# Soil management of limed areas cultivated with banana identified by magnetic susceptibility[1]

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## ABSTRACT

The geostatistics technique is widely used to identify the variability of soil attributes, although being expensive due to the large number of samples that it requires. In this sense, magnetic susceptibility has been an alternative to assess landscape variation, a fact that can assist in sampling planning. This study aimed to evaluate the potential of magnetic susceptibility in identifying specific soil management zones and its relationship with soil attributes that can assist in the management of correction and fertilization in an area cultivated with banana with limestone application modes. In a banana orchard, 42 soil samples were collected at a depth of 0.00 to 0.20 m, with a 30 x 35 m sampling grid. The attributes evaluated were magnetic susceptibility, pH, organic matter, aluminum, H + Al, base saturation and cation exchange capacity, clay, sand, and silt. A descriptive and geostatistical analysis of the data was performed. Spearman correlation analysis was used to identify which attributes are associated with magnetic susceptibility. Magnetic susceptibility correlates with chemical and granulometric attributes in the Entisols. Magnetic susceptibility proved to be an efficient attribute in identifying specific management zones, assisting in the sampling planning of soils cultivated with banana.

**Keywords:** limestone; precision agriculture; correlation; geostatistics.

## INTRODUCTION

The identification of the spatial variability of soil attributes before cultivation can indicate better management alternatives to reduce the effects on crop production through precision agriculture (PA) (Zonta *et al.*, 2014). The absence of this knowledge can induce planning errors in agricultural areas, for example, in the application of conditioners and fertilizers, which are usually applied in a single dose based on the average levels of nutrients contained in the soil (Silva Neto *et al.*, 2011). This fact highlights the need to consider the knowledge of spatial variability in the management of agricultural inputs (Matias *et al.*, 2015).

The use of PA with the knowledge of spatial variability of soil attributes constitutes an essential tool for agricultural production, enabling increased productivity, optimizing the use of resources, and reducing the impact on the environment (Zonta *et al.*, 2014; Machado *et al.*, 2018). However, due to the high number of samples required in order to spatially represent the attribute (Souza *et al.*, 2014), its practice may be unfeasible due to the increased cost, in addition to requiring time for collection and laboratory

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analysis (Matias *et al.*, 2015).

The use of magnetic susceptibility (MS) can assist in the indirect assessment of soil attributes and the identification of areas with variability, also called areas of specific management, without the need to increase the number of samples and thereby reducing costs (Santos *et al.*, 2011; Matias *et al.*, 2013; Lourenço *et al.*, 2014; Cervi *et al.*, 2019).

Currently, there are no studies related to PA in fruit trees such as banana in the Brazilian cerrado region. Thus, this research aimed to study the possible efficiency of Magnetic Susceptibility in the identification of specific management zones and its relationship with soil attributes that can assist in the management of soil correction and fertilization in an area cultivated with banana.

## MATERIAL AND METHODS

### *Characterization of the study area and sampling*

The study was conducted in a banana orchard located in Cristino Castro county, state of Piauí, with an elevation of 223 m and the geographic coordinates: latitude 8° 49' S and longitude 44° 13' W (Figure 1). The study area is located in a transition region between Cerrado and Caatinga biomes. The climate is Aw type, according to the Köppen classification, with a dry season in winter and hot and rainy summer, with an average temperature of 27 ºC and a mean annual accumulated precipitation of 900 mm.

The experimental area was subdivided into two different sub-areas regarding the way of limestone application. In one sub-area, 4 t ha$^{-1}$ of dolomitic limestone was applied to the planting rows, without incorporation. In the second sub-area, 4 t ha$^{-1}$ of the same limestone was applied in total area, being later incorporated into the soil. Limestone was incorporated using a harrow before the plants were planted in the area. In order to meet the need for nutrients, 50 kg ha$^{-1}$ of the NPK formulation 20-00-20 was monthly applied through fertigation, besides the application of 0.2 kg of single superphosphate and 0.2 kg of mono ammonium phosphate per planting hole.

In each sub-area, 21 composite samples collected at a depth of 0.00-0.20 m were demarcated. Each composite sample was formed by five single samples collected at 0.50 m from the matrix plant, totaling 42 points that were properly georeferenced with a 35 x 30 m sample grid. The soil samples were air-dried and passed through a 2 mm mesh sieved for further analysis. After 24 months of Limestone application, the following chemical attributes were determined: potential of hydrogen (pH) in water at a 1 : 2.5 ratio, organic matter (OM) by wet oxidation, aluminum content (Al$^{3+}$), potential acidity (H + Al), cation exchange capacity (CEC), and base saturation (V%) according to the methodology proposed by Teixeira *et al.* (2017).

The clay, sand, and silt contents were determined by

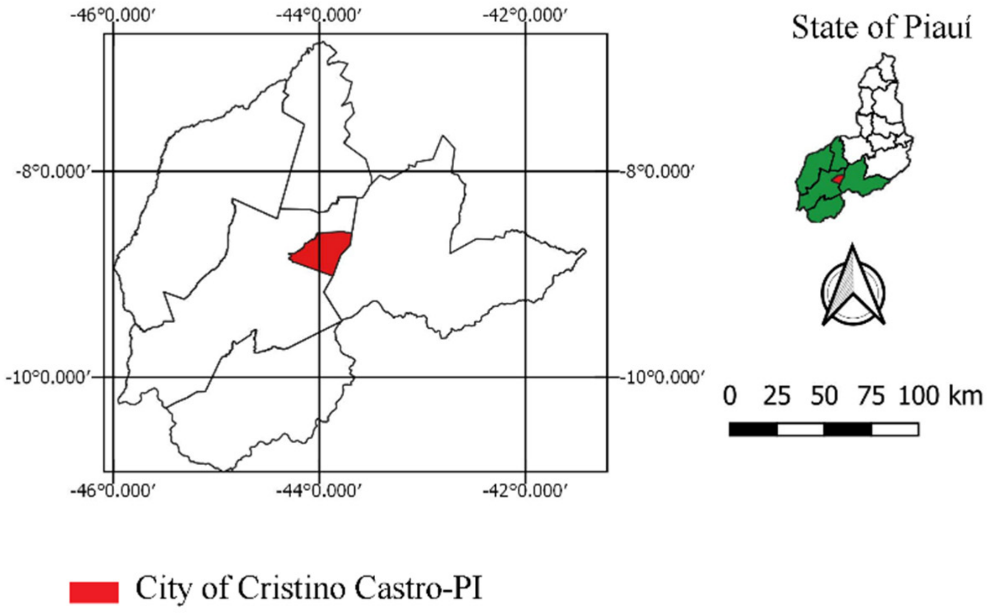

**Figure 1**: Location of the area in which the study was performed.

the pipette method, using NaOH 0.1 mol $L^{-1}$ as a chemical dispersant and mechanical agitation at low speed for 16 hours (Teixeira *et al.*, 2017).

For the determination of the Magnetic Susceptibility (MS), 10 g of soil (TFSA) from each sample was weighed, placed in a container, and then subjected to reading using a Bartington MS2 device at low frequency. Afterward, the values obtained in the readings were subjected to Eq. 1, defined by Dearing (1999):

$$MS = L/(10*PA) \quad (1)$$

where:

MS - magnetic susceptibility value ($10^{-6}$ $m^3$ $kg^{-1}$); and,

L - reading obtained with the device;

PA is the weight of the sample (g).

The attribute data were analyzed using descriptive statistics through measures of location, coefficient of variation (CV), and central tendency, analyzing asymmetry and kurtosis, and maximum, minimum, and amplitude values with the Minitab® software. The Kolmogorov-Smirnov test was performed to verify the normality ($P < 0.05$) of the evaluated attributes. The CV was classified according to Warrick & Nielsen (1980), in which CV values below 12% are considered low, values between 12 and 60% are considered average, and values above 60% are high.

Semivariograms were adjusted based on the assumption of stationarity of the intrinsic hypothesis to analyze the spatial dependence of the attributes. For the adjustments of the semivariograms, the GS+ ® software was used, in which the spherical, exponential, and Gaussian tests were assessed to verify those that best fit. The choice of models was made by observing the residual sum of squares (SQR), the determination coefficient ($R^2$), and the correlation coefficient, obtained by the cross-validation technique (CRVC). The spatial variability of soil attributes was mapped using the ordinary kriging interpolation method. With the models adjusted, the Surfer® software was used to model the specific management zones for each attribute.

The scope and degree of spatial dependence (GDE) were determined for each evaluated attribute. The GDE was classified based on the ratio between the nugget effect and the threshold, using the mathematical formula $(C_0/C_0 + C_1)*100$ according to Cambardella *et al.* (1994), in which values lower than 25% are considered strong, values between 25 and 75% are considered of moderate dependence, and values above 75% are considered of weak dependence (Seidel & Oliveira, 2016).

The MS map was compared with the remaining attributes to verify the similarity of their distribution patterns, observing whether the MS can be used as an indicator of soil spatial variability. In order to better understand spatial variability, Spearman's correlation between attributes was performed, allowing to identify which attributes are associated with MS.

## RESULTS AND DISCUSSION

### *Descriptive statistics*

The results show that among the chemical attributes, only the pH presented a low CV according to Warrick & Nielsen (1980). The chemical attributes of V%, H + Al, and CEC presented a CV considered average. MS and $Al^{3+}$ presented a CV considered high, above 62%, highlighting $Al^{3+}$, which presented a CV value above 100%, probably due to the neutralization of this element by limestone (Table 1).

The CV was low for the sand content, while OM, silt, and clay presented average CV. According to Soares *et al.* (2015), the granulometric attributes usually present low variation in space because they are formed over a long time when compared to chemical attributes. However, the soil under study is formed by sediment deposition, with sand, clay, and silt particles being transported by water. This sediment transportation and deposition can increase the amount of these particles at low elevation points in a shorter time scale, increasing the variation.

It was verified that the asymmetry and kurtosis coefficients were close to zero, and the pH, H + Al, V%, MS, and the granulometric components showed a negative kurtosis coefficient, indicating that the tail is more elongated to the left. The mean and median of the attributes are close, with the mean presenting values above the median, indicating that the maximum values did not significantly interfere with the mean, which may indicate that these data may present normal distribution, providing more reliability in the exploratory analysis of the data, as reported by Zhen *et al.* (2019). According to the Kolmogorov-Smirnov normality test at $p < 0.05$, only the pH, H + Al, CEC, V%, clay, sand, and silt attributes were considered normal. The normality of data is one of the basic requirements of classical statistics, whereas, for geostatistics, there must be spatial dependence on the attributes.

**Table 1:** Descriptive statistics of chemical attributes, soil size, and magnetic susceptibility in an area cultivated with banana

| Attribute | Median | DP | CV | Min | Max | Ampl | Cs | Ck | KS |
|---|---|---|---|---|---|---|---|---|---|
| pH (water) | 5.36 | 0.60 | 11.08 | 4.35 | 7.07 | 2.72 | 0.39 | -0.34 | 0.11* |
| OM (g $kg^{-1}$) | 4.72 | 2.22 | 44.51 | 1.54 | 11.42 | 9.87 | 1.20 | 1.46 | 0.21* |
| $Al^{3+}$ (cmol $dm^{-3}$) | - | 0.14 | 169.3 | 0.00 | 0.40 | 0.40 | 1.37 | 0.31 | 0.43* |
| H + AL (cmol $dm^{-3}$) | 1.78 | 0.83 | 43.66 | 0.64 | 3.85 | 3.20 | 0.56 | -0.37 | 0.11* |
| CEC (cmol $dm^{-3}$) | 2.86 | 0.81 | 27.14 | 1.35 | 5.19 | 3.83 | 0.59 | 0.41 | 0.10* |
| V% | 37.92 | 18.69 | 48.99 | 8.73 | 75.74 | 67.01 | 0.15 | -1.06 | 0.07* |
| Clay (g $kg^{-1}$) | 77.38 | 24.34 | 29.53 | 40.91 | 133.19 | 92.27 | 0.21 | -0.82 | 0.10* |
| Sand (g $kg^{-1}$) | 837.10 | 70.90 | 8.51 | 696.60 | 954.30 | 257.70 | -0.17 | -0.64 | 0.10* |
| Silt (g $kg^{-1}$) | 86.57 | 49.52 | 58.47 | 2.33 | 185.95 | 183.62 | 0.10 | -0.64 | 0.06* |
| MS (g $kg^{-1}$) | 0.03 | 0.02 | 69.42 | 0.01 | 0.10 | 0.08 | 0.82 | -0.77 | 0.21* |

DP - Standard deviation; CV - Coefficient of variation; Min - Minimum; Max - Maximum; Ampl - Amplitude; Cs - Asymmetry; Ck - Kurtosis; KS - Kolmogorov-Smirnov test statistics; * - Significant at ($p < 0.05$).

It is worth highlighting that the fact that some attributes present high variation and lack of normality may indicate that the mean is not the best alternative for the purposes of interpretation and later decision-making in the management of fertilization and soil correction, as it does not represent the real values of the entire area. Similar results were reported by Matias *et al.* (2015), who described that when this result occurs, it demonstrates that there are soil attributes that may have their spatial dynamics altered depending on the management adopted and/or influence of soil formation factors requiring other assessment methods.

### *Geostatistics analysis and correlation*

The results of the geostatistics parameters show that all attributes are spatially dependent, which is fundamental for the spatial prediction of attributes (Table 2). It is possible to observe that the chemical attributes were adjusted to the spherical model, while the granulometric, clay, sand, and silt attributes were adjusted to the Gaussian model. Studies by Matias *et al.* (2015) and Freitas *et al.* (2017) point out that environmental variables tend to adjust to the spherical model since natural conditions normally present an abrupt change in their variation.

It is worth noting that the application of the conditioner and the type of soil can influence these parameters. Bernardi *et al.* (2018) and Matias *et al.* (2013) studied the compartments of a landscape and observed that the same attribute presented different models, showing different patterns along the landscape.

H + Al presented the lowest $R^2$ value, while the remaining attributes had higher values. Regarding the CRVC, except for sand, the intercept values close to zero and slope close to the other attributes show how much the estimated values are similar to the real values, allowing greater accuracy in the prediction of the attributes through kriging (Song *et al.*, 2019).

The degree of spatial dependence (GDE), which is the ratio between $(C_0/C_0 + C_1)*100$, showed that magnetic susceptibility (MS), as well as the other chemical and granulometric attributes evaluated, presented strong spatial autocorrelation, according to the classification proposed by Cambardella *et al.* (1994). When evaluating the attributes, it can be stated that all attributes showed strong spatial dependence, even after the management adopted in the area, as well as the type of soil formation, indicating that the sampling grid is efficient and capable of identifying spatial variability with greater precision.

The MS, OM, clay, and H + Al attributes present the smallest ranges, probably because they are more sensitive to change or alterations in the soil. Studies by Matias *et al.* (2015) and Magiera *et al.* (2019) demonstrate that MS and OM can easily be changed according to anthropic activities. Santos *et al.* (2011) showed that MS has a greater reach and could be used as a reference for the identification of management zones. The pH range and V% showed higher values. For V%, although presenting a high CV, the variation occurs abruptly over greater distances.

Based on the semivariograms, it was possible to create the isoline maps (Figure 2). In the maps, it is possible to verify that the application and incorporation of limestone

**Table 2:** Models and parameters of the semivariograms of chemical and granulometric attributes and magnetic susceptibility in an area cultivated with banana

| **Atribute** | **$C_0$** | **$C_1 + C_0$** | **GDE** | **Reach (m)** | **Model** | **$R^2$** | **CRVC** | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | **a** | **b** |
| pH | 0.0580 | 0.3330 | 17.42 | 129 | Spherical | 1.00 | -0.57 | 1.10 |
| OM | 0.0100 | 5.7410 | 0.17 | 75 | Spherical | 0.91 | 0.57 | 0.09 |
| $Al^{3+}$ | 0.0001 | 0.0334 | 0.30 | 125 | Spherical | 1.00 | 0.00 | 0.89 |
| H + Al | 0.0500 | 0.7410 | 6.75 | 75 | Spherical | 0.73 | 0.16 | 0.92 |
| CEC | 0.1700 | 3.4300 | 4.96 | 105 | Spherical | 1.00 | 0.03 | 1.02 |
| V% | 64.0000 | 427.3000 | 14.98 | 155 | Spherical | 0.85 | -0.13 | 0.99 |
| clay | 66.0000 | 663.7000 | 9.94 | 79 | Gaussian | 1.00 | 0.21 | 1.00 |
| sand | 590.0000 | 5872.0000 | 10.05 | 95 | Gaussian | 1.00 | -9.48 | 1.00 |
| silt | 117.0000 | 2603.0000 | 4.49 | 99 | Gaussian | 0.92 | -0.32 | 1.00 |
| MS | 0.1000 | 254.1000 | 0.04 | 82 | Spherical | 0.99 | -2.99 | 1.10 |

EPP - Pure nugget effect; $C_0$ - Nugget effect; $C_0 + C_1$ - Landing; GDE - Degree of spatial dependence; $R^2$ - Model determination coefficient; CRVC - Regression coefficient of cross-validation; a - Intercept; b – Slope.

significantly influenced the relationship of the attributes in the soil, with higher values of pH, V%, and CEC in places where limestone was incorporated (I). In contrast, the lowest values of $Al^{3+}$ and H + Al were observed in this same area, attributes easily changed with the application of soil conditioners.

The incorporation of the conditioner into the soil provides a greater contact area between the particles and soil moisture, increasing the rate of dissolution and reaction of the limestone and increasing the concentration of bases in the soil and the chemical reactions that reduce the concentration of soluble hydrogen and aluminum ions in the soil. In turn, the conditioner applied only to the soil surface is more susceptible to horizontal losses due to dragging in the rainy season, besides increasing the time of reaction and vertical translocation in the soil profile. It is worth noting that the banana tree is a semi-perennial plant. After the orchard is installed, when the plants are mature, it is not possible to incorporate limestone because the root system is superficial. The incorporation is done only in the pre-planting correction.

The MS showed higher values in the area where limestone was not incorporated, showing zones of lower concentration when there was soil turning, demonstrating that the MS is very sensitive to anthropic activities. Magiera *et al.* (2019) reported that the improvement in susceptibility was much more pronounced in forest profiles compared to open areas subjected to modification. This may be more evident in this study with the negative correlation between the attributes of pH and V%, results that corroborate those reported by Lourenço *et al.* (2014).

The fact that the zones with lower MS values are observed in anthropized places is probably due to the physical migration and homogenization of magnetic particles. Soil turning increases macroporosity and, consequently, the speed and quantity of vertically transported particles.

In the area in which soil turning was performed, even with the lowest values of MS, in general, in some points this attribute was more pronounced, showing that other factors can influence the variability of this attribute, besides anthropic activity (Matias *et al.*, 2013; 2015).

Minerals with magnetic characteristics can be inherited from the source material of soil formation or formed through reactions of biotic and abiotic processes in the soil. Thus, several pedogenetic factors can directly affect the concentrations of ferrimagnetic minerals in the soil (Lourenço *et al.*, 2014; Cervi *et al.*, 2019).

Jordanova (2016) state that microenvironmental conditions can lead to the transformation of ferrihydrite into ferromagnetic maghemite, increasing the magnetic properties of soils. In the case of variation in MS, it may be related to soil granulometry in the study area. Figure 2 shows the similarity in the spatial distribution of MS with clay and silt, although different from the sand map. This similarity and/or difference can be confirmed with the correlation between these attributes.

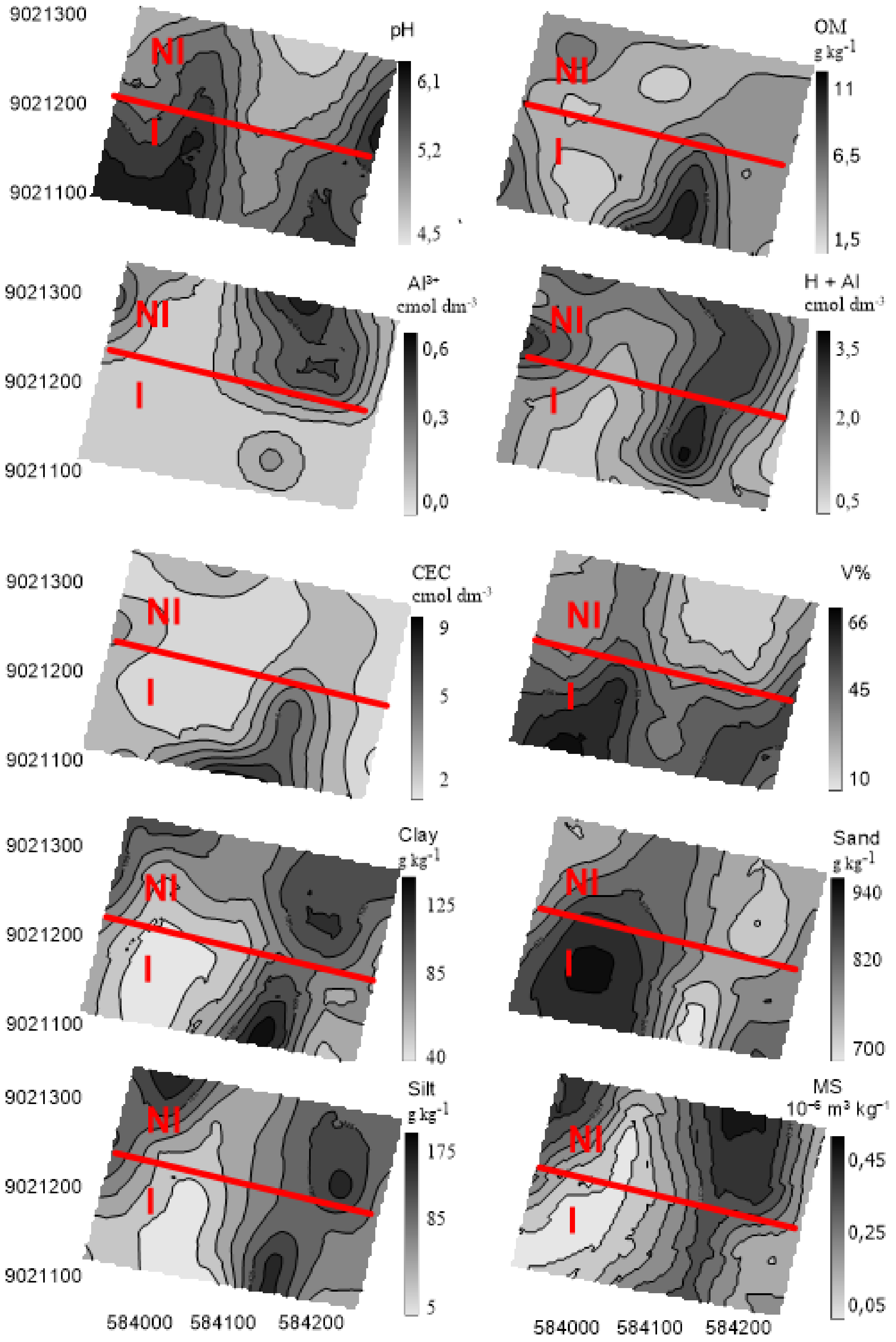

**Figure 2**: Spatial variability maps of pH, organic matter (OM), aluminum ($Al^{3+}$), H + Al, base saturation (V%), cation exchange capacity (CEC), clay, sand, silt, and magnetic susceptibility (MS) of a soil cultivated with banana in areas with non-incorporated (NI) and incorporated conditioner (I).

The negative correlation between MS and sand shows that this particle does not present high levels of ferrimagnetic minerals, but rather that the clay and silt particles are the ones most significantly expresses the magnetic signal in the study area (Table 3). Matias *et al.* (2013), studying the potential of MS to separate soil classes, verified that there is a correlation between soil granulometry and MS values, indicating potential magnetic minerals that can infer these values.

The explanation for the correlation between MS and clay may probably be related to the presence of iron oxides, very common in soils of this region. Similar results were obtained by Matias *et al.* (2013). Due to their smaller size, iron oxides can be easily transported and deposited in lower areas, increasing the magnetic signal of that location. This same behavior was observed by Grison *et al.* (2016), who state that iron ions can form organometallic compounds by increasing the magnetic signal of the location under favorable conditions. This statement can be further evidenced by the significant correlation between MS and soil organic matter.

**Table 3:** Correlation between chemical attributes, soil granulometry, and magnetic susceptibility in areas cultivated with banana subjected to limestone incorporation and without limestone incorporation

| Attributes | MS | pH | $Al^{3+}$ | H + Al | CEC | V | OM | Clay | Sand |
|---|---|---|---|---|---|---|---|---|---|
| pH | -0.65** | | | | | | | | |
| $Al^{3+}$ | 0.69** | -0.78** | | | | | | | |
| H + Al | 0.64** | -0.64** | 0.53** | | | | | | |
| CEC | 0.35** | 0.01** | 0.01** | 0.53** | | | | | |
| V% | -0.58** | 0.81** | -0.75** | -0.65** | 0.16** | | | | |
| OM | 0.34** | 0.01** | -0.02** | 0.29** | 0.63** | 0.18** | | | |
| Clay | 0.71** | -0.51** | 0.54** | 0.52** | 0.29** | -0.46** | 0.44** | | |
| Sand | -0.78** | 0.49** | -0.53** | -0.48** | -0.28** | 0.46** | -0.42** | -0.88** | |
| Silt | 0.75** | -0.46** | 0.48** | 0.44** | 0.25** | -0.44** | 0.41** | 0.80** | -0.98** |

"*" and "**" - Significant at $p < 0.05$ and $p < 0.01$.

Also, a positive correlation was identified between the pH and V% attributes. These same attributes were negatively correlated with $Al^{3+}$ and H + Al, which were higher in the area in which the conditioner was not incorporated (Table 3). For agricultural purposes, the concentrations of these elements must be reduced as much as possible so that they do not harm the development of the crops, demonstrating that the incorporation is necessary before installing the crops.

## CONCLUSIONS

Magnetic susceptibility correlates with all analyzed chemical attributes and soil granulometry.

Magnetic susceptibility proved to be an efficient attribute in the identification of specific management zones, assisting in the sampling planning of soils cultivated with banana.

Magnetic susceptibility can assist in planning sampling of soil cultivated with banana in soil with surface and incorporated liming.

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