of K$^+$ (Santos et al., 2015b); 2) valence charge: K$^+$ is a monovalent cation, being poorly adsorbed to soil colloids compared to Ca^{2+} and Mg^{2+} (Ramos et al., 2013); 3) sandy soils: the soils of this experiment are in general sandy; and, 4) nutrient extraction: K$^+$ is the second nutrient most extracted by mango trees.

Table 2. Descriptive analysis of the soil chemical properties in the layers of 0.0-0.2 m and 0.2-0.4 m of the Barreiro de Santa Fé, Mandacaru, and Sempre Verde areas cultivated with irrigated mango cv. Tommy Atkins in the São Francisco River Valley region, Brazil.

Properties	Mean	Min	Max	CV	C_{CV}	Mean	Min	Max	CV	C_{CV}
Barreiro de Santa Fé area										
	---------------0.0-0.2 m--------------					---------------0.2-0.4 m--------------				
Ca^{2+} (cmol$_c$ dm^{-3})	4.51	3.15	6.25	16	M	3.46	2.36	4.63	17	M
Mg^{2+} (cmol$_c$ dm^{-3})	1.83	1.47	2.29	11	M	1.56	1.08	2.10	13	M
Na$^+$ (cmol$_c$ dm^{-3})	0.20	0.09	0.30	32	VH	0.26	0.22	0.30	14	M
K$^+$ (cmol$_c$ dm^{-3})	0.29	0.15	0.44	25	H	0.53	0.26	0.92	31	VH
H+Al (cmol$_c$ dm^{-3})	0.92	0.66	1.16	15	M	1.31	1.16	1.65	16	M
Al^{3+} (cmol$_c$ dm^{-3})	0.14	0.10	0.20	34	VH	0.09	0.05	0.10	24	H
SB (cmol$_c$ dm^{-3})	6.90	4.97	9.31	14	M	5.79	4.41	7.74	12	M
T (cmol$_c$ dm^{-3})	7.68	5.80	9.54	11	M	7.07	5.90	9.08	11	M
BS (%)	88.12	82.87	92.87	3	L	82.41	75.62	88.61	4	L
pH	7.09	6.49	7.76	4	L	6.79	6.35	7.37	4	L
Mandacaru area										
Properties	Mean	Min	Max	CV	C_{CV}	Mean	Min	Max	CV	C_{CV}
	---------------0.0-0.2 m--------------					---------------0.2-0.4 m--------------				
Ca^{2+} (cmol$_c$ dm^{-3})	2.38	1.54	3.78	22	H	1.19	0.60	1.93	27	H
Mg^{2+} (cmol$_c$ dm^{-3})	0.82	0.50	1.43	27	H	0.65	0.42	0.87	19	M
Na$^+$ (cmol$_c$ dm^{-3})	0.06	0.04	0.13	41	VH	0.05	0.04	0.09	35	VH
K$^+$ (cmol$_c$ dm^{-3})	0.43	0.21	0.92	42	VH	0.33	0.13	0.62	38	VH
H+Al (cmol$_c$ dm^{-3})	1.06	0.33	1.82	0	L	0.72	0.33	1.32	42	VH
Al^{3+} (cmol$_c$ dm^{-3})	0.13	0.10	0.20	36	VH	0.18	0.05	0.30	37	VH
SB (cmol$_c$ dm^{-3})	3.78	2.65	6.16	22	H	2.33	1.60	3.71	23	H
T (cmol$_c$ dm^{-3})	5.07	3.32	7.97	23	H	3.02	2.29	4.09	15	M
BS (%)	77.64	60.11	90.58	11	M	75.49	58.31	91.03	12	M
pH	6.81	5.94	7.74	7	L	6.76	5.87	8.00	8	L
Sempre Verde area										
Properties	Mean	Min	Max	CV	C_{CV}	Mean	Min	Max	CV	C_{CV}
	---------------0.0-0.2 m--------------					---------------0.2-0.4 m--------------				
Ca^{2+} (cmol$_c$ dm^{-3})	6.00	3.00	10.22	31	VH	5.98	3.00	10.61	33	VH
Mg^{2+} (cmol$_c$ dm^{-3})	2.09	1.50	2.56	14	M	1.89	0.73	2.73	27	H
Na$^+$ (cmol$_c$ dm^{-3})	0.26	0.13	0.43	28	H	0.29	0.13	0.43	27	H
K$^+$ (cmol$_c$ dm^{-3})	0.67	0.38	1.21	31	VH	0.72	0.26	1.56	45	VH
H+Al (cmol$_c$ dm^{-3})	1.19	0.50	2.15	44	VH	1.10	0.50	1.82	36	VH
Al^{3+} (cmol$_c$ dm^{-3})	0.05	0.05	0.05	0	L	0.06	0.05	0.10	35	VH
SB (cmol$_c$ dm^{-3})	8.91	5.72	11.77	20	M	8.82	5.01	13.47	24	H
T (cmol$_c$ dm^{-3})	9.98	6.21	13.72	19	M	9.84	6.00	13.97	22	H
BS (%)	88.90	79.32	96.83	5	L	88.80	77.10	97.11	5	L
pH	6.51	6.20	6.87	3	L	6.44	6.05	6.74	3	L

H+Al: potential acidity; Al^{3+}: exchangeable acidity; SB: sum of basis; T: potential cation exchange capacity; BS: base saturation; pH: hydrogen potential; Min: minimum; Max: maximum; CV: coefficient of variation (%); Ccv: classification of the coefficient of variation according to Pimentel-Gomes and Garcia (2002) – low variability (L) = CV ≤10%, medium (M) = 10% < CV ≤ 20%, high (H) 20% < CV ≤ 30%, and very high (VH) CV > 30%.

In general, the variables of the Mandacaru area showed the lowest range values in both layers (Table 3). Lower range values indicate greater heterogeneity of the soil property in the area, observed for T and pH (Santos et al., 2015a). Liming practices may have influenced the high spatial variability of pH and T, due to the frequent pH corrections at the end of each cycle of the mango crop in the São Francisco River Valley region through liming management (Natale et al., 2010). The variables which were interpolated by Kriging method or inverse distance weighting (IDW) method can be found in Table 3.

The maps of the pH, T and BS mean values allowed the visualization of the spatial distribution of these soil properties in the three areas according to the agronomic classification ranges (Figures 2, 3 and 4). The pH maps showed that the values were above the optimum values (Table 2) in great part of the mango field for all study areas (Figure 2A, 3A and 4A). The excessive increase in pH can compromise the solubilization of micronutrients (Hansel & Oliveira, 2016), mainly B and Zn, important in mango crop (Bhatt et al., 2012), making their uptake almost impossible.

Table 3. Variogram model parameters and interpolation method of the soil properties in the layers of 0.0-0.2 m and 0.2-0.4 m of the Barreiro de Santa Fé, Mandacaru, and Sempre Verde areas cultivated with irrigated mango cv. Tommy Atkins in the São Francisco River Valley region, Brazil.

Properties	Model	C_0	C_0+C	R	R²	RSS	IM
	0.0-0.2 m layer						
	Barreiro de Santa Fé area						
T	EXP	0.23	1.17	83.02	0.401	0.0689	Krig
BS	PNE	4.98	4.98	-	-	-	IDW
pH	SPH*	0.00	0.06	53.28	0.783	7.74×10^{-5}	Krig
	Mandacaru area						
T	SPH	0.05	1.37	39.70	0.648	0.0469	Krig
BS	GAU	2.31	66.61	46.11	0.816	594	Krig
pH	GAU	0.06	0.27	60.97	0.975	4.38×10^{-4}	Krig
	Sempre Verde area						
T	SPH	2.12	4.25	121.90	0.683	0.41	Krig
BS	PNE	29.77	29.77	-	-	-	IDW
pH	SPH	0.01	0.03	155.80	0.842	2.70×10^{-5}	Krig
	0.2-0.4 m layer						
	Barreiro de Santa Fé area						
T	SPH	0.39	0.87	140.00	0.664	0.0523	Krig
BS	PNE	8.05	8.05	-	-	-	IDW
pH	SPH*	0.02	0.08	153.37	0.895	1.97×10^{-4}	Krig
	Mandacaru area						
T	GAU	0.01	0.26	38.94	0.86	1.13×10^{-3}	Krig
BS	GAU	3.09	93.76	44.86	0.74	745	Krig
pH	EXP	0.07	0.30	78.34	0.954	3.26×10^{-4}	Krig
	Sempre Verde area						
T	SPH	2.74	6.34	100.27	0.782	0.585	Krig
BS	EXP	3.09	34.53	116.40	0.99	1.66	Krig
pH	SPH	0.00	0.03	138.30	0.729	8.45×10^{-5}	Krig

T: potential cation exchange capacity; BS: base saturation; pH: hydrogen potential; C_0: nugget effect; C_0+C: sill; R: range; R²: coefficient of determination; RSS: residual sums of squares; IM: interpolation method; Krig: Kriging; IDW: inverse distance weighting; SPH: spherical model; PNE: pure nugget effect; EXP: exponential model; GAU: Gaussian model; *The semivariograms were estimated with the residuals.

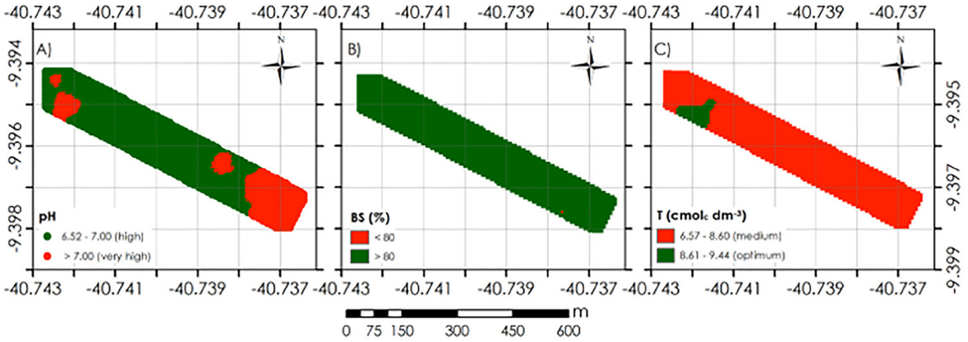

Figure 2. Maps of average values of A) pH, B) base saturation (BS), and C) potential cation exchange capacity (T) of the Barreiro de Santa Fé area cultivated with irrigated mango cv. Tommy Atkins in the São Francisco River Valley region, Brazil.

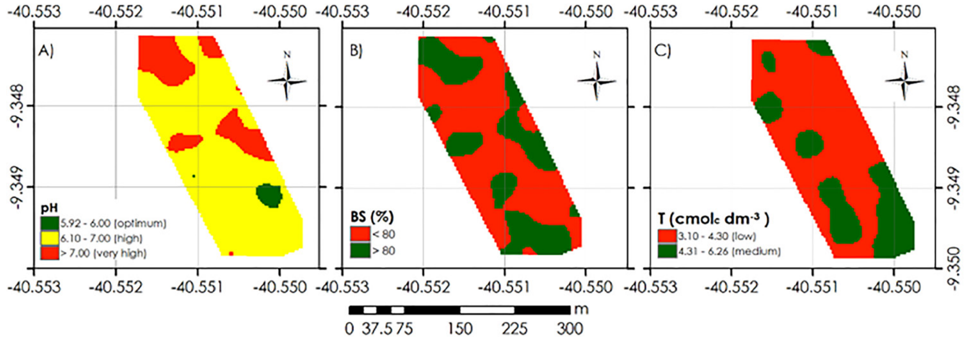

Figure 3. Maps of average values of A) pH, B) base saturation (BS), and C) potential cation exchange capacity (T) of the Mandacaru area cultivated with irrigated mango cv. Tommy Atkins in the São Francisco River Valley region, Brazil.

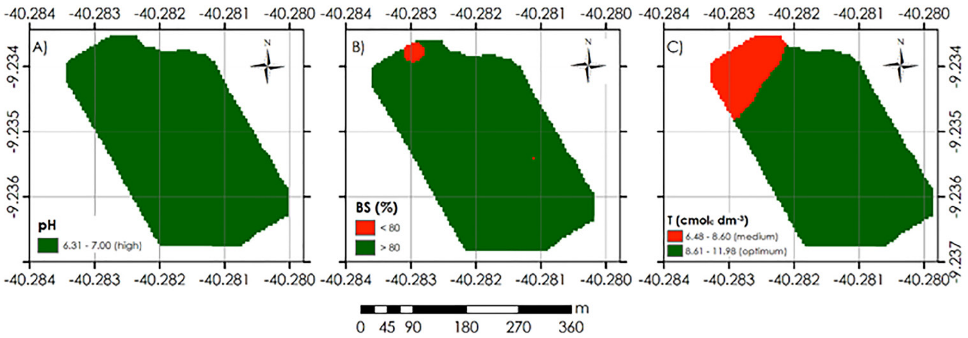

Figure 4. Maps of average values of A) pH, B) base saturation (BS), and C) potential cation exchange capacity (T) of the Sempre Verde area cultivated with irrigated mango cv. Tommy Atkins in the São Francisco River Valley region, Brazil.

In the Barreiro de Santa Fé (Figure 2B) and Sempre Verde (Figure 4B) areas, BS values were above 80% in the total area and in most of their field, respectively. On the other hand, the Mandacaru area showed zones of BS below 80% (Figure 3B), demonstrating the need for correction in some areas of the crop field. The T content maps for the Barreiro de Santa Fé (Figure 2C) and Mandacaru (Figure 4C) areas showed medium and low values (Table 2), respectively, for the most part of the mango fields. These T results in the areas may be related to the low clay content (Santos et al., 2015b), since, depending on the type and quality of the clay, it can increase the negative charges and decrease the point of zero charge of the soil (Ribeiro et al., 2011).

Based on the T and BS mean values maps, the Liming Requirement (LR) map was created (Figures 5 and 6). In the Mandacaru area, 63.42% of the area requires liming. To simplify the limestone application, the Mandacaru area was divided into four management zones as shown in Figure 5, in which zone 1 represents 36.58% of the area, zone 2 - 35.42%, zone 3 - 20.80%, and zone 4 - 7.20%. On the other hand, in the Sempre Verde area, only 1.20% of the area requires liming, so only two zones were delimited (Figure 6). In the Barreiro de Santa Fé area, the BS values in the entire area were higher than the recommended value for the mango crop (BS = 80%) (Correia et al., 2018); therefore, it was not necessary to create an LR map. It is important to highlight that for farmers to adopt site-specific management, the development of management zones must be simple, functional, and economically feasible (Rodrigues & Corá, 2015).

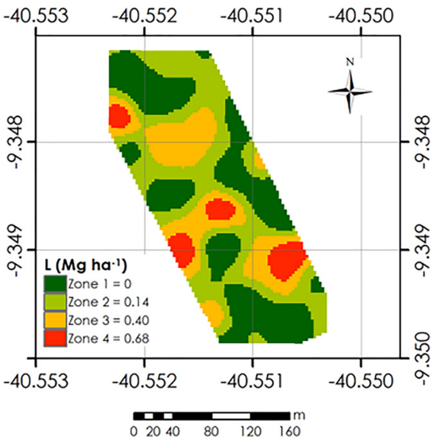

Figure 5. Management zone of Liming Requirement (LR) of the Mandacaru area cultivated with irrigated mango cv. Tommy Atkins in the São Francisco River Valley region, Brazil.

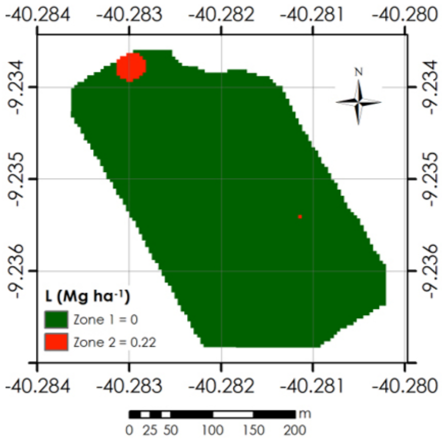

Figure 6. Management zone of Liming Requirement (LR) of the Sempre Verde area cultivated with irrigated mango cv. Tommy Atkins in the São Francisco River Valley region, Brazil.

If the classical liming application without taking into account the spatial variability were adopted, 0.14 Mg ha^{-1} of limestone would be applied to the Mandacaru area (Table 2). Comparing this mean value (0.14 Mg ha^{-1}) with the mean values of the zones found for this area (Figure 5), the LR would be adequate only for zone 2, consequently, there would be over-liming in 36.58% of the area, in zone 1 (LR = 0), and under-liming in 28% of the area, in zones 3 and 4 (LR = 0.4 and 0.8 Mg ha^{-1}, respectively). In the Sempre Verde area, there would be no need for liming if the mean from classical statistics were used (Table 2). However, zone 2 (LR = 0.22 Mg ha^{-1}) would have under-liming in 1.20% of the area.

Thus, it is possible to verify that the zoning technique, using spatial analysis, minimizes recommendation errors when compared to classical statistics. These errors may cause negative economic effects, for example, when the plant does not respond to very high limestone applications (Natale et al., 2011). Additionally, when this over-liming reduces the availability of important nutrients in the mango crop due to excessive pH elevation (Hansel & Oliveira, 2016), it is necessary to increase the fertilization with micronutrients using foliar application, which depends on machines and agricultural implements that increase production costs. In addition, high pH values can cause a decrease in $H_2PO_4^-$ and an increase in HPO_4^{2-}, since phosphorus in the $H_2PO_4^-$ form is absorbed more quickly by plant roots than HPO_4^{2-}, which can be considered a negative effect of high pH values (Araujo & Machado, 2006).

Both soils with low pH values (acidic soils) and soils with high pH values (alkaline soils) can cause problems for crop development. However, soils with acidic pH are easily corrected in the short term by liming, whereas soils with high pH values are more difficult to correct and require much more time and investment to reduce the values to the ideal pH range (Leite et al., 2010). The method used to correct areas with high pH values can be performed through the use of acid-forming substances, such as sulfur, which reduces pH values due to its biological transformation into sulfuric acid (Severo et al., 2019).

Although there are some works in Brazil for correcting soils with high pH values, there are no precise answers regarding the time to reduce the pH to the ideal range. Leite et al. (2010) observed reduction in pH values from 9.2 to values below 7 in 155 days after the application of sulfuric acid in an experiment conducted in a greenhouse in the municipality of Areia, Paraíba state, Brazil. Severo et al. (2019) verified that 58 days were necessary to reduce the pH from 10.15 to 6.5 after the application of sulfuric acid in a Fluvent soil with a sandy-loam texture, in an experiment carried out in a greenhouse in the municipality of Pombal, Paraíba state, Brazil. In addition, there is no established methodology to calculate the amount of sulfur acid for pH reduction. Therefore, over-liming should be avoided.

Considering these implications, LR established through zoning allows the application of limestone in a more specific and regionalized way. The use of this technique for applying limestone is totally executable since liming is performed manually in the São Francisco River Valley.

Conclusions

1. The use of classical statistics would not be appropriate for liming recommendation in mango fields in the São Francisco River Valley region since the errors would cause either under- or over-liming, which may prevent the plant from expressing its full production potential.

2. The use of precision farming techniques to delineate management zones was adequate to separate the areas into smaller and more homogeneous zones, for a more precise recommendation of liming.

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