Revista Ciência Agronômica, v. 53, e20207293, 2022
Centro de Ciências Agrárias - Universidade Federal do Ceará, Fortaleza, CE
www.ccarevista.ufc.br

Scientific Article
ISSN 1806-6690

Spatial distribution of soil attributes and macronutrients in banana leaves under the application of limestone[1]

Distribuição espacial de atributos do solo e macronutrientes em folhas de bananeira sob aplicação de calcário

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ABSTRACT - The aim of the present study was to evaluate the spatial variability of the chemical attributes of the soil and macronutrients in leaves by means of the geostatistic analysis of a soil cultivated with banana in an area with two different methods of applying corrective. The study was carried out in the district of Cristino Castro, Piauí, where 21 soil samples were collected at a depth of 0.00-0.20 m from an area of incorporated limestone, and 21 samples from an area without limestone on the surface, giving a total of 42 duly georeferenced points. The following were analysed in the soil samples: pH, OM, P, K^+, Ca^{2+}, Mg^{2+}, Al^{3+}, H+Al; and the sum of bases, cation exchange capacity and base saturation were calculated. The Ca^{2+}, Mg^{2+}, K^+ and P content was determined in leaves collected from the same locations as the soil. The results were investigated using analysis of variance, descriptive analysis and geostatistics, and by interpretating the levels of the chemical attributes of the soil and plants. The chemical attributes and nutrient content of the leaves showed a significant variation in the study areas. The use of geostatistics allowed zones with different patterns of behaviour to be identified, which can help in the specific management of soil correctives and fertiliser using precision agriculture. The spatial variability of Ca^{2+} in the soil was similar to the variability of the nutrient in the banana leaves.

Key words: Liming. Nutrient levels. Precision Agriculture, *Musa spp* L.

RESUMO - O presente estudo teve como objetivo avaliar a variabilidade espacial de atributos químicos do solo e macronutrientes nas folhas por meio da análise da geoestatística em um solo cultivado com bananeira em uma área com diferentes modos de aplicação de corretivo. O trabalho foi conduzido no município de Cristino Castro-PI, sendo coletada 21 amostras de solo da área com calcário incorporado e 21 da área sem calcário em superfície, na profundidade de 0,00-0,20 m, totalizando 42 pontos devidamente georreferenciado. Nas amostras de solo foram analisados: pH, MO, P, K^+, Ca^{2+}, Mg^{2+}, Al^{3+}, H+Al e calculado soma de bases, capacidade de troca catiônica e saturação por base. Os teores de Ca^{2+}, Mg^{2+}, K^+ e P foleares, foram determinados em folhas coletadas nos mesmos pontos em que foram coletados solo. Os resultados foram analisados por meio da análise de variância, análise descritiva, geoestatística e interpretação dos níveis dos atributos químicos do solo e teores na planta. Os atributos químicos do solo e teores de nutrientes foliares tiveram variação significativa nas áreas estudada. O uso da geoestatística permitiu identificar zonas com diferentes padrões de comportamento o que pode auxiliar no manejo específico de correção e adubação do solo por meio da agricultura de precisão. A variabilidade espacial de Ca^{2+} no solo foi semelhante a variabilidade desse nutriente nas folhas de bananeira.

Palavras-chave: Calagem. Níveis de nutrientes. Agricultura de precisão. *Musa spp* L.

DOI: 10.5935/1806-6690.20220047
Editor-in-Chief: Prof. Alek Sandro Dutra - alekdutra@ufc.br
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Received for publication in 07/04/2020; approved in 15/02/2022

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INTRODUCTION

The banana (*Musa spp*) is important on the domestic market, with a production of over seven million tons in 2019 (IBGE, 2020). Banana farming in the north-east of the country is currently seen as a strong agricultural activity, especially in new areas of cultivation, such as in the south-west of the state of Piauí, and in areas with the potential for irrigated crops, making the region a significant domestic producer of the banana (CONAB, 2019).

Agricultural production has been undergoing major changes, which have allowed for increased productivity, better quality of the harvested product, and meeting the concepts of environmental sustainability (MISGINA, 2016). Many factors are involved in growing crops, and important among them is the application of fertiliser. This is because most products come from non-renewable resources and represent a high cost in the production process.

Despite advances in research into the production of new fertilisers, various factors, such as a pH of less than 5 and the presence of hydrogen ions, can negatively affect the availability and absorption of nutrients by plants (SINGH *et al*., 2017). Liming, which consists in the application of limestone to raise the pH and, consequently, the concentration of calcium and/or magnesium in the soil, is one of the alternatives that have contributed to better chemical soil conditioning in the Cerrado region, allowing different crops to be grown (BERNARDI *et al*., 2018), among them the banana, which requires ideal conditions to achieve good production.

Despite being one of the main practices for improving the chemical conditions of low-fertility soils, the method of application and the amount to be applied should take certain technical criteria into consideration. Some studies differ regarding the recommendation of whether limestone should be applied to the surface or incorporated in the most varied types of soil. Nobile *et al*. (2017), claim that simply applying limestone to the surface did not change the chemical attributes of the soil in the 0.0 to 0.20 or 0.20 to 0.40 m layers. Campos *et al*. (2011) found that the surface application of limestone promoted an improvement in the chemical conditions of the soil used for cultivating plants to a depth of 0.20 m. According to Sousa and Lobato (2004), the ideal levels of calcium and magnesium for the banana are around 5 $cmol_c$ for calcium and 1.5 $cmol_c$ for Mg, with a base saturation of 50%.

The spatial variability of the chemical attributes of soils is another factor that can compromise the efficiency of applying correctives and fertilisers, thereby affecting crop yields (LI *et al*., 2019; SANCHEZ *et al*., 2012). According to Carneiro *et al*. (2016), this variability can be caused by natural factors or human action such as the processes and factors of soil formation or the application of fertilisers, especially when applied indiscriminately.

Geostatistics is an ideal tool for the assessment and study of the spatial variability of soils and plants in agricultural areas (FAR; REZAEI-MOGHADDAM, 2018). By means of geostatistics, it is possible to identify areas with different patterns of fertility, allowing for regionalised fertility management. This is not possible with conventional soil fertility management, which is based on the use of average reference levels of nutrients to calculate the quantity of inputs to be applied (SANCHEZ *et al*., 2012).

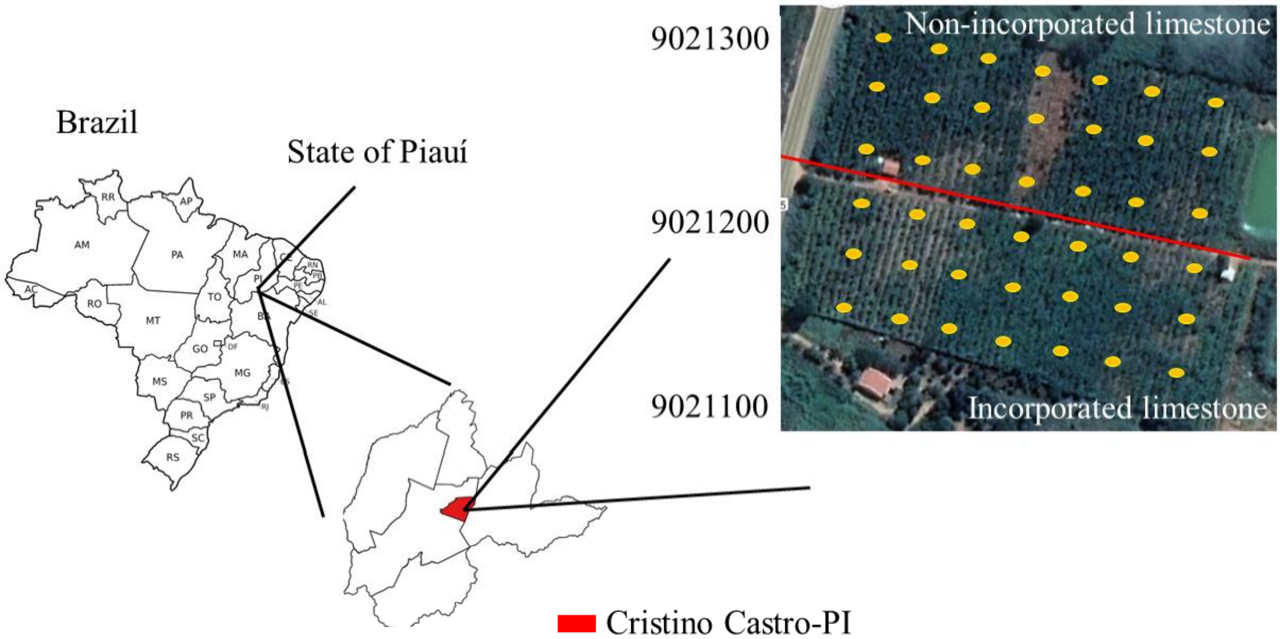
Studies of spatial variability are mainly focused on well-established areas that are cultivated with major commodities. However, studies that focus on fruit cultivation, for example the banana, are still scarce, especially in areas with the potential for agricultural expansion (SONG *et al*., 2019). Such studies would allow the appropriate and efficient use of inputs. The aim of this study, therefore, was to describe the spatial variability of the chemical attributes of the soil and banana leaves using geostatistics, in an area of banana cultivation with different methods of applying corrective, with a view to the variable-rate application of fertilisers.

MATERIAL AND METHODS

The study was carried out in the south-west of the state of Piauí, in the district of Cristino Castro, located at 8°49’ S and 44°13’ W, at altitude of approximately 223 m (Figure 1). The study site is a transition region between the Cerrado and Caatinga biomes. The soil was classified as a Fluvic Neosol (SANTOS *et al*., 2018). The climate in the region has a dry season during the winter and a hot and rainy summer, with an average temperature of 27 °C and average accumulated annual rainfall of 900 mm, being classified as type Aw acccording to the Köppen classification (1936).

The soil and leaf samples were collected in a 5 ha area of banana plantation that included the ‘Prata’, ‘Apple’ and ‘Grand Nain’ varieties. These were planted in 2016, in single rows, at a spacing of 3 m between the plants and 5 m between the rows, which were irrigated by sprinkler. The experimental area, which consisted of native forest before installing the orchard, was divided into two sub-areas. In the first, 4 t ha^{-1} dolomitic limestone was applied over the whole area and later incorporated into the soil by harrowing (I). In the second area, 4 t ha^{-1} of the same limestone was applied to the rows without being incorporated (NI). In both areas, 0.2 kg single superphosphate and 0.2 kg monoammonium phosphate were applied per hole. Each month, 50 kg ha^{-1} of 20-00-20 formula were applied via fertigation.

Figure 1 - Location of the district of Cristino Castro, Piauí, showing the study area



Forty-two duly georeferenced points were marked out in the study area using a 35 x 30 m regular sampling grid. For each point in each sub-area, 21 composite samples were collected in the 0.00-0.20 m layer two years after applying the limestone. Each composite sample was the result of five single samples, spaced 0.50 m from the mother plant.

After collection, the soil samples were sent to the laboratory, where they were air-dried and sieved through a 2 mm mesh. The following chemical attributes were then determined: hydrogen potential (pH) in water in the proportion 1:2.5; aluminium content (Al^{3+}); potential acidity (H+Al); phosphorus (P) and potassium (K^+) using Mehlich 1 solution; calcium (Ca^{2+}) and magnesium (Mg^{2+}) using a 1M KCl solution; and organic matter (OM). With the above results, the sum of bases (SB), cation exchange capacity (CEC) and base saturation (V%) were also calculated as per the methodology proposed by Teixeira *et al*. (2017).

To determine the nutritional content of the plants, 42 leaf samples were collected at the same points as the soil samples. As per the methodology proposed by Sousa and Lobato (2004), the middle part of the leaf blade was used, discarding the midrib of the third leaf from the apex, when the plants were at the start of inflorescence.

The leaves were washed with distilled water to avoid possible contamination by residue. They were then dried at 65 °C in a forced air circulation oven to constant weight. After drying, the leaves were ground, and the levels of P, K^+, Ca^{2+} and Mg^{2+} were determined following the methodology proposed by Silva *et al*. (2009).

The results were submitted to analysis of variance, comparing the chemical attributes of the soil between the areas of incorporated and non-incorporated limestone using the F-test at 5% probability. Each subarea was analysed using descriptive statistics, calculating measurements of location (mean and median), variability (coefficient of variation) and central tendency (asymmetry and kurtosis) using the Minitab® software. In addition, the Kolmogorov-Smirnov test was carried out to verify the normality of the attributes under evaluation. The coefficient of variation (CV) was classified as per Warrick and Nielsen (1980), where values of between 12% and 60% are considered average, and values less and greater than this range are classified as low and high, respectively.

Spatial dependence was analysed by means of adjustments to the semivariograms (VIEIRA, 2000), based on the assumption of stationarity for the intrinsic hypothesis estimated by (Equation 01). The GS+® software was used to obtain the semivariograms. The following models were fitted to the data: spherical, exponential and Gaussian. The theoretical models were chosen by observing the sum of squared residuals, the coefficient of determination (R^2) and the correlation coefficient, obtained using the technique of cross-validation (CVRC). By means of the generated semivariogram models, each attribute in the unsampled areas was predicted via kriging, and represented on contour maps using the Surfer® Golden software (2014).

$$\hat{\gamma}(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[Z(X_1) - Z(X_1 + h) \right]^2 \quad (1)$$

The degree of spatial dependence (DSD) was classified based on the ratio between the nugget effect and the sill using the mathematical formula $(C_0/C_0+C_1)*100$, with values of less than 25% considered strong, between 25% and 75% moderate, and greater than 75% weak (CAMBARDELLA *et al.*, 1994). The levels of macronutrients in the soil and leaves were then determined using the method proposed by Sousa and Lobato (2004). An analysis of the chemical attributes in the two subareas was also carried out in order to observe the differences between the methods of applying corrective.

RESULTS AND DISCUSSION

Descriptive statistics and analysis of variance

Analysis of variance of the parameters pH, Ca^{2+}, Mg^{2+}, OM, SB and V% by F-test at 5% probability, shows that the values for these attributes were higher in the area where the corrective had been incorporated (Table 1). The levels of Al^{3+} and H+Al were higher in the area with no incorporation. It should be noted that for the purposes of agricultural cultivation, it is important that the levels of Al^{3+} and the potential acidity be reduced as much as possible to avoid toxicity to the plants, and that, in turn, the plants have a more suitable environment for their development (BERNARDI *et al*., 2018).

The results corroborate those of Caires *et al*. (2015) and Nobile *et al*. (2017), who concluded that

Table 1 - Descriptive statistics of the chemical attributes of soil cultivated with banana in an area with incorporated (I) and non-incorporated (NI) limestone

Attribute	Area	Mean	Median	SD	CV	Cs	Ck	KS
pH	I	5.77 a	5.89	0.51	8	0.35	0.56	0.153^{ns}
	NI	5.13 b	5.04	0.51	10	0.98	0.64	0.147^{ns}
OM (g kg^{-1})	I	5.60 a	5.25	2.78	49	0.72	-0.33	0.169^{ns}
	NI	4.10 b	4.19	0.92	22	-1.12	0.99	0.170^{ns}
P (mg kg^{-1})	I	8.45 a	8.18	6.13	72	0.82	-0.41	0.182^{ns}
	NI	11.29 a	7.07	8.70	77	0.69	-1.15	0.302**
K^+ ($cmol_c$ dm^{-3})	I	0.06 b	0.06	0.03	46	0.08	-0.17	0.200**
	NI	0.10 a	0.10	0.03	35	0.76	0.38	0.199^{ns}
Ca^{2+} ($cmol_c$ dm^{-3})	I	1.41 a	1.24	0.80	56	0.91	0.28	0.181^{ns}
	NI	0.33 b	0.31	0.28	84	1.30	2.03	0.158^{ns}
Mg^{2+} ($cmol_c$ dm^{-3})	I	0.41 a	0.43	0.23	55	0.06	-0.75	0.078^{ns}
	NI	0.19 b	0.16	0.10	53	1.02	0.49	0.170^{ns}
Na^+ ($cmol_c$ dm^{-3})	I	0.02 a	0.01	0.02	80	1.93	3.10	0.223**
	NI	0.01 a	0.01	0.01	62	1.81	4.84	0.162^{ns}
Al^{3+} ($cmol_c$ dm^{-3})	I	0.00 b	0.00	0.00	-	-	-	-
	NI	0.19 a	0.20	0.19	102	0.46	-1.09	0.265**
H + Al ($cmol_c$ dm^{-3})	I	1.47 b	1.57	0.66	45	1.40	3.44	0.159^{ns}
	NI	2.21 a	2.26	0.73	33	0.04	-0.72	0.103^{ns}
SB ($cmol_c$ dm^{-3})	I	1.91 a	1.71	0.97	51	0.92	0.57	0.159^{ns}
	NI	0.66 b	0.61	0.32	49	0.95	1.07	0.120^{ns}
CEC ($cmol_c$ dm^{-3})	I	3.43 a	3.05	1.38	40	1.52	2.56	0.179^{ns}
	NI	2.96 a	2.82	0.87	29	1.01	0.83	0.125^{ns}
V %	I	53.34 a	50.66	15.77	29	0.53	0.49	0.105^{ns}
	NI	25.52 b	22.41	13.67	53	0.93	0.22	0.126^{ns}

Attributes with the same following mean values do not differ by analysis of variance. SD = standard deviation; CV = coefficient of variation; Cs = asymmetry; Ck = kurtosis; KS = Kolmogorov-Smirnov test statistics; * = significant at ($p < 0.05$); ^{ns} = not significant incorporating corrective promotes greater neutralisation of the soil acidity and increased levels of exchangeable Ca^{2+} to a depth of 0.2 m. Whereas the effect of applying the corrective with no incorporation was restricted to the surface layer, probably due to the low solubility of the limestone and the smaller area of contact of the corrective with the soil particles, thereby prolonging the reaction period of the corrective. Campos *et al*. (2011) reported that surface correction can be efficient, however, it should be carried out over many years and in instalments, especially in areas with sandy-textured soils.

Analysis of variance of the leaf attributes (Table 2) by F-test at 5% probability showed that Ca^{2+} and P were also more highly concentrated in the area where the corrective was incorporated, showing greater availability of these nutrients, confirming the effect on soil acidity of applying limestone, and consequently promoting nutrient availability to the plants and improving the levels present in the banana leaves. Limestone and P have low mobility in the soil when applied to the surface, and their availability may be limited to the surface layer only, making absorption by the roots difficult (CAMPOS *et al*., 2011).

Classification of the mean levels of the soil attributes as per the interpretation proposed by Sousa and Lobato (2004) shows that in Area I the attributes most influenced by the application of limestone, namely pH, CEC and V%, achieved an interpretation that was closer to the ideal conditions for cultivating the crop, with a pH close to 5.5, CEC between 4.1 and 6 for sandy soils, and a V% of 60%. With the exception of K^+, the other attributes had the same interpretation, always below the appropriate levels for crop development, probably a reflection of the small amount of fertiliser applied during cultivation (Table 1).

Interpretation of the leaf content shows that the levels of Ca^{2+} and P were determined to be adequate for the banana in each of the two areas, while Mg^{2+} was classified as low (Table 2), adequate levels being 1.8 to 2.7 g kg^{-1} for P, 3 to 6 g kg^{-1} for Ca^{2+}, and 2 to 8 g kg^{-1} for Mg^{2+}. In turn, K^+ was similar to the behaviour of the element in the soil, where higher concentrations in the leaves were seen in Area NI, probably due to the smaller losses of this element in the soil, which remains available for a longer period.

In general, it appears that incorporating limestone promotes better results regarding the correction of soil acidity and the availability of some nutrients, compared with not incorporating the limestone. In addition, other factors such as texture, soil compaction and the slope of the area can interfere with the efficiency of surface liming as these can reduce water infiltration and favour the loss of inputs when erosion occurs (ALVAREZ *et al*., 2015).

In banana farming, the application of inputs generally occurs within the canopy projection, which can increase efficiency over time. However, the banana has the characteristic of 'moving' in the area due to the tillers always appearing next to the older plants, modifying the area where the input is applied for each harvest. This can limit the efficiency of soil correction when there is no incorporation, as well as the application of fertiliser to areas with previously established orchards. With greater nutrient availability, the plants can benefit and give greater production.

It can be seen that the mean and median values of the attributes under evaluation were similar in both Area I and Area NI (Table 1). The coefficients of asymmetry and kurtosis for most of the attributes under study presented values close to zero. In Area I, the attributes H + Al and CEC stand out with a higher coefficient of asymmetry, as do the attributes Na^+ and Ca^{2+} in Area NI.

The values for the coefficients of asymmetry and kurtosis in this study demonstrate that most of the attributes

Table 2 - Descriptive statistics and analysis of variance at $p < 0.05$ of the nutritional content of banana leaves in a cultivated area with the application of incorporated (I) and non-incorporated (NI) corrective

Attribute	Area	Mean	Median	SD	CV	Cs	Ck	KS
P (g kg^{-1})	I	1.892 a	1.897	0.20	10.78	-0.14	-0.3	0.116^{ns}
	NI	1.594 b	1.582	0.26	16.46	-0.21	-0.46	0.093^{ns}
K^+ (g kg^{-1})	I	25.32 b	24.00	11.87	46.91	0.08	-0.17	0.200**
	NI	45.50 a	42.50	23.07	50.71	1.42	1.61	0.226**
Ca^{2+} (g kg^{-1})	I	2.093 a	2.046	0.289	13.82	0.19	1.36	0.169^{ns}
	NI	1.722 b	1.695	0.280	16.27	0.11	-0.84	0.076^{ns}
Mg^{2+} (g kg^{-1})	I	2.95 a	3.04	1.49	50.75	-0.38	-0.46	0.127^{ns}
	NI	2.54 a	2.44	0.96	38.03	0.06	-0.27	0.099^{ns}

Attributes with the same letters following the mean values do not differ by analysis of variance. SD = standard deviation; CV = coefficient of variation; Cs = asymmetry; Ck = kurtosis; KS = Kolmogorov-Smirnov test statistics; * = significant at ($p < 0.05$); ^{ns} = not significant under study had a normal and symmetrical distribution. The Kolmogorov-Smirnov normality test showed that of the soil attributes, only Na^+ and K^+ in Area I, and P and Al^{3+} in Area NI did not have a normal distribution; while for the leaf nutrients, only K^+ did not have a normal distribution in either area (Table 2). According to Carneiro *et al*. (2016), a lack of normality can occur due to natural variation in the processes of soil formation, or even due to soil management and fertilisation; however, for geostatistics it is necessary for the attributes to show a variation with spatial dependence.

Among the chemical attributes of the soil, only pH had a low coefficient of variation (< 12%) according to the classification by Warrick and Nielsen (1980). This result corroborates that of Carneiro *et al*. (2016), when studying the spatial variability of chemical attributes and fertility management in a dystrophic Red Latosol in the Cerrado region of Piauí. The low CV for the soil pH possibly occurred due to this attribute having naturally low spatial variability compared to other chemical attributes, where the variation depends on the processes of soil formation, as noted by Bottega *et al*. (2013).

Na^+ and P in Area I, and Ca^{2+}, Na^+, P and Al^{3+} in Area NI, had a CV greater than 60%, showing the high spatial variation of these attributes in the study area. The other attributes presented a CV between 12% and 60%, and were considered of average variation in both areas. Al^{3+} was highlighted in Area I, where the mean value was zero, showing that the element was completely neutralised due to incorporation of the corrective. Studies by Goenster Jordan *et al*. (2018) show pronounced differences in the variability of the chemical attributes of the soil in the study area, and that each attribute can have a different variation, demonstrating that in addition to environmental factors, the management adopted in the area of cultivation can contribute to the spatial variation of the soil attributes.

In the leaves, only P in Area I had a low CV, the other nutrients showing medium variation. The existence of variability in the soil attributes and in the leaf nutrients shows that the distribution of these nutrients is heterogeneous, i.e. the soil attributes and leaf nutrients in the area under study have different spatial values, the heterogeneity being more marked in attributes with a high CV. This heterogeneity of the soil attributes may be related to the source material of the soil and also to other factors such as correction management, the fertiliser used, slope of the area, and sediment deposition and soil texture (GÃO *et al*., 2019). Also important in the case of Area I are the different methods of applying the limestone and the presence of sediment deposited over time.

Geostatistical analysis

The values for the nugget effect (C_0), sill (C_0+C_1), range, adjusted semivariogram models, degree of spatial dependence (DSD) and cross-validation regression coefficients (CVRC) in the geostatistical analysis are shown in Table 3. With the exception of P, K^+, and Al^{3+} in the soil and K^+ in the leaves, the other soil and leaf attributes adjusted to a semivariogram model. The adjustment of these attributes indicates that the sampling grid was suitable for both areas.

All the soil attributes that showed spatial dependence adjust to the spherical or Gaussian model (Table 3). Freitas *et al*. (2017), note that the spherical model generally best fits the chemical attributes, as they show abrupt changes in the soil. Of the leaf nutrients, only Ca^{2+} presented a spherical model, Mg^{2+} and P adjusted to the exponential model. The results for R^2, CVRC and DSD show that the semivariogram models agree with those established for the parameters of geostatistics.

The DSD indicates the magnitude of the spatial continuity of an attribute in an area, where the stronger the dependence, the greater the reliability of the semivariograms and, consequently, of the isoline maps (Table 3). In the study area, Mg^{2+} in Area I and H + Al showed a moderate DSD, and only CEC in Area NI showed a low DSD. The other soil attributes and all of the leaf attributes had a high value for DSD.

Previous studies have shown that chemical attributes show different behaviour regarding DSD, as reported by Gazala *et al*. (2017) and Gão *et al*. (2019). According to Siqueira *et al*. (2010), several factors can influence the DSD of the attributes, such as soil texture or the processes of soil formation, which may result in the attributes showing stronger dependence, whereas anthropogenic activities, which are often localised, such as soil management and the application of inputs, are related to low spatial dependence.

For the soil attributes in Area I, pH had the lowest range at 69 m, and Mg^{2+} had the highest at 114 m. In Area NI, Mg^{2+}, K^+ and CEC had the lowest values for range (59, 64 and 72 m, respectively); Ca^{2+}, Na^+, SB and V% had the greatest range, with values of 119, 159, 183 and 116 m respectively. The range for the nutrient content of the leaves was 209, 93 and 121 m, respectively, for Ca^{2+}, Mg^{2+} and P. Range is a parameter that indicates the distance within which the samples are spatially correlated (CORRÊA *et al*., 2017).

Therefore, after adjustments to the semivariogram and verification of the spatial dependence of the attributes, with some variables showing a strong DSD, it was possible to determine the spatial variability and mapping of specific management zones in the study area (Figure 2). It is important to highlight the difference in the range of the soil and leaf macronutrients, demonstrating that maps of management zones specific to the attributes under study may show a different spatial variation.

Table 3 - Models and semivariogram parameters of soil chemical attributes and leaf content in banana cultivated in areas with incorporated (I) and non-incorporated (NI) limestone

Variable	Area	C_0	$C_1 + C_0$	DSD	Range (m)	Model	R^2	CVRC	
								a	b
Soil									
pH	I	0.01400	0.2040	6.86	69	Spherical	0.92	2.93	0.49
	NI	0.01800	0.3780	4.76	84	Gaussian	1.00	0.32	0.95
OM	I	0.01000	11.130	0.09	81	Spherical	0.89	0.45	0.92
	NI	0.00100	0.9410	0.11	68	Gaussian	0.57	1.20	0.71
P	I	-	-	-	-	PNE	-	-	-
	NI	0.10000	75.8000	0.13	81	Gaussian	0.43	0.38	1.03
K^+	I	-	-	-	-	PNE	-	-	-
	NI	0.00001	0.0059	0.17	65	Gaussian	0.65	0.02	0.80
Ca^{2+}	I	0.00100	3.2360	0.03	91	Gaussian	0.85	0.02	1.00
	NI	0.00010	0.6530	0.02	119	Spherical	0.90	0.09	0.73
Mg^{2+}	I	0.02000	0.0520	38.46	114	Spherical	0.86	0.14	0.66
	NI	0.04360	0.1770	24.63	59	Gaussian	0.63	0.03	0.85
Na^+	I	0.000001	0.0004	0.24	74	Gaussian	0.62	0.00	1.00
	NI	0.00010	0.0100	1.00	159	Spherical	0.93	0.00	0.95
Al^{3+}	I	-	-	-	-	PNE	-	-	-
	NI	0.00420	0.0610	6.89	92	Gaussian	0.99	0.00	1.00
H + Al	I	0.00100	0.5610	0.18	78	Spherical	0.89	0.21	0.86
	NI	0.30450	0.6100	49.92	98	Spherical	0.88	0.03	0.98
SB	I	0.01000	3.6700	0.27	88	Gaussian	0.87	0.18	0.91
	NI	0.04360	0.1772	24.60	193	Gaussian	0.93	0.31	0.53
CEC	I	0.01000	6.7190	0.15	87	Gaussian	0.88	0.13	0.99
	NI	0.46000	0.5990	76.79	72	Spherical	0.78	-0.20	1.09
V%	I	-	-	-	-	PNE	-	-	-
	NI	11.20000	86.8400	12.90	116	Spherical	0.94	0.72	0.98
Plant									
P	I + NI	0.0103	0.0921	11.2	121	Exponential	0.97	0.37	0.70
K^+	I + NI	-	-	-	-	PNE	-	-	-
Ca^{2+}	I + NI	1.8700	16.2000	11.5	209	Exponential	0.97	3.03	0.84
Mg^{2+}	I + NI	0.0590	1.3610	4.3	93	Spherical	0.87	0.87	0.70

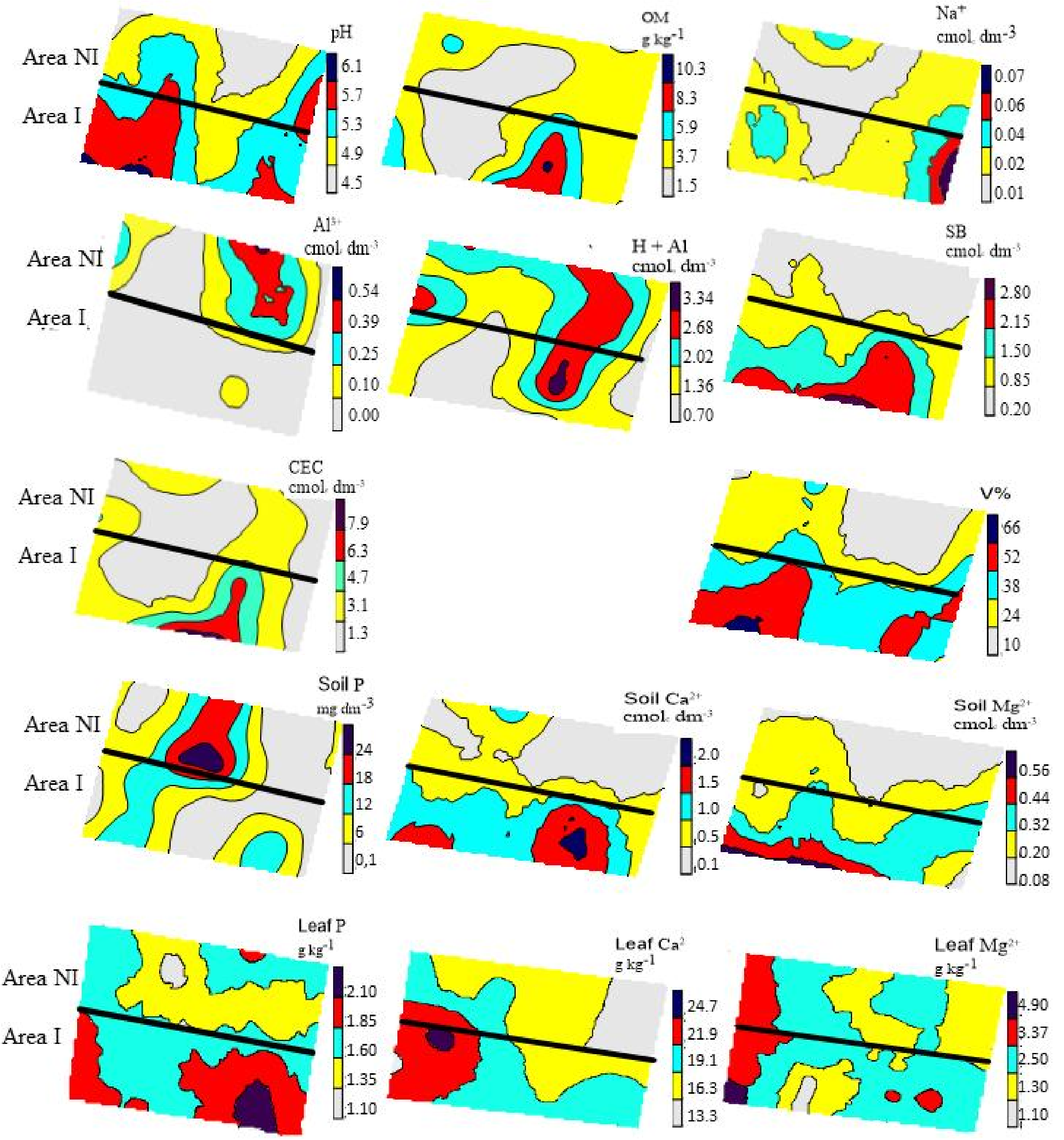
PNE = pure nugget effect; C_0= nugget effect; $C_0 + C_1$ = sill; DSD = degree of spatial dependence; R^2 = coefficient of determination of the model; CVRC = cross-validation regression coefficient; a = intercept; b = slope

The isoline maps were prepared using all the sampling points in order to show the distribution of the attributes in the two areas and confirm the results shown by the descriptive statistics and analysis of variance. Matias *et al*. (2014), studying the behaviour of the geomorphic surface at three different positions, concluded that it is possible to separate several areas on one map of spatial variability. They found that the geomorphic surfaces coincide with the compartments of controlled variability, suggesting that the variability of the soil attributes shows spatial agreement with the boundaries between the geomorphic surfaces in the field (MATIAS *et al*., 2014). In the present study, differences were seen in the areas with and without limestone, indicating that regardless of whether the maps were combined or separated into two areas, there is still a difference between the areas (Figure 2), confirming the result of Table 3. Figure 2 shows a similarity between the zones of variation for Ca^{2+} and Mg^{2+} in the soil, Ca^{2+} in the leaves, and the value for pH, indicating a correlation between these attributes.

In the upper part of the study area (NI), corresponding to where the corrective was applied without being incorporated, the map shows the lowest values for pH and for the concentrations of Mg^{2+} and Ca^{2+} in both the soil and the leaves, while in the lower part, where the corrective was incorporated (I), the values are higher.

Interpretating nutrient levels for the purposes of recommendation

Figure 2 - Variability maps for soil pH (H_2O), organic matter (OM), calcium (Ca^{2+}), magnesium (Mg^{2+}), phosphorus (P), potassium (K), sodium (Na^+), aluminium (Al^{3+}) hydrogen+aluminum (H + Al), base saturation (V%), sum of bases (SB), cation exchange capacity (CEC) and the nutrients in banana leaves, in areas with incorporated (I) and non-incorporated (NI) corrective



The variability of the soil nutrients allowed the macronutrients to be classified in different classes, which, as per the classification proposed by Sousa and Lobato (2004), ranged from very low to adequate. Figure 2 shows the different zones formed by variations in the concentration of the elements in the soil. According to Vasu *et al*. (2017), using isoline maps that make it possible to identify and delineate areas with different patterns of spatial behaviour can help to better manage soil fertility, such as employing the technique of precision agriculture.

The concentrations of Ca^{2+} and Mg^{2+} in the soil ranged from 0.1 to 1.79 and 0.1 to 0.6 $cmol_c\ dm^{-1}$ respectively, presenting zones with low levels and another with adequate levels based on the interpretation tables proposed by Sousa and lobato (2004), where adequate levels for Ca^{2+} are between 1.5 to 7 $cmol_c\ dm^{-1}$ and for Mg^{2+} 0.5 to 2 $cmol_c\ dm^{-1}$. The behaviour of these elements in the leaves was similar to that in the soil, where, as discussed above, the highest levels were seen in the area of incorporated limestone. P in the soil had levels that varied between 0.5 and 24 mg kg^{-1}, presenting zones with very low levels and one zone of medium level. P levels in the leaves varied, and were interpreted as low, with one other zone where the level was adequate for the banana.

The maps (Figure 2) show that Al^{3+} and H + Al had higher values in the area where the corrective had been applied without being incorporated, while in the same area the values of pH, SB, V% and CEC were lower compared to the area where the corrective had been incorporated, confirming the efficiency of incorporation - data that corroborate those of Nobile *et al*. (2017).

CONCLUSIONS

1. The variation in soil attributes follows the method of limestone application;
2. Soil correction based on spatial variability allows limestone to be applied as required by the banana crop, avoiding any excess or deficit;
3. The variability of Ca^{2+} in the soil was similar to the variability of the nutrient in the banana leaves.

ACKNOWLEDGEMENTS

The authors wish to thank the Federal University of Piauí (UFPI) and the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (Processo no. 88887.467428/2019-00) for their support in carrying out this study.

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