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Scientific Article
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Fertility variability in a Latosol cultivated with fertigated banana[1]

Variabilidade da fertilidade de um Latossolo cultivado com bananeira fertirrigada

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ABSTRACT - Banana production requires strategies to assess the variability of fertigation areas since production can be reduced by consecutive cultivation in chemically-restricted soils and at different elevations. From this perspective, this study aimed to investigate the spatial variability of soil chemical attributes and the soil carbon stock and relate these parameters to the elevation of a banana plantation fertigated by a micro-sprinkler system. The study was conducted at the Irrigation Perimeter Nupeba (Riachão das Neves/BA), in an area cultivated with the banana cultivar Prata for 18 years. In April 2017, single soil samples were collected in an area with a minimum elevation of 440.6 m and a maximum of 445.8 m, at the depths of 0-0.20 m and 0.20-0.40 m, with a sampling grid composed of 40 georeferenced points and spaced 10 meters. The following parameters were determined: pH, total organic carbon (COT), soil organic matter (OM), nitrogen (N), phosphorus (P), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), aluminum (Al^{3+}), potential acidity (H+Al), sum of bases (SB), cation exchange capacity (CEC), base saturation (V%), and carbon stock (Est C). The data were evaluated by descriptive statistics and geostatistics and showed normal distribution. There was spatial variability, allowing the construction of fertility maps. The maps showed that the elevation especially influences the OM, COT, N, and Est C, also showing the distribution and concentration of nutrients in the soil, allowing to minimize the variability through the application of varied nutrient contents aiming at their homogeneous supply to banana plants.

Key words: *Musa* spp. Geostatistics. Elevation. Soil nutrients.

RESUMO - A produção de bananas requer estratégias que melhor identifiquem a variabilidade das áreas fertirrigadas, considerando que a produção pode ser reduzida mediante cultivo consecutivo em solos com restrições químicas e de diferentes altitudes. Objetivou-se estudar a variabilidade espacial dos atributos químicos e estoque de carbono do solo e relacioná-los à altitude de um bananal fertirrigado por microaspersão. O estudo foi realizado em perímetro irrigado de Nupeba (Riachão das Neves/BA), em área cultivada há 18 anos com banana prata. Em abril de 2017, amostras simples de solo foram coletadas em área com altitude mínima de 440,6 m e máxima de 445,8 m, nas profundidades de 0-0,20 m e 0,20-0,40 m, com uma malha experimental composta por 40 pontos georreferenciados e espaçados a cada 10 metros. Foram determinados: pH, carbono orgânico total (COT), matéria orgânica do solo (OM), nitrogênio (N), fósforo (P), potássio (K^+), cálcio (Ca^{2+}), magnésio (Mg^{2+}), alumínio (Al^{3+}), acidez potencial (H+Al), soma de bases (SB), capacidade de troca catiônica (CEC), saturação por base (V%) e estoque de carbono (Est C). Os dados foram avaliados pelos métodos da estatística descritiva e geoestatística e apresentou distribuição normal. Houve variabilidade espacial, permitindo a elaboração de mapas de fertilidade. Os mapas apontaram que a altitude influencia principalmente a OM, COT, N e Est C, mostrando também a distribuição e a concentração dos nutrientes no solo, o que possibilita minimizar a variabilidade por meio da aplicação de fertilizantes em quantidades variadas, visando sua oferta homogênea às bananeiras.

Palavras-chave: *Musa* spp. Geoestatística. Altitude. Nutrientes no solo.

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INTRODUCTION

According to the Brazilian Institute of Geography and Statistics (2020), banana production (*Musa* spp.) in Brazil has grown significantly in recent years, increasing from 566,336 Mg in 2000 to 6,637,308 Mg in 2020. Most producing areas in Brazil are located in the Southeast and Northeast regions, mainly in the states of São Paulo and Bahia, which account for 15.3% and 13.3% of the national production, respectively.

In Bahia, where a tropical climate predominates, banana cultivation requires supplementary irrigation since evapotranspiration is higher than precipitation (OLIVEIRA *et al*., 2021). In addition, the rapid annual growth of banana demands significant soil nutrient levels, with fertigation emerging as a viable tool to supply the nutrient demands of this crop. In this scenario, due to the possibility of using local and split fertilization in fertigation systems, soil fertility evaluation is essential to standardize producing areas and improve the quality of banana plantations (ALVES *et al*., 2019). Fertigation brings benefits such as applying adequate fertilizer levels, especially if the irrigation system adopts a mulch cover (XAVIER *et al*., 2020), resulting in higher plant heights, increased yield, and higher water, nitrogen, and potassium-use efficiency by banana plants (SOUZA *et al*., 2021).

Another factor to be considered for the variability of nutrients and soil organic matter is the local topography, which influences soil properties by affecting the microclimate, drainage, outflow, erosion, and soil formation (ALMEIDA *et al*., 2019). Moreover, attention should be paid to areas with intensive banana cultivation, in which soil variability can be affected by particle size distribution (OLIVEIRA *et al*., 2013) and the depth and physical attributes of the soil, impacting plant roots (MIOTTI *et al*., 2013), in addition to the spatial variability of chemical attributes due to the microrelief (ARTUR *et al*., 2014).

Additionally, soil attributes can vary spatially on a reduced geographic scale due to management factors, e.g., fertigation and crop rotation (SILVA *et al*., 2018). Therefore, the analysis of the spatial variability of soil chemical attributes in the planting area is important to provide appropriate fertility management, allowing the localized application of nutrients in deficient places (MACEDO NETO *et al*., 2020; MATIAS *et al*., 2015).

From this perspective, banana production in Bahia requires strategies to optimize the viability assessment of fertigated areas since production can be reduced by consecutive cultivation in chemically restricted soils and at different elevations. Therefore, this study aimed to investigate the spatial viability of chemical attributes and the soil carbon stock and relate these parameters to the terrain elevation of banana plantations at the irrigation permitter Nupeba in the municipality of Riachão das Neves/BA to allow more specific correction, fertilization, or fertigation interventions for each area while considering their topography.

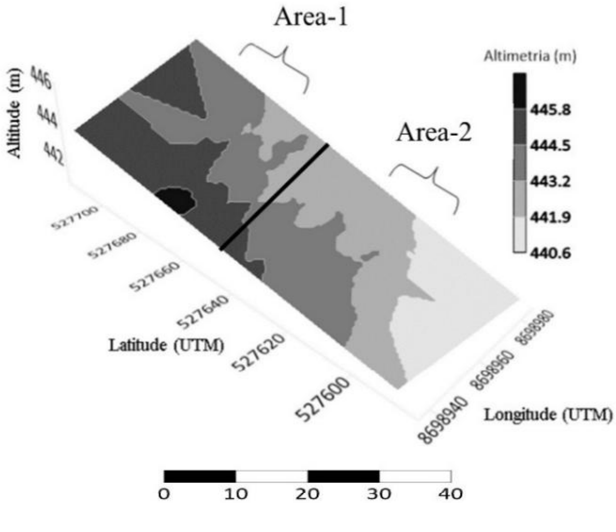
MATERIAL AND METHODS

The study was conducted in April 2017 at the Irrigation Perimeter Nupeba, managed by the Development Company of the São Francisco and Parnaíba Valleys (2020) in the municipality of Riachão das Neves (11°44’49’’S and 11°54’23’’W, 440 m of elevation), western Bahia. According to the current Köppen classification, the climate is classified as Aw, i.e., hot and semi-humid (ALVARES *et al*., 2013). The mean annual temperature is 27 °C, with a mean annual precipitation of 1,000 mm and a rainy season from October to April, with November, December, and January ranking as the rainiest months (INSTITUTO NACIONAL DE METEOROLOGIA, 2020). The soil was classified as a dystrophic RED-YELLOW LATOSOL with a clayey-sandy texture (SANTOS *et al*., 2018).

A Cerrado area of two hectares (Figure 1) cultivated with banana for eighteen years was selected for the study. The banana cultivar Prata was planted using a spacing of 2.4 m between plants and 2.0 and 4.0 m between single and double rows, respectively. The plants were irrigated by a micro-sprinkler system and received fertigation.

The area was initially divided into two parts (area-1 and area-2). Area-1 has a higher elevation (443.2 a 445.8 m), whereas area-2 has a lower elevation (440.6 to 443.2 m) (Figure 1).

Figure 1 - Location and geographic position of areas 1 and 2 in the study



According to the history of the area, 2 Mg of dolomitic limestone were applied throughout its entire extent (area-1 and area-2) in December 2015, in addition to the following fertilizers applied according to the crop production cycle: biweekly broadcast fertilization with 55 g of potassium chloride and 30 g of ammonium sulfate; monthly fertilization with 120 g of single superphosphate.

Soil samples were collected in January 2017 during the reproductive phase of the crop and before the beginning of fertigation at the 0-0.20 m depth. Soil analyses were performed according to the methods described by Teixeira *et al*. (2017), and the results are described in table 1.

The content of micronutrients used in the irrigation water and the parameters for the adequation and proper functioning of the fertigation system in the banana planting area obtained in February 2017, are shown in table 2.

For the evaluation of spatial variability, deformed single soil samples were collected in April 2017 (after harvest) from 40 georeferenced points distant 10 m from each other at the depths of 0-0.20 m and 0.20-0.40 m, totaling 80 samples, 40 for each depth. The soil samples were collected, air-dried, ground, macerated, and sieved through a 2 mm mesh (TFSA), after which they were sent to laboratory analyses.

According to the methods described by Teixeira *et al*. (2017), already informed in the soil characterization described in table 1, the following attributes were analyzed: pH in H_2O; calcium (Ca^{2+}) and magnesium (Mg^{2+}) extracted with potassium chloride (KCl) 1 mol L^{-1} and quantified by complexometric titration with EDTA; phosphorus (P), determined with Mehlich^{-1} extractor and colorimetric determination; potassium (K^+), extracted with a diluted solution of hydrochloric acid and determined by flame photometry; organic matter (OM), obtained by incineration in a muffle furnace and with results expressed as percentage (GOLDIN, 1987); carbon (C), obtained by high-temperature oxidation using potassium dichromate; potential acidity (H+Al), determined by extraction with a buffered calcium acetate solution at pH 7.0 and quantified by titration with sodium hydroxide (NaOH) and phenolphthalein as an indicator; and aluminum (Al^{3+}), determined by extraction with NaOH in the presence of bromothymol blue as an indicator. The sum of bases (SB), potential acidity (H+Al), cation exchange capacity (CEC), and base saturation (V) were also calculated.

The total nitrogen content (N) was quantified by sulfuric digestion and dosed by Kjeldahl distillation (BREMNER, 1996). The carbon stock (Est C) was determined by the equivalent soil mass procedure described by Ellert and Bettany (1995), using as reference the soil mass of a treatment, which is taken as the basis for calculating the stock in the remaining treatments through the following expression: Est C (Mg ha^{-1} = C content (g kg^{-1}) x Ds x E, where Ds = soil density (g cm^{-3}) and E = thickness (m) of the considered layer.

Table 1 - Results of the soil physicochemical analysis before fertigation in an area cultivated with banana for 18 years

pH	C	P	K	Ca	Mg	Al	SB	H + Al	CEC	V
H_2O	g kg^{-1}	mg dm^{-3}	---------- cmol$_c$ dm^{-3} ----------							(%)
4.30	15.00	1.00	0.27	1.60	0.70	1.60	2.57	8.40	10.97	23.43
S		Na	B	Fe			Mn	Cu		Zn
	---------- mg dm^{-3} ----------									
14.20		2.50	0.20	44.00			0.50	2.00		1.00
Silt		Clay	Fine sand	Coarse sand		Gravel		Densities		
								Soil (Ds)		Particle (Dp)
	---------- g kg^{-1} ----------									g cm^{-3}
171		518	137	174		0.00		1.10		2.70

SB – Sum of bases; H+Al – Potential acidity; CEC – Cation exchange capacity; V% - Base saturation. Source: Companhia de Desenvolvimento dos Vales do São Francisco e do Parnaíba (2020)

Table 2 - Micronutrients used in the irrigation water and fertigation parameters adopted for banana plants (Prata)

B Kg	Cu g	Mn Kg	Zn Kg	Dilution Liter	Conductivity dS m^{-1}	Fertigation time	Advancement time
1.40	800.00	11.60	2.80	440	0.96	32 min	18 min

B – Boron; Cu – Copper; Mn – Manganese; Zn – Zinc, Source: Companhia de Desenvolvimento dos Vales do São Francisco e do Parnaíba (2020)

Table 3 - Agronomic classification of the soil chemical attributes used to interpret the results for soil fertility evaluation in the present study

Variables	Agronomic Classification				
pH in H2O	Very high acidity	High acidity	Average	Weak	Alkaline
	< 4.50	4.50 – 50.0	5.10 – 6.00	6.10 – 6.90	> 7.00
	Very low	Low	Average	Good	Very good
K^+ cmolc dm^{-3}	< 0.50	0.50 – 1.00	1.00 – 2.00	-	> 2.00
P mg dm^{-3}	< 8.00	8.10 – 11.40	11.50 – 15.80	15.90 – 24.00	> 24.00
Ca^{2+} cmolc dm^{-3}	0.40	0.41 – 1.20	1.21 – 2.40	2.41 – 4.00	> 4.00
Mg^{2+} $cmol_c$ dm^{-3}	0.15	0.16 – 0.45	0.46 – 0.90	0.91 – 1.50	> 1.50
H+Al $cmol_c$ dm^{-3}	1.00	1.01 – 2.50	2.51 – 5.00	5.01 – 9.00	> 9.00
SB $cmol_c$ dm^{-3}	0.60	0.61 – 1.80	1.81 – 3.60	3.61 – 6.00	> 6.00
CEC $cmol_c$ dm^{-3}	1.60	1.61 – 4.30	4.31 – 8.60	8.61 – 15.00	> 15.00
V%	20.00	20.10 – 40.0	40.1 – 60.00	-	-

Source: Ribeiro, Guimarães and Alvarez (1999)

The statistical analysis was performed by a exploratory data study using the software MINITAB®, calculating the measures of location (mean, median, minimum, and maximum), the measures of variability (coefficient of variation – CV%), and the measures of central tendency (asymmetry and kurtosis) for verification of normality of the chemical attributes evaluated.

The semivariograms were obtained with the software GS+® (ROBERTSON, 2008), and the data were adjusted to the following models: (a) spheric, (b) exponential, and (c) gaussian. Based on these models, the attributes in non-sampled zones were predicted by kriging and represented in contour maps using the software SURFER®. The degree of spatial dependence (GDE) was classified based on the nugget effect and the threshold (C_0/C_0+C_1), with a weak dependence above 75%, moderate between 25% and 75%, and strong under 25% (CAMBARDELLA *et al*., 1994). In the spatial distribution maps of the soil chemical attributes, the contents were interpreted according to the Agronomic Classification description performed by Ribeiro, Guimarães end Alvares (1999), as seen in table 3.

RESULTS AND DISCUSSION

Descriptive statistics

The mean, variance, coefficient of variation, minimum value, maximum value, asymmetry, and kurtosis were estimated to assess the existence of central tendency and data dispersion. The mean and median values were similar for the soil chemical attributes, indicating symmetric data distribution (Table 4).

The zero value indicates symmetric distribution on both sides of the mean (TRIPATHI *et al*., 2015). When the values are positive, the distribution is asymmetric to the right; if negative, the distribution is asymmetric to the left (ZANÃO JÚNIOR *et al*., 2010). Both in area-1, with elevations higher than 443 m, and in area-2, with elevations between 440 and 443 m, 53% of the values expressed asymmetry to the right and 47% expressed asymmetry to the left. The P and K attributes in area-1 at the 0-0.20 m depth and P in area-2 at the 0.20-0.40 m depth showed positive values far from zero (Table 4).

The kurtosis values should be preferentially zero. However, values ranging from +2 to –2 are accepted, although they may indicate that the data are not normally distributed (OLIVEIRA *et al*., 2021). In area-1, at the 0-0.20 m depth, P and K showed kurtosis above +2, whereas, for 0.20-0.40 m, P, K, Mg, and Al were higher than +2. For area-2, at the 0-0.20 m depth, the values of P, Al, H+Al, and V% showed kurtosis above +2, whereas, at 0.20-0.40 m, the pH, OM, N, P, Mg, Al, COT, and Est C values resulted in kurtosis above +2 (Table 4).

At 0-0.20 m in area-1, the pH, OM, Ca, SB, CEC, V%, COT, and Est C showed coefficients of variation (CV%) under 30%. For area-2, only the pH, SB, CEC, and V% resulted in a CV% under 30%. At 0.20-0.40 m, the values of pH, Ca, SB, CEC, and V% (areas 1 and 2) showed CV% values under 30% (Table 4). The lowest CV% was observed for the pH, showing that this variable is the most homogeneous in the soil. The homogeneity of pH is related to the subtle slope of the area and the parent material from which the soil is formed (ABDELRAHMAN *et al*., 2021).

Table 4 - Descriptive statistics of the soil chemical attributes (area-1 and area-2) at the 0-0.20 m and 0.20-0.40 m depths

Variables	Area	Mean	Med.	Standard deviation	Min.	Max.	Ass.	Kur.	CV
Depth 0-0.20 m									
pH in H_2O	1	6.29	6.22	0.514	5.46	7.35	0.52	0.04	8.17
	2	6.22	6.19	0.81	4.49	8.04	0.16	0.39	13.11
OM%	1	1.57	1.56	0.321	0.96	2.047	-0.21	-0.98	20.38
	2	1.13	1.12	0.37	0.32	1.94	0.33	1.06	33.07
N g kg^{-1}	1	0.07	0.07	0.01	0.04	0.10	-0.21	-0.98	20.38
	2	0.05	0.05	0.01	0.01	0.09	0.33	1.06	33.07
P mg dm^{-3}	1	28.86	16.99	41.12	1.55	191.37	3.57	14.16	142.46
	2	24.19	18.00	24.52	3.48	97.56	2.10	4.38	101.35
K $cmol_c$ dm^{-3}	1	0.15	0.13	0.06	0.07	0.38	2.18	6.08	44.33
	2	0.16	0.15	0.09	0.04	0.40	1.30	1.49	58.46
Ca $cmol_c$ dm^{-3}	1	8.49	8.10	1.70	5.80	11.60	0.16	-0.94	20.09
	2	6.78	7.05	2.12	1.4	10.70	-0.67	1.40	30.87
Mg $cmol_c$ dm^{-3}	1	1.51	1.40	0.49	0.60	2.40	-0.03	-0.56	32.85
	2	1.32	1.20	0.62	0.50	3.00	0.99	1.27	46.93
Al $cmol_c$ dm^{-3}	1	0.15	0.20	0.13	0.00	0.30	-0.15	-1.83	86.50
	2	0.23	0.01	0.77	0.00	3.50	4.35	19.20	337.56
H+Al $cmol_c$ dm^{-3}	1	4.09	4.15	1.40	1.8	6.90	0.17	-0.64	34.34
	2	3.33	2.55	2.32	1.00	10.70	1.88	4.42	69.67
SB $cmol_c$ dm^{-3}	1	10.16	10.19	1.66	7.49	13.82	0.40	-0.42	16.42
	2	8.35	8.42	2.38	2.11	11.76	-0.81	1.06	28.54
CEC $cmol_c$ dm^{-3}	1	14.26	14.30	2.30	10.50	17.40	-0.25	-1.42	16.15
	2	11.69	12.05	1.98	7.10	14.80	-0.61	0.17	17.01
V%	1	71.71	71.76	7.55	57.23	82.79	-0.26	-0.50	10.53
	2	71.99	75.04	1.98	17.50	92.03	-1.80	4.31	24.31
COT g kg^{-1}	1	9.17	9.11	1.87	5.59	11.90	-0.21	-0.98	20.38
	2	6.61	6.52	2.18	1.88	11.29	0.33	1.06	33.07
Est C Mg ha^{-1}	1	31.37	30.52	6.53	19.37	41.18	-0.17	-1.11	20.82
	2	24.02	23.18	7.54	6.97	39.54	0.24	1.13	31.40
Depth 0.20-0.40 m									
pH in H_2O	1	6.46	6.53	0.58	5.02	7.81	-0.22	1.54	9.08
	2	6.37	6.36	0.53	5.49	7.91	1.08	2.54	8.35
OM%	1	0.82	0.86	0.53	-0.28	1.51	-0.62	-0.37	64.80
	2	0.59	0.69	0.56	-0.96	1.21	-1.53	2.13	95.06
N g kg^{-1}	1	0.04	0.04	0.02	-0.01	0.07	-0.62	-0.37	64.80
	2	0.02	0.03	0.02	-0.04	0.06	-1.53	2.13	95.06
P mg dm^{-3}	1	18.4	2.75	45.00	0.54	185.00	3.27	10.85	244.84
	2	21.90	4.22	46.90	-1.85	190.30	3.01	9.32	213.77
K $cmol_c$ dm^{-3}	1	0.10	0.09	0.03	0.06	0.20	1.49	2.42	33.87
	2	0.08	0.08	0.03	0.04	0.16	1.11	1.25	36.71

Continuation Table 4

Ca $cmol_c\ dm^{-3}$	1	7.86	7.55	1.42	5.90	11.30	0.66	0.02	18.09
	2	7.25	7.30	1.70	4.60	10.70	0.26	-0.55	23.54
Mg $cmol_c\ dm^{-3}$	1	1.32	1.25	0.88	-0.50	3.90	0.84	3.21	67.25
	2	0.91	1.20	1.21	-3.80	2.10	-3.29	12.92	133.49
Al $cmol_c\ dm^{-3}$	1	0.06	0.01	0.10	0.00	0.40	2.25	5.61	153.21
	2	0.03	0.01	0.05	0.00	0.20	1.87	3.15	158.89
H+Al $cmol_c\ dm^{-3}$	1	3.47	2.55	2.00	0.80	8.40	0.85	0.20	57.68
	2	2.54	2.55	0.79	1.70	4.30	0.92	0.39	31.32
SB $cmol_c\ dm^{-3}$	1	9.28	8.94	1.73	6.77	12.97	0.40	-0.68	18.64
	2	8.25	8.35	1.81	5.63	11.38	0.20	-0.84	22.01
CEC $cmol_c\ dm^{-3}$	1	12.76	11.95	2.87	7.60	17.50	0.13	-0.94	22.52
	2	10.80	10.50	1.90	8.60	15.70	1.15	1.26	17.62
V%	1	74.11	75.98	10.55	-0.16	91.74	-0.30	-0.23	14.24
	2	76.03	78.67	7.65	56.75	85.70	-0.88	0.30	10.07
COT $g\ kg^{-1}$	1	4.76	5.01	3.09	-1.65	8.83	-0.62	-0.37	64.80
	2	3.43	4.01	3.26	-5.63	7.08	-1.53	2.13	95.06
Est C $Mg\ ha^{-1}$	1	16.15	17.31	10.58	-5.18	30.42	-0.52	-0.53	65.50
	2	12.53	14.82	11.88	-20.49	25.35	-1.55	2.15	94.81

1 – area-1; 2 – area -2; Med. – median; Min. – minimum values; Max. – maximum values; Ass. – asymmetry; Kur. – kurtosis; CV – coefficient of variation

The contents of Al and P showed the highest CV% values, showing that these were the most homogeneous variables (Table 4). This could be related to the lower uniformity of P distribution in the area since tropical soils may have low P availability as P binds to clay minerals and forms little-soluble compounds (BOLFARINI *et al*., 2020). The possible uneven limestone application may have contributed to a lower uniformity in the ions that neutralize Al, thus increasing the CV%. High CV% values for Al are usually observed in geostatistical studies such as the one conducted by Oliveira *et al*. (2020), in which the authors evaluated two soil depths (0-0.10 and 0.10-0.20 m) and detected a high CV% at 0.10-0.20 m.

In the remaining soil chemical attributes, the CV% expressed high variability (Table 4). This feature is reported by Matias *et al*. (2015), who attributed the high variability of chemical attributes to the interactions between soil formation processes and management practices, e.g., correctives and fertilizers. Sanches *et al*. (2020) reported that high CV% values are associated with low fertility zones, especially influenced by the water dynamics in convex areas, which reduces the soil capacity to maintain nutrients.

The Est C values showed a higher CV% for area-2 at 0.20-0.40 m, similar to COT (Table 4). Oliveira *et al*. (2021) attributed the variability in COT distribution in an area cultivated with fertigated banana especially to the dynamics between the deposition, decomposition, and accumulation of labile crop material.

Geostatistics

The results of the joint geostatistical analysis with data from both areas showed that all chemical attributes considering the total area had spatial dependence (Table 5). At the soil depth of 0-0.20 m, the contents of OM, N, P, K, and Mg and the values of H+Al, SB, and V showed better adjustment to the gaussian model. The contents of Ca and Al and the values of CEC and Est C fit the spherical model, whereas the pH and COT fit the exponential model. For the 0.20-0.40 m depth, most variables (pH, P, K, Mg, Al, H+Al, COT, and Est C) fit the gaussian model, whereas the remaining variables (Ca, SB, CEC, and V%) showed better adjustment to the spherical model. Bernardi *et al.* (2016) showed that the gaussian and spherical models best described the behavior of the soil chemical attributes. Macedo Neto *et al*. (2020) stressed that the exponential and gaussian models showed the highest frequencies for soil fertility variables since these models were related to cause (fertilization) and effect (fertility) results in addition to spatial dependence.

The degree of spatial dependence for the 0-0.20 m depth was described according to Cambardella *et al*. (1994) as strong (< 25%) for pH, P, K, Ca, Mg, H+Al, SB, CEC, V%, COT, and Est C, and moderate (25% to 75%) for OM, N, and Al. At 0.20-0.40 m, all variables obtained a strong degree of dependence under 25% (Table 5).

Table 5 - Estimated models and semivariogram parameters adjusted for soil chemical attributes (total area) at the 0-0.20 m and 0.20-0.40 m depths

Attributes	Model	C_0	C_0+C_1	GDE	Distance (m)	R^2	CRVC	
							b	a
0-0.20 m depth								
pH in H_2O	Exponential	0.031	0.38	8.16	48.9	0.96	0.99	0.09
OM%	Gaussian	0.098	0.197	49.75	111.89	0.61	0.62	0.51
N g kg^{-1}	Gaussian	0.000244	0.00049	49.90	72.57	0.74	0.63	0.02
P mg dm^{-3}	Gaussian	1	605	0.17	12.74	0.86	1	1.48
K cmol$_c$ dm^{-3}	Gaussian	0.00001	0.1582	0.01	15.25	0.69	0.58	0.07
Ca cmol$_c$ dm^{-3}	Spherical	0.001	3.057	0.03	19.54	0.88	0.62	2.9
Mg cmol$_c$ dm^{-3}	Gaussian	0.001	0.329	0.30	22.59	0.96	0.76	0.34
Al cmol$_c$ dm^{-3}	Spherical	0.00488	0.01476	33.06	26.97	0.89	0.65	0.03
H+Al cmol$_c$ dm^{-3}	Gaussian	0.001	2.194	0.05	23.56	0.92	1	-0.14
SB cmol$_c$ dm^{-3}	Gaussian	0.003	2.975	0.10	14.37	0.99	0.82	1.57
CEC cmol$_c$ dm^{-3}	Spherical	0.01	5.359	0.19	26.19	0.96	0.94	0.62
V%	Gaussian	0.1	72.08	0.14	21.5	0.77	1	0.14
COT g kg^{-1}	Exponential	0.01	4.706	0.21	11.31	0.94	1	-0.96
Est C Mg ha^{-1}	Spherical	0.7	47.42	1.48	6.75	0.81	1	-1.19
0.2-0.40 m depth								
pH in H_2O	Gaussian	0.0001	0.1982	0.05	13	0.96	-1.72	17.65
OM%	Spherical	0.0001	0.3152	0.03	16.59	0.73	0.62	0.24
N g kg^{-1}	Spherical	0.000001	0.00074	0.13	16.1	0.27	0.65	0.01
P mg dm^{-3}	Gaussian	1	892.9	0.11	20.75	0.86	0.43	9.97
K cmol$_c$ dm^{-3}	Gaussian	0.000001	0.00069	0.14	10.53	0.72	0.66	0.03
Ca cmol$_c$ dm^{-3}	Spherical	0.045	2.099	2.14	12.56	0.49	1	-0.82
Mg cmol$_c$ dm^{-3}	Gaussian	0.001	1.193	0.08	15.58	0.63	0.72	0.33
Al cmol$_c$ dm^{-3}	Gaussian	0.00001	0.00805	0.12	19.83	0.89	-0.85	0.09
H+Al cmol$_c$ dm^{-3}	Gaussian	0.001	1.332	0.08	23.43	0.98	1.14	-0.35
SB cmol$_c$ dm^{-3}	Spherical	0.001	2.551	0.04	4.12	0	0.87	1.06
CEC cmol$_c$ dm^{-3}	Spherical	0.24	6.832	3.51	23.63	0.79	0.85	1.69
V%	Spherical	0.1	68.83	0.15	29.56	0.82	0.96	2.16
COT g kg^{-1}	Gaussian	0.01	9.77	0.10	12.22	0.72	0.84	0.48
Est C Mg ha^{-1}	Gaussian	0.1	118.4	0.08	12.32	0.7	0.88	0.96

C_0 – Nugget effect; C_0+C_1 - Threshold; GDE – Degree of spatial dependence [GDE% = (C_0/C_0+C_1) x 100]; R² – Coefficient of Determination of the Model; CRVC – Regression coefficient of the cross-validation; b – Angular coefficient; a – Interceptor

The strong spatial dependence implies that the model was sufficient to detect the variability of the location, indicating that the soil attributes are not randomly distributed in the space and that these attributes can be influenced by intrinsic soil factors such as the parent material, mineralogy, relief, organisms, and time (OLIVEIRA *et al*., 2021; VOGADO *et al*., 2020). Therefore, the higher the correlation, the greater the spatial dependence between attributes, with different values described by Cambardella *et al*. (1994) between OM (moderate = 25% to 75%) and COT (strong < 25%) (Table 5), possibly due to the difference of the methods analyzed.

With regard to the range, the attributes evaluated showed differences at the two depths, with a wider overall range at the 0-0.20 m depth, except for P, V%, COT, and Est C. The highest range value was obtained by OM, with 111.89 m, whereas the lowest was obtained by Est C, with 6.75 m (Table 5). The range informs about the maximum distance at which a sampling point is affected by another point in any variable, i.e., the greater the range, the more homogeneous is the distribution of the variable in the study area (VOGADO *et al*., 2020).

At 0-0.20 m, the pH, Mg, H+Al, SB, CEC, and COT showed the highest coefficients of determination (R^2), above 0.90%. For the subsurface (0.20-0.40 m), the highest R^2 values were obtained by the pH (0.96%) and H+Al (0.98%) (Table 5). The R^2 exposes as percentages how much of the variation in the estimated semivariance values is explained by the models, thus showing that the semivariogram meets the spatial interpolation conditions (OLIVEIRA *et al*., 2021).

The cross-validation regression coefficient (CVRC) is used to evaluate alternative models of single and cross semivariograms based on kriging and cokriging. Each point in the spatial domain can be individually removed and its value estimated even without existing. Therefore, a map for estimated and observed values can be constructed for each point (OLIVEIRA *et al*., 2020).

For the CVRC, the angular coefficient values should be close to one (b). In the present study, the values of P, H+Al, V%, COT, and Est C for the 0-0.20 m depth reached 1, whereas the remainder ranged from 0.58 (K) to 0.99 (pH) (Table 5). At 0.20-0.40 m, the CVRC for the K contents reached 1, whereas the remaining variables ranged from 1.14 (H+Al) to – 1.72 (pH). The CVRC of the intercept should be close to zero (a). At 0-0.20 m, the values were best represented by the N, Al, pH, and COT variables, whereas the most uneven values were observed for the Ca contents (2.9) and the Est C (– 1.19). At 0.20-0.40 m, the variables of OM, N, K, Ca, Mg, Al, H+Al, COT, and Est C were close to zero, whereas the values of pH (17.65), P (9.97), SB (1.06), CEC (1.69), and V% (2.16) were the most divergent.

Based on the results of the semivariograms, the spatial distribution maps of soil chemical attributes at 0-0.20 m and 0.20-0.40 m were constructed by considering the total area and its subdivision into areas with higher and lower elevations (Figure 2).

The pH of area-2 (lower elevation) at 0-0.20 m showed the best values and distribution, ranging from 5.9 to 7.0 (Figure 2). The pH was uniform at 0.20-0.40, ranging from 6.2 to 6.7 and being fit for banana cultivation, as seen in Table 3. Souza *et al*. (2021) studied fertigated banana and obtained pH values of 6.3 and 6.1 for the 0-0.20 and 0.20-0.40 m depths, respectively.

The pH increase decreased the Al^{3+} concentrations, allowing lower valence cations (K^+, Ca^{2+}, Mg^{2+}) to dominate the exchange complex, thus improving the mineral nutrition of banana plants due to their high demand for cation nutrients (ALVES *et al*., 2019). Since the studied soil is sandy (Table 1), part of the limestone applied on the surface might have been reallocated to the subsurface, allowing greater pH uniformity in all areas and at all depths studied (Figure 2).

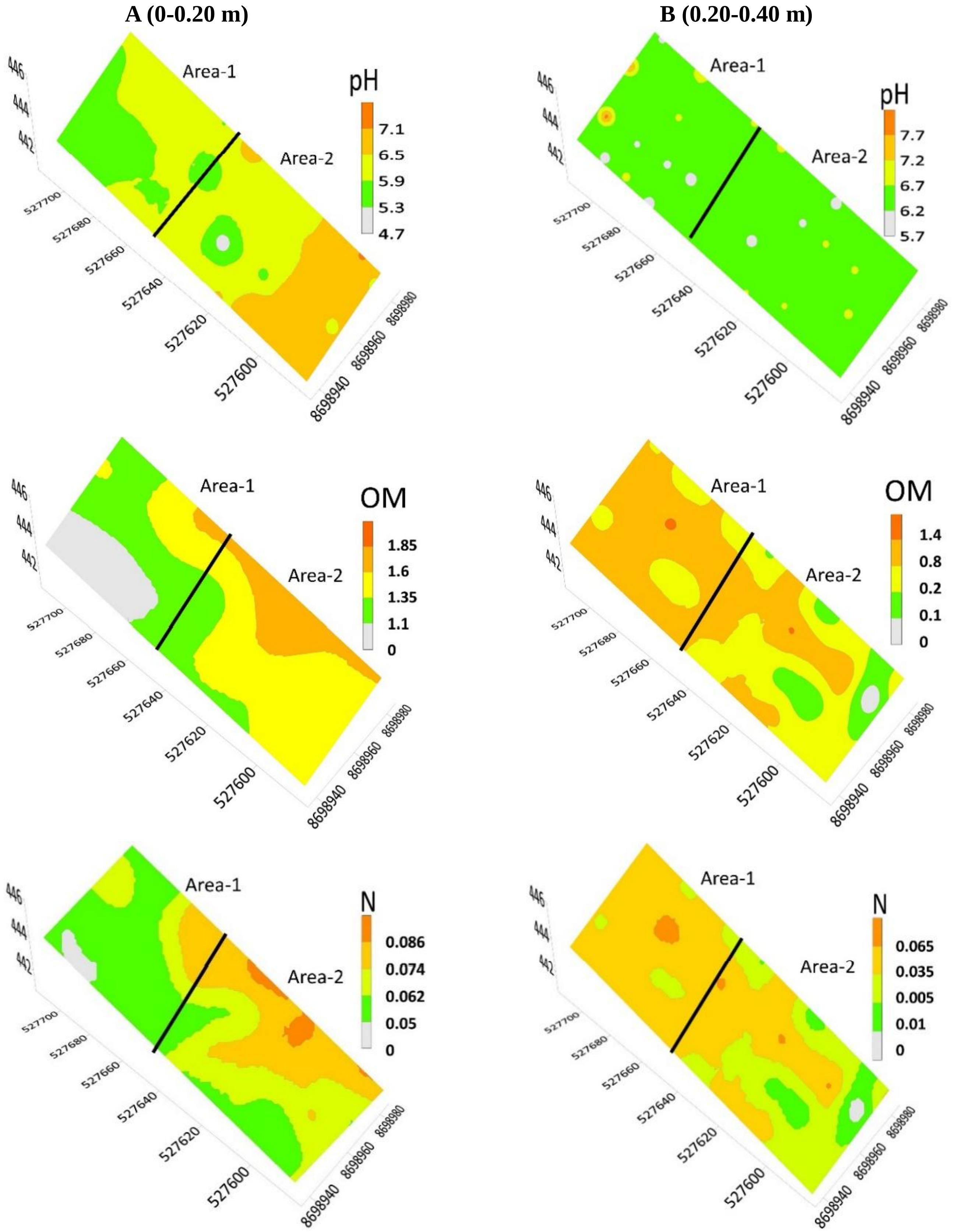
The soil organic matter content (OM) in the total area was higher at the lowest topography (area-2), with values ranging from 1.35% to 1.85% at 0-0.20 m (Figure 2). The lowest OM contents in area-1 are partly due to the OM movement toward area-2 caused by rainwater and the deposition of labile crop material on the surface (BRITO *et al*., 2017). For the 0.20-0.40 m depth, the OM contents decreased to values between 0.2% and 0.8% (Figure 2). In this scenario, studies have shown that OM tends to accumulate where there is a greater deposition of crop residues or at the lowest part of the terrain, influenced by the microrelief (ARTUR *et al*., 2014; OLIVEIRA *et al*., 2013, 2021).

The highest nitrogen concentrations (N) at the 0-0.20 m depth occurred in area-2 (lower elevation), ranging from 0.062 to 0.074 g kg^{-1}. In area-1 (higher elevation), the N contents ranged from 0.05 to 0.062 g kg^{-1} (Figure 2). The highest N content for the 0.20-0.40 m depth occurred in area-1, with values ranging from 0.035 to 0.065 g kg^{-1}. The superiority of N at the surface of the lower area and at the subsurface of the higher area highlights that soil N availability is intimately related to OM cycling, as observed in the maps, which show that the locations with higher N concentrations are the same as for OM (Figure 2).

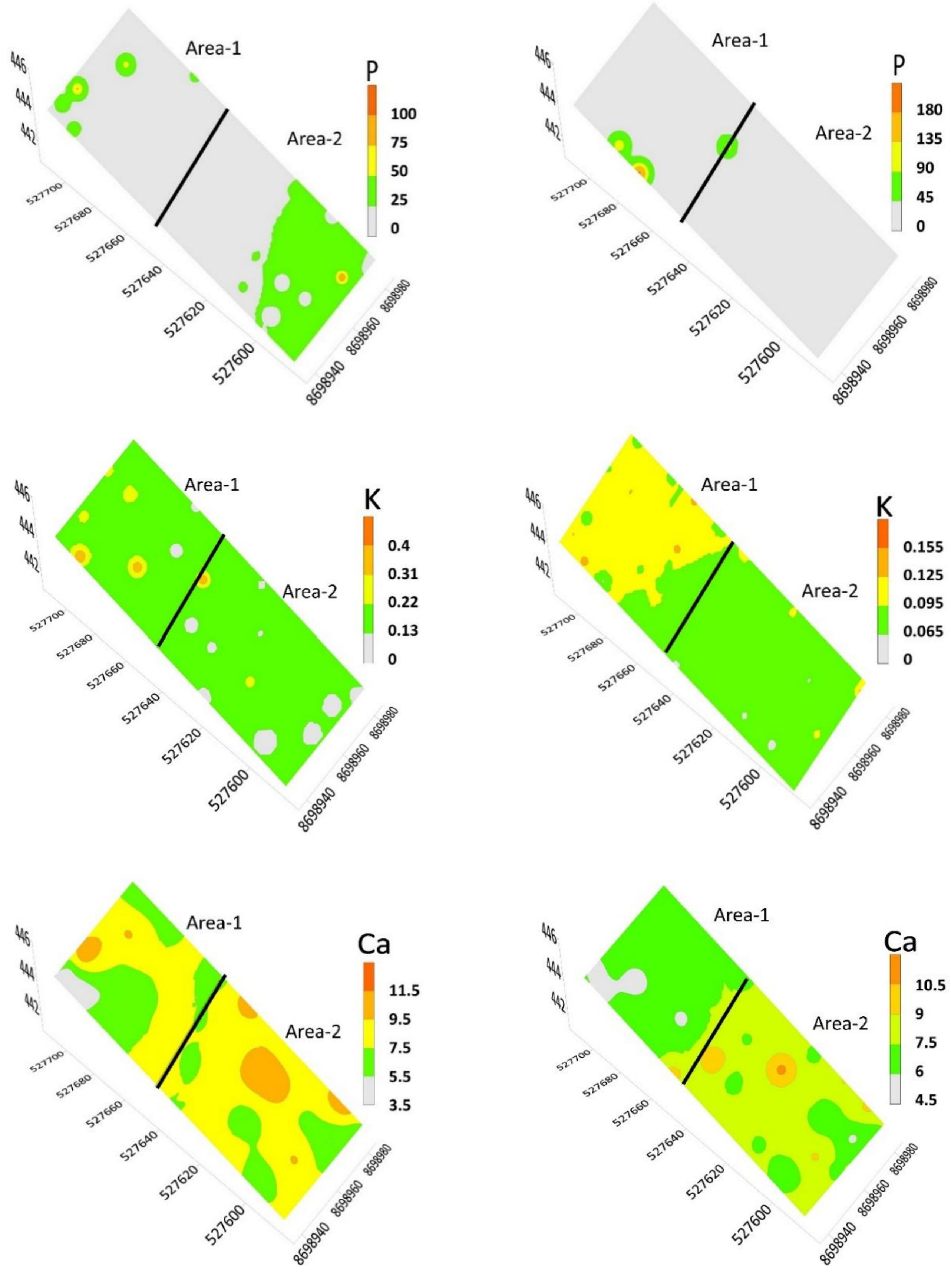
At 0-0.20 m in the higher area (area-1), the phosphorus levels (P) ranged from very low to good (Table 3). In a considerable part of area-1, the P values were above very good, ranging from 25 to 50 mg dm^{-3} (Figure 2). Despite fertilization with P according to the crop requirements, the map is categoric with regard to the low soil P mobility, especailly when observing the 0.20-0.40 m depth, where P is limited to a maximum of 45 mg dm^{-3} regardless of the area (Figure 2).

The nutritional status of banana plants is affected by phosphorus fertilization since the foliar levels of phosphorus, calcium, sulfur, copper, and zinc are changed according to the P levels applied due to the interaction between soil nutrients and plant metabolism (BOLFARINI *et al*., 2020). For Borges and Souza (2010), soils with less than 30 mg dm^{-3} require phosphorus fertilization, suggesting that the studied areas require P replacement considering the means shown in Table 4 and the P distribution observed in the map (Figure 2).

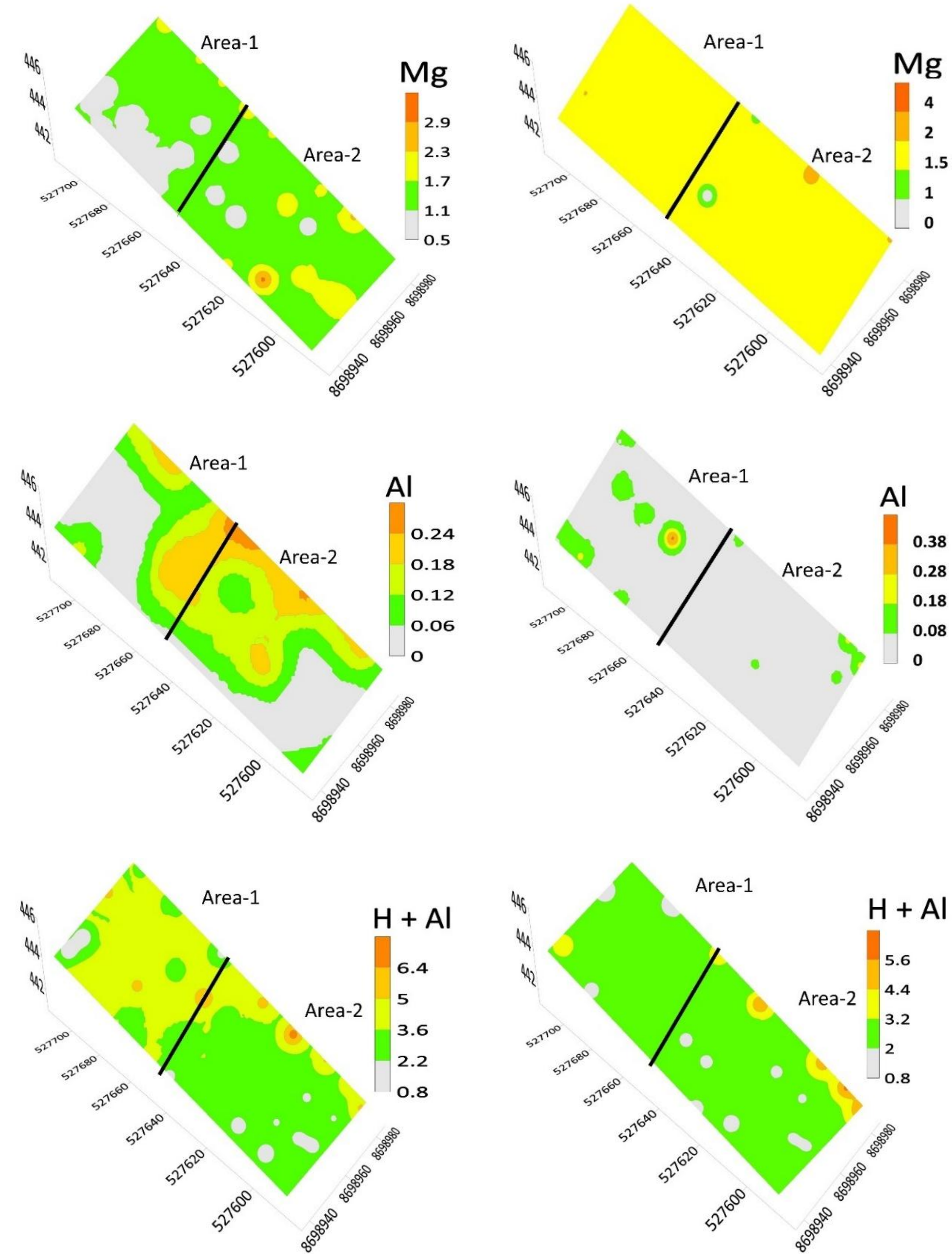
Figure 2 – Spatial variability maps of the chemical attributes of a Latosol at depths A (0-0.20 m) and B (0.20-0.40 m) in a total area with fertigated banana and its subdivisions into area-1 (higher elevation) and area-2 (lower elevation)



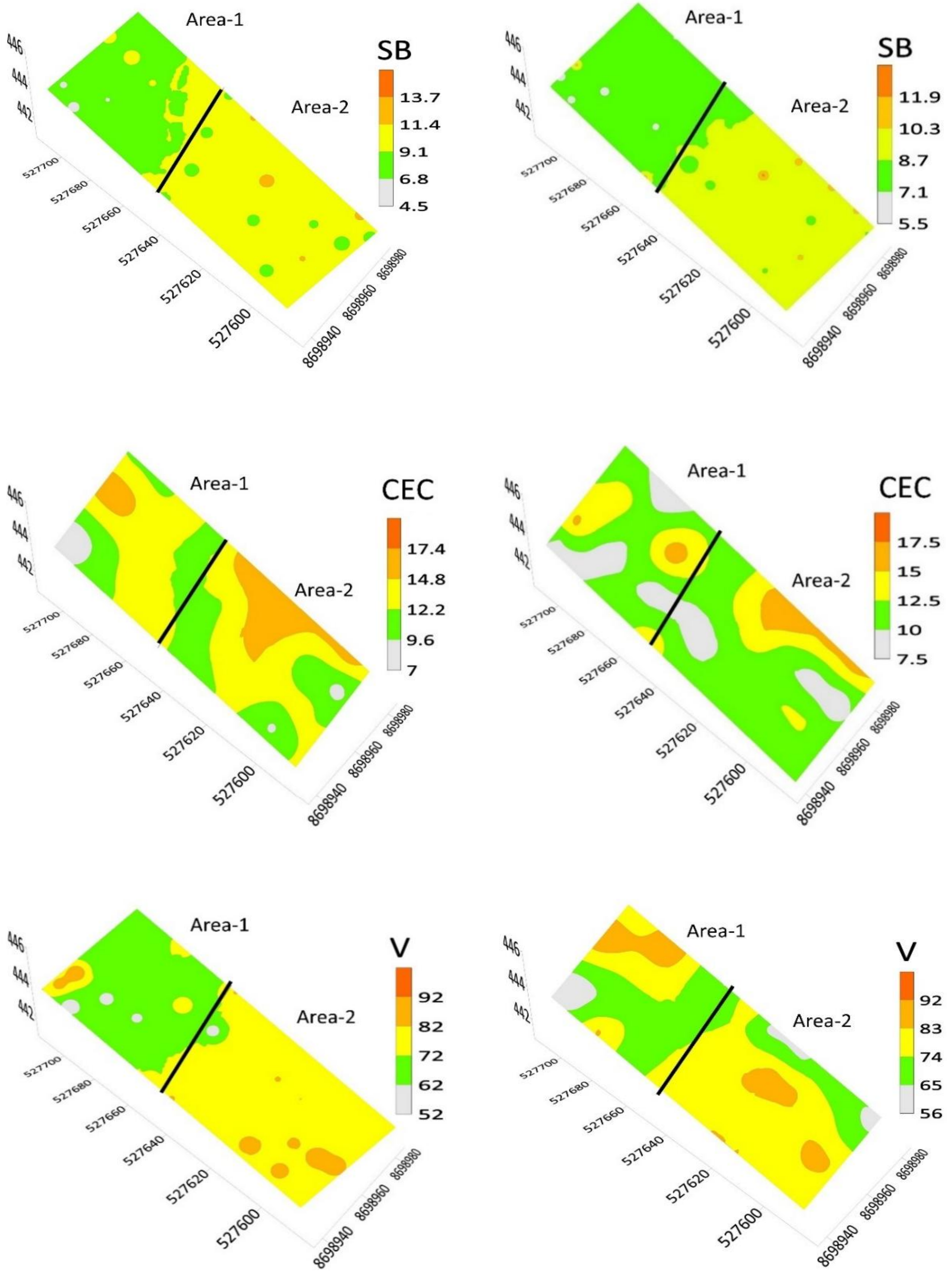
Continuation Figure 2



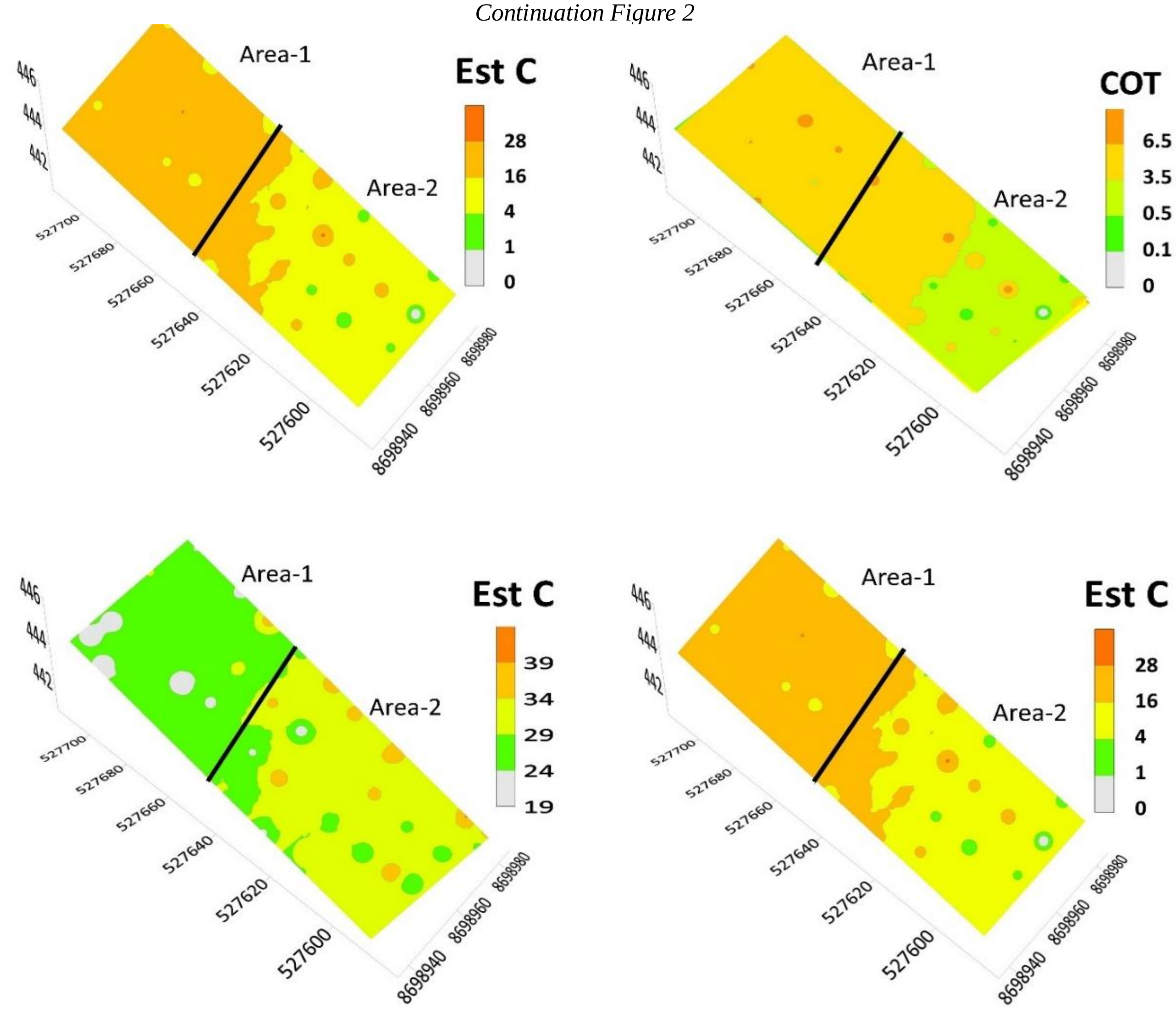
Continuation Figure 2



Continuation Figure 2



Continuation Figure 2



pH – potential of hydrogen; OM – organic matter; N – nitrogen; P – phosphorus; K – potassium; Ca – calcium; Mg – magnesium; Al – aluminum; H+Al – potential acidity; SB – sum of bases; CEC – cation exchange capacity; V – base saturation; COT – total organic carbon; Est C – carbon stock

The results indicate low potassium contents (K) in the soil at the 0-0.20 m depth (total area), ranging from 0.13 to 0.22 $cmol_c$ dm^{-3} (Figure 2) and being classified as very low (Table 3). For the 0.20-0.40 m depth in area-1 (higher elevation), the predominant values ranged from 0.095 to 0.125 $cmol_c$ dm^{-3}. For area-2 (lower elevation), the values ranged from 0.065 to 0.095 $cmol_c$ dm^{-3}.

Despite the biweekly broadcast fertilization in the area with 55 g of potassium chloride and the fact that part of the K was recycled with the return of two-thirds of the plant biomass (BORGES *et al*., 2015), this was not enough to avoid the low K values observed in the soil, resulting in low yield and quality since the available K was not sufficient to balance the crop cycle (XAVIER *et al*., 2020). At lower depths, the low K values may also be due to K extraction by harvest or leaching due to broadcast fertilization and its mobility in the sandy soil, as proposed by Oliveira *et al*. (2021) in the same area.

Calcium (Ca) showed very good contents, as expressed in Table 3. For the 0-0.20 m depth, both in area-1 (higher elevation) and in area-2 (lower elevation), the values surpassed 5.5 $cmol_c$ dm^{-3}. At the 0.20-0.40 m depth in area-1 (higher elevation), the contents of this nutrient ranged from 6.0 to 7.5 $cmol_c$ dm^{-3}, whereas, in area-2 (lower elevation), the Ca contents were higher than 7.5 $cmol_c$ dm^{-3} (Figure 2). Ca contributes to fruit quality by increasing cell wall thickness (SHAN *et al*., 2020). When deficient in Ca, banana quality is lower and can easily result in peel rupture when at fruit maturity (ZHANG *et al*., 2020). The adequate Ca contents observed in this study can be achieved by applying 2 Mg of dolomitic limestone with about 30% of calcium oxide in its composition.

The contents of magnesium (Mg) at the 0-0.20 m depth were considered good to very good (Table 3), concentrating between 1.1 and 1.7 $cmol_c$ dm^{-3} in area-2 (Figure 2). On the other hand, in area-1, with a higher relief, the results showed more variability, ranging from 0.5 to 1.7 $cmol_c$ dm^{-3}, and considered average to very good (Table 3). For the 0.20-0.40 m depth, the values showed high variability and ranged from very low to very high (Table 3). The adequate Mg availability for banana shoots is responsible for increasing the content of total soluble solids, avoiding blueish spots known as the blue disease, and increasing banana yield and quality (ZHANG *et al*., 2020).

The relationship between K, Ca, and Mg in the soil can be applied to this study, consisting of the antagonism of K in relation to other cations. If Ca or Mg are disproportionally present and dominate the exchange complex over K, soil K availability to plants will be reduced (LAEKEMARIAM; KIBRET; SHIFERAW, 2018). In the study developed by Han *et al*. (2019), in which the authors observed K uptake by plants and soil K, the researchers noticed that the mean soil K decreases as limestone addition increases and that K uptake by plants increased significantly with limestone application.

With regard to aluminum (Al), Ribeiro, Guimarães end Alvarez (1999) reported that the maximum saturation value tolerated by banana is 10%. For the 0-0.20 m depth in areas 1 and 2, aluminum saturation was 1.48% and 2.75%, respectively. On the other hand, for the 0.20-0.40 m depth in areas 1 and 2, aluminum saturation was 0.65% and 0.36%, respectively. Therefore, the values obtained in the present study kept at levels appropriate to crop development. At the 0-0.20 m depth, regardless of the area, the values ranged from 0.0 to 0.24 $cmol_c$ dm^{-3}. On the other hand, for the 0.20-0.40 m depth in the total area, the values ranged from 0 to 0.18 $cmol_c$ dm^{-3} (Figure 2). When observing the maps, the distributions of the pH, Al, and H+Al are perceptibly antagonistic as the highest concentrations of Al and H+Al represented areas with lower pH.

The potential acidity values (H+Al) in area-1 (higher elevation) at the 0-0.20 m depth ranged from 3.6 to 5.0 $cmol_c$ dm^{-3}. This variable decreased in area-2 (lower elevation), ranging from 2.2 to 3.6 $cmol_c$ dm^{-3}. For the 0.20-0.40 m depth in the total area, the values of H+Al ranged from 2.0 to 3.2 $cmol_c$ dm^{-3} (Figure 2). The higher H+Al concentration in area-1 could be related to the higher OM content of area-1.

For Leite *et al*. (2013), in addition to biological activity, higher H+Al values can be attributed to soil charges, with the release of intermediate compounds that, when reaching the colloidal state, can disassociate and release hydrogen. Values classified as average (2.51 – 5.00 $cmol_c$ dm^{-3}) (Table 3) indicate that the cultivated area does not present toxicity, thus not harming root development (OLIVEIRA *et al*., 2021).

The sum of bases (SB) in area-1 (higher elevation) at the 0-0.20 m and 0.20-0.40 m depths showed values from 6.8 to 9.1 $cmol_c$ dm^{-3} and 7.1 to 8.7 $cmol_c$ dm^{-3}, respectively (Figure 2). In area-2 (lower elevation), the surface levels (9.1 to 11.4 $cmol_c$ dm^{-3}) were also higher than those of the subsurface (8.7 to 10.3 $cmol_c$ dm^{-3}). These values fit the very good class (Table 3), remaining above 6.0 $cmol_c$ dm^{-3}. The high SB value is mainly due to Ca and Mg, whose values were interpreted as good and very good, unlike K, which showed very low results.

The cation exchange capacity (CEC) showed higher values at the 0-0.20 m depth (Figure 2), classified as good to very good (Table 3). The values were higher in area-1 (higher elevation) (12.2 to 17.4 $cmol_c$ dm^{-3}), whereas area-2 (lower elevation) showed greater heterogeneity, ranging from 9.6 to 17.4 $cmol_c$ dm^{-3}. For the 0.20-0.40 m depth, regardless of the area, there was a predominance of values ranging from 10 to 12.5 $cmol_c$ dm^{-3}. Since part of the CEC is occupied by potential acidity, it can be inferred that the effect of acidity is more evident in areas with lower nutrient availability, possibly influencing the crop yield (SANTOS *et al*., 2017).

The base saturation values (V%) remained above 60% at both depths, indicating that the total area shows good fertility (V% > 50%) (Table 3). For area-1 (higher elevation) at the 0-0.20 m depth, the values were mostly in the range from 62 to 72%. On the other hand, the values were higher for area-2 (lower elevation), ranging from 72 to 82% (Figure 2). There was greater variability at the 0.20-0.40 m depth, with values ranging from 62 to 85% and from 65 to 83% in areas 1 and 2, respectively.

The total organic carbon values (COT) decreased from the surface to the subsurface. The lowest values of this attribute were observed in area-2 (lower elevation) at the 0.20-0.40 m depth (0.5 to 3.5 g kg^{-1}). On the other hand, the highest values were observed in area-2 (lower elevation) at the 0-0.20 m depth (5.5 to 9.5 g kg^{-1}) (Figure 2).

The reduction in COT values is also evidenced when comparing the values prior to the implementation of the experiment, decreasing from 15 g kg^{-1} (Table 2) to 9.17 g kg^{-1} (Table 4), i.e., a 39% loss that was not reestablished even after 18 consecutive months of banana cultivation, possibly because, as a labile material, COT can be easily decomposed and removed during the rainy period and deposited at a lower elevation. Almeida *et al*. (2019), observed similar results for COT in banana cultivation at different relief positions, with higher COT contents in the middle third region (0-0.15 m depth), which was attributed to replacement and removal by water erosion.

Soil organic matter is the most sensitive parameter for evaluating a management system and intimately relates to the CEC (SOLLY et al., 2020). In weathered soils such as Latosols, which have oxidic mineralogy resulting in low-activity clays, OM is the main responsible for maintaining the CEC at the surface and subsurface layers (RAMOS et al., 2018). Dias et al. (2019) detected a high correlation between the CEC and OM variables such as COT, particulate C, and labile C.

Area-2 (lower elevation) showed the largest carbon stocks (Est C) at the 0-0.20 m depth, maintaining values in the range from 29 to 34 Mg ha^{-1}. The lowest values were established at the 0.20-0.40 m depth, with 4 to 16 Mg ha^{-1} in area-2 (lower elevation) (Figure 2). In general, the Est C values are higher at the surface than at the subsurface, possibly due to the constant decomposition of banana residues, with values conditioned to the increase or not of soil density (ROSADO *et al*., 2012). Soils cultivated with fertigated banana favor the development of the microbiota responsible for decomposing residues. Therefore, the greater the input of labile dry matter from banana plants, the faster the decomposition process (BRITO *et al*., 2017), with the release of nutrients and carbon fixation in the soil.

CONCLUSIONS

1. The difference in elevation influences the soil organic matter, total organic carbon, total nitrogen, and the carbon stock;
2. The diagnosis of soil fertility showed that potassium was the most deficient nutrient. Adequate calcium and magnesium values are related to limestone application;
3. All variables showed spatial variability with degrees of dependence ranging from strong to moderate;
4. The variability maps clearly show the distribution and concentration of soil nutrients, allowing interventions in fertilization interventions and the application of inputs at varied rates aiming at their homogeneous supply to plants.

REFERENCES

ABDELRAHMAN, M. A. E. *et al*. Deciphering soil spatial sariability through geostatistics and interpolation techniques. **Sustainability**, v. 13, n. 1, p. 1-13, 2021.

ALMEIDA, M. C. *et al*. Relief position and soil properties under continuous banana cropping in subhumid climate in Northeast Brazil. **Revista Brasileira de Ciência do Solo**, v. 43, p. 1-16, 2019.

ALVARES, C. A. *et al*. Köppen's climate classification map for Brazil. **Meteorologische Zeitschrift**, v. 22, n. 6, p. 711-728, 2013.

ALVES, P. F. S. *et al*. Soil chemical properties in banana crops fertigated with treated wastewater. **Revista Caatinga**, v. 32, n. 1, p. 234-242, 2019.

ARTUR, A. G. *et al*. Variabilidade espacial dos atributos químicos do solo, associada ao microrrelevo. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 18, p. 141-149, 2014.

BERNARDI, A. D. C. *et al*. Spatial variability of soil properties and yield of a grazed alfalfa pasture in Brazil. **Precision Agriculture**, v. 17, n. 6, p. 737-752, 2016.

BOLFARINI, A. C. B. *et al*. Yield and nutritional evaluation of the banana hybrid 'FHIA-18' as influenced by phosphate fertilization. **Journal of Plant Nutrition**, v. 43, n. 9, p. 1-13, 2020.

BORGES, A. L. *et al*. Nutrição e adubação. *In*: FERREIRA, C. F. *et al*. **O agronegócio da banana**. 1. ed. Brasília: Embrapa, 2015. cap. 11, p. 331-398.

BORGES, A. L.; SOUZA, L. S. **Recomendação de adubação e calagem para bananeira**. Cruz das Almas: Embrapa Mandioca e Fruticultura, 2010. 5 p.

BREMNER, J. M. Nitrogen Total. *In*: SPARKS, D. L. **Methods of soil analysis**. 3. ed. Madison: SSA Book, 1996. cap. 37, p. 1085-1121.

BRITO, C. F. B. *et al*. Production, decomposition and chemical characteristics of banana litterfall. **Revista Caatinga**, v. 30, n. 1, p. 45-52, 2017.

CAMBARDELLA, C. A. *et al*. Field scale variability of soil properties in central Iowa soils. **Soil Science Society of America Journal**, v. 58, n. 5, p. 1501-1511, 1994.

COMPANHIA DE DESENVOLVIMENTO DOS VALES DO SÃO FRANCISCO E DO PARNAÍBA. **Projetos públicos de irrigação**. 2020. Disponível em: https://www.codevasf.gov.br/linhas-de-negocio/irrigacao/projetos-publicos-de-irrigacao/elenco-de-projetos/em-producao/nupeba-riacho-grande . Accessed on: 28 may 2021.

DIAS, F. P. M. *et al*. Effects of land-use change on chemical attributes of a Ferralsol in Brazilian Cerrado. **Catena**, n. 177, p. 180-188, 2019.

ELLERT, B. H.; BETTANY, J. R. Calculation of organic matter and nutrients stored in soils under contrasting management regimes. **Canadian Journal of Soil Science**, v. 75, p. 529-538, 1995.

GOLDIN, A. Reassessing the use of loss-on-ignition for estimating organic matter content in noncalcareous soils. **Communications in Soil Science and Plant Analysis**, v. 18, n. 9, p. 1111-1116, 1987.

HAN, T. *et al*. The links between potassium availability and soil exchangeable calcium, magnesium, and aluminum are mediated by lime in acidic soil. **Journal of Soils and Sediments**, v. 19, p. 1381-1392, 2019.

INSTITUTO BRASILEIRO DE GEOGRÁFICA E ESTATÍSTICA. **Produção agrícola municipal – PAM**. 2020.

Disponível em: https://www.ibge.gov.br/estatisticas/economicas/agricultura-e-pecuaria/9117-producao-agricola-municipal-culturas-temporarias-e-permanentes.html?=&t=resultados. Accessed on: 13 feb. 2020.

INSTITUTO NACIONAL DE METEOROLOGIA. Ministério da Agricultura, Pecuária e Abastecimento. **Boletim Agroclimático Mensal**. Disponível em: http://www.inmet.gov.br/portal/index.php?r=home2/index . Accessed on: 13 feb. 2020.

LAEKEMARIAM, F.; KIBRET, K.; SHIFERAW, H. Potassium (K)-to-magnesium (Mg) ratio, its spatial variability and implications to potential Mg-induced K defciency in Nitisols of Southern Ethiopia. **Agriculture & Food Security**, v. 7, n. 13, p. 1-10, 2018.

LEITE, L. F. C. *et al*. Qualidade química do solo e dinâmica de carbono sob monocultivo e consórcio de macaúba e pastagem. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 17, p. 1257-1263, 2013.

MACEDO NETO, A. A. L. *et al*. Diagnosis and spatial variability of soil fertility and crop production in a teak area in eastern Pará state. **CERNE**, v. 26, n. 1, p. 37-47, 2020.

MATIAS, S. S. R. *et al*. Variabilidade espacial de atributos químicos em Latossolo cultivado de modo convencional com soja no cerrado piauiense. **Revista Agro@mbiente**, v. 9, p. 137-148, 2015.

MIOTTI, A. A. *et al*. Profundidade e atributos físicos do solo e seus impactos nas raízes de bananeiras. **Revista Brasileira de Fruticultura**, v. 35, n. 2, p. 536-545, 2013.

OLIVEIRA, B. A. *et al.* Spatiality of soil chemical attributes in a banana cultivation area in west Bahia. **Revista Caatinga**, v. 34, n. 1, p. 177-188, 2021.

OLIVEIRA, D. P. *et al*. Microrrelevo e a distribuição de frações granulométricas em Cambissolos de origem calcária. **Revista Ciência Agronômica**, v. 44, n. 4, p. 676-684, 2013.

OLIVEIRA, J. T. *et al*. Spatial variability of irrigated common bean yield correlated with the fertility of a sandy soil. **Engenharia Agrícola**, v. 40, n. 5, p. 645-656, 2020.

RAMOS, F. T. *et al*. Soil organic matter doubles the cation exchange capacity of tropical soil under no-till farming in Brazil. **Science of Food and Agriculture**, v. 98, n. 9, p. 3595-3602, 2018.

RIBEIRO, A. C.; GUIMARÃES, P. T. G.; ALVAREZ, V. V. H. **Recomendações para o uso de corretivos e fertilizantes em minas gerais:** 5ª aproximação. Viçosa: Comissão de Fertilidade do Solo do Estado de Minas Gerais, 1999. 359 p.

ROBERTSON, G. P. ***GS+* geostatistics for the environmental sciences:** GS+ user's guide. Plainwell: Gamma Design Software, 2008, 152 p.

ROSADO, T. L. *et al*. Efeito da cobertura vegetal nos atributos físicos de um LATOSSOLO AMARELO cultivado com banana. **Enciclopédia Biosfera**, v.8, n.15, p. 721-728, 2012.

SANCHES, G. M. *et al.* Comprehensive assessment of spatial soil variability related to topographic parameters in sugarcane fields. **Geoderma**, v. 362, 114012, 2020.

SANTOS, H. G. *et al*. **Sistema brasileiro de classificação de solos**. 5. ed. Rio de Janeiro: Embrapa Solos, 2018. 356 p.

SANTOS, R. O. *et al.* Spatial variability of soil fertility and its relation with cocoa yield. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 21, p. 88-93, 2017.

SHAN, Z. J. *et al*. Long-term cultivation of fruit plantations decreases mineralization and nitrification rates in calcareous soil in the karst region in southwestern China. **Forests**, v. 11, n. 12, p. 1-12, 2020.

SILVA, C. S. *et al.* Spatial dependency and correlation of properties of soil cultivated with oil palm, Elaeis guineensis, in agroforestry systems in the eastern Brazilian Amazon. **Acta Amazonica**, v. 48, n. 4, p. 280-289, 2018.

SOLLY, E. F. *et al.* A critical evaluation of the relationship between the effective cation exchange capacity and soil organic carbon content in swiss forest soils. **Frontiers in Forests and Global Change**, v. 3, n. 98, p. 1-12, 2020.

SOUZA, E. A. *et al*. Agronomic performance of 'BRS Princesa' banana under fertigation and mulching. **Semina: Ciências Agrárias**, v. 42, n. 3, p. 979-998, 2021.

TEIXEIRA, P. C. *et al*. **Manual de métodos de análise de solo**. 3. ed. Rio de Janeiro, RJ: Embrapa Solos, 2017. 574 p.

TRIPATHI, R. *et al*. Characterizing spatial variability of soil propertie in salt affected coastal India using geostatistics and kriging. **Arabian Journal of Geosciences**, v. 8, n. 12, p. 10693-10703, 2015.

VOGADO, R. F. *et al*. Spatial variability of carbon and nitrogen stocks in integrated management systems and pasture in a cerrado region. **Research, Society and Development**, v. 9, n. 11, e67291110220, 2020.

XAVIER, F. A. S. *et al*. Irrigation systems, fertigation and mulch: effects on the physical, chemical and biological attributes of the soil with banana crop in Northeastern Brazil. **Communications in Soil Science and Plant Analysis**, v. 51, n. 20, p. 2592-2605, 2020.

ZANÃO JÚNIOR, L. A. *et al.* Variabilidade espacial de atributos químicos em diferentes profundidades em um Latossolo em sistema de plantio direto. **Revista Ceres**, v. 57, n. 3, p. 429-438, 2010.

ZHANG, J. *et al*. Organic fertilizer application and Mg fertilizer promote banana yield and quality in an Udic Ferralsol. **PLOS ONE**, v. 15, n. 3, e0230593, 2020.