



SPATIAL DISTRIBUTION OF SOIL CHEMICAL PROPERTIES IN THE CERRADO OF TOCANTINS

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ABSTRACT

Information on spatial variability of soil chemical properties is allowing an increasingly efficient management of soil fertility. This study was conducted in the municipality of Santa Rosa do Tocantins, TO, in the 2018/2019 crop year. The objectives of the study were to characterize the spatial variability of chemical properties of a dystrophic Red Latosol in the Cerrado of Tocantins using geostatistics and optimize the management of soil fertility by means of precision agronomy techniques, for more efficient input use in agricultural production areas. For the experiment, 49 soil samples were collected at 0.2 m depth, from equidistant points in a regular grid 100 m apart, over an area of 150 ha. Each sample was composed of 5 subsamples. The soil properties evaluated included pH, bases sum, potential acidity, organic matter, total cation exchange capacity, base saturation, phosphorus, sulfur, potassium, calcium, magnesium, boron, copper, iron, manganese, and zinc. A descriptive analysis was carried out, highlighting the mean, median, minimum, and maximum values for each soil variable. In addition, the coefficients of variation, asymmetry, kurtosis, and the normality test of Kolmogorov-Smirnov were performed. The area presented significant variations in chemical and macronutrient attributes and little variation in micronutrients, except for zinc. The study reveals variations in different soil attributes and the need for correction depending on the requirements of the crop.

Palavras-chave:

Geostatística
Krigagem
Atributos
Amostragem

DISTRIBUIÇÃO ESPACIAL DE ATRIBUTOS QUÍMICOS DO SOLO NO CERRADO DO TOCANTINS

RESUMO

O conhecimento da variabilidade espacial dos atributos químicos do solo está possibilitando cada vez mais um manejo eficiente da fertilidade. O trabalho foi realizado no município de Santa Rosa do Tocantins, TO, na safra agrícola de 2018/2019. O objetivo do estudo foi caracterizar a variabilidade espacial dos atributos químicos do Latossolo Vermelho distrófico no cerrado tocantinense, através de técnicas da geoestatísticas a fim de, futuramente, contribuir com a otimização do manejo da fertilidade do solo, através de técnicas de agricultura de precisão, para aplicações mais eficientes de insumos em áreas de produção agrícola. Para a realização do experimento foram coletadas 49 amostras de solo na profundidade de 0,2 m, a cada 100 metros em uma malha regular, numa área de 150 hectares, com pontos equidistantes entre si, uma amostra composta com 5 subamostras. As avaliações realizadas foram: pH, soma de bases, acidez potencial, matéria orgânica, capacidade de troca de cátions total, saturação por bases, fósforo, enxofre, potássio, cálcio, magnésio, boro, cobre, ferro, manganês e zinco. Para cada variável avaliada do solo realizou-se a análise descritiva, destacando os valores da média, mediana, mínimo e máximo. Além disso foram observados os coeficientes de variação, assimetria, curtose e o teste de normalidade de Kolmogorov-Smirnov. A área apresentou variações significantes nos atributos químicos e macronutrientes e pouca variação nos micronutrientes, exceto zinco. Demonstrando, assim, algumas variações em diferentes atributos do solo e revelando a necessidade de correção conforme as necessidades da produção agrícola.

INTRODUCTION

The spatial variability of soil properties is the result of concurrent pedogenetic processes and can be demonstrated through surveys and analyzes of soils, as well as by the differences observed in crop productions (SILVA *et al.*, 2010).

The Cerrado has a large spatial variability of soils, which is manifested even in small plots. One of the first steps to the management of variability is to recognize the need to understand it and manage it properly. This stems from the fact that the desired gain in productivity depends on the steps to map, manage, and reduce the variability, as well as to make it economically and technically feasible to the production of crops (SENAR, 2015b).

Clearly the precision agriculture plays an essential role in the proper management of local soil fertility and has been widely used (FAPTO, 2016). Inputs are applied in a variable way, aiming at meeting specific needs of each site, optimizing the productive process and reducing environment impacts caused mainly by poor farming practices. In this regard, it is paramount to characterize the spatial variability of chemical attributes through accurate soil sampling, which is capable of representing and reducing the variations in the production environment (BOTTEGA *et al.*, 2013).

Sample collection for the designing of variability maps requires large number of sample points and can be done through automatic or semi-automatic (mainly) collections (SENAR, 2015a).

The principles of agricultural experimentation take into account that soil variability occurs completely at random (ZANÃO JÚNIOR *et al.*, 2010; ZONTA *et al.*, 2014), thus the need of using geostatistics as a tool to prove the presence of spatial dependence and understand the variability in the production site (CARNEIRO *et al.*, 2016). From this perspective, geostatistics is not limited to obtaining a model of spatial independence, but also to emphasizing non-sampled points in the area in order to optimize adequate land management (SRIVASTAVA, 1996; GOOVAERTS, 1997).

Geoestatistics follows the premise that closer

sample points tend to be more similar to each other, and this similarity decreases as the distance between points increases. In this way, geoestatistics is essential for precision agriculture, by consisting of a semi-automatic map design, in which values are estimated for non-sampled areas with relative accuracy, reducing costs and time to map soil variability (SENAR, 2015a).

Spatial and time variability is the result of the different conditions of the land in respect to soil fertility, acidity, and other important factors for agricultural productivity in space and time (SENAR, 2015b).

Therefore, the objective of this work was to understand the spatial distribution of the main chemical properties of a Red Dystrophic Latosol in the Cerrado of Tocantins and contribute to future optimization of soil fertility management using precision agriculture techniques, providing a more efficient input use in areas of agricultural production.

MATERIAL AND METHODS

The study was carried out in an area of commercial agriculture, in Santa Helena farm, in the 2018/2019 crop year. The farm is located in the municipality of Santa Rosa do Tocantins (-11° 54' 42" S and -48° 13' 82" W), 289 m average altitude. The climate of the region is rainy tropical AW (KÖPPEN, 1948), with 26.5 °C average annual temperature and 1500 mm annual rainfall, with the rainy season between October and April and the dry season between May and September. The soil was classified as dystrophic Red Latosol of clay texture (EMBRAPA, 2018), with average contents of 583.7 g kg⁻¹ (58.37%) of sand, 51.5 g kg⁻¹ (5.15%) of silt, and 364.8 g kg⁻¹ (36.48%) of clay, of sandy clay textural class (RIBEIRO *et al.*, 1999).

The study area was opened up for cultivation in 2005 and has since then been cultivated in the crop rotation system, alternating soybean in the rainy season and corn in the off-season. Correction and fertilization of the soil at the opening of the

area were carried out by incorporating 140 kg.ha⁻¹ of P₂O₅ and 140 kg.ha⁻¹ of K₂O with heavy tilling.

The production year at the Santa Helena farm started by the planting of the soybean into the corn stalks, in the Cerrado Red Latosol, in November 2018. The production system previously used in the farm was the conventional system, but from the 2017/2018 crop year, precision agriculture technologies were implemented to improve the management of soil fertility, and in the 2018/2019 crop year, the spatial analysis was introduced.

Five simple samples were collected at 0.2 m depth, from equidistant points in a regular grid 100 m apart, over an area of 150 ha, forming a composite sample. The collection was carried out using a *Saci Trail* sampler, a quad bike mounted soil sampling unit, with a hydraulic soil probe platform. A total of 49 composed samples were collected in the study area. Each sample collected was georeferenced, with geographical coordinates of the collection point, to delimit the study area and to generate the maps of the soil fertility variability using geostatistics tools.

The collected samples were packed and sent to the soil analysis laboratory in Gurupi – TO. The chemical and granulometric analyses of the soil included: pH (in H₂O); sum of bases (SB) (cmol_c dm⁻³); potential acidity (H + Al, cmol_c dm⁻³), organic matter (OM, dag.kg⁻¹), available phosphorus (P, mg dm⁻³); sulfur (S, mg dm⁻³); potassium (K⁺, cmolc dm⁻³); calcium (Ca²⁺, cmolc dm⁻³); and magnesium (Mg²⁺, cmolc dm⁻³); boron (B, mg dm⁻³); copper (Cu²⁺, mg dm⁻³); iron (Fe²⁺, mg dm⁻³); manganese (Mn²⁺, mg dm⁻³); and zinc (Zn²⁺, mg dm⁻³). Along with the results of the soil analyses, the potential cation exchange capacity (CEC, cmol_c dm⁻³) and base saturation (V%) were also calculated.

Descriptive analysis was performed for each attribute of the soil evaluated. In addition, the coefficients of variation, asymmetry, kurtosis, and the Kolmogorov-Smirnov normality test, at 5% probability, were computed. The spatial dependence of the points was analyzed through geostatistics, and the correlations between neighboring points were calculated by the semivariogram using the

software GS⁺ (ROBERTSON, 2008; VIEIRA, 2000).

The semivariograms were adjusted and the nugget effect (C₀), variance (C₁), sill (C₀ + C₁), and range (A) were defined. Adjustment of the mathematical models and the semivariograms were performed on the basis of spatial dependence degree (GDE), the highest coefficient of determination (R²) and smallest sum of squared deviations (SSD). SSD is calculated by the following Equation 1:

$$SDD = \left[\frac{C_1}{C_0 + C_1} \right] * 100 \quad (1)$$

Where,

SDD = spatial dependence degree (%);

C₁ = variance; and

C₀ + C₁ = sill.

The spatial dependence degree was calculated based on the variance and the sill of each variable and classified as: weak (SDD <25%); moderate (SDD between 25 and 75%); and strong (SDD > 75%), according to Robertson (2008). Interpolation was performed by the kriging method, which allowed the generation of isoline maps (representation of a surface of connected points of the same value) of the variables analyzed using the software Surfer 8 (GOLDEN SOFTWARE, 2002).

RESULTS AND DISCUSSION

The descriptive analysis of the chemical properties (Table 1) of the dystrophic red latosol showed that, overall, the mean levels of most chemical attributes are rated as medium (pH, P, Ca²⁺, Mg²⁺, Cu²⁺, Fe²⁺, SB, and CEC_(T)) and good (K⁺, Zn²⁺, and V%) (RIBEIRO *et al.*, 1999), which is recommended for most crops, including soybean that is frequently grown in the area.

Table 1 shows that only the means of Mn was classified as “very low” and B as “low”, while, the K levels in the soil are classified as “good” and above the average required by most crops. In general, the soil of the area has good fertility, with

Table 1. Descriptive statistics of chemical attributes, macro and micronutrients of the Red Latosol in the Cerrado of Tocantins, at the Santa Helena farm, Municipality of Santa Rosa – TO

Variable	Mean	Med.	Value		Coefficient			¹ KS
			Min.	Max.	² CV	³ Cs	⁴ Ck	
pH H ₂ O	5.41	5.4	5	5.6	2.33	-0.653	0.939	0.170*
H+Al (cmol _c dm ⁻³)	1.93	2.0	1.6	2.5	13.92	0.541	-0.385	0.171*
P (mg dm ⁻³)	11.21	9.8	4.5	30.6	48.61	1.646	2.869	0.173*
K ⁺ (mg dm ⁻³)	91.18	89	63	135	20.38	0.391	-0.657	0.100*
S (mg dm ⁻³)	17.26	17.6	5.5	30.9	34.62	0.017	-0.389	0.098*
Ca ²⁺ (cmol _c dm ⁻³)	2.13	2.1	1.5	2.7	13.28	0.111	-0.49	0.115*
Mg ²⁺ (cmol _c dm ⁻³)	0.55	0.50	0.3	0.8	19.29	0.569	0.551	0.276*
B (mg dm ⁻³)	0.20	0.20	0.14	0.25	14.22	0.087	-0.415	0.223*
Cu ²⁺ (mg dm ⁻³)	0.92	0.90	0.7	1.4	16.59	0.565	0.625	0.165*
Fe ²⁺ (mg dm ⁻³)	23.60	23.00	16	34	16.89	1.005	1.011	0.137*
Mn ²⁺ (mg dm ⁻³)	2.81	2.80	1.5	4.1	20.19	0.360	0.232	0.114*
Zn ²⁺ (mg dm ⁻³)	1.53	1.40	0.9	3.4	30.50	1.599	4.015	0.199*
SB (cmol _c dm ⁻³)	2.91	2.90	2.06	3.69	12.79	0.127	-0.194	0.082*
CEC _(T) (cmol _c dm ⁻³)	4.83	4.81	3.87	5.69	8.95	0.073	-0.597	0.089*
V%	60.13	60.30	47.7	69.5	7.88	-0.470	0.535	0.125*
OM (dag kg ⁻¹)	1.75	1.8	0.9	2.4	18.56	-0.677	0.306	0.195*

Source: Authors

CEC: potential cation exchange capacity; V%: Base saturation; SB: Sum of bases; H + Al: potential acidity; OM: Organic matter; P: Phosphorus; K⁺: Potassium; S: sulfur; Ca²⁺: Calcium; Mg²⁺: Magnesium; B: Boron; Cu: Copper; Fe: Iron; Mn: Manganese; Zn: Zinc. ¹KS: Kolmogorov-Smirnov normality test; ²CV: coefficient of variation (%); ³Cs: Skewness coefficient; ⁴Ck: Kurtosis coefficient; Med.: Median; Min.: Minimum; Max.: Maximum; (*) significant by the normality test of Kolmogorov-Smirnov at 5% probability; (ns) non significant by the normality test of Kolmogorov-Smirnov at 5% probability

V% value, above 50% (SANA *et al.*, 2014). The CEC (4.83 cmol_c dm⁻³) in Table 1 (the sum of Ca²⁺, Mg²⁺, K⁺, Al³⁺+ H⁺) shows the soil has low clay activity (CEC <27 cmol_c dm⁻³ of clay) (ZARONI; SANTOS, 2019) and has low capacity of storage of these nutrients, especially those required in large quantities by the plant. Still, according to Table 1, the pH values (5.4) are not in the ideal range, between 6.1 to 6.9, and are classified as “weak acidity”, according to Ribeiro *et al.* (1999).

The mean and median of all soil chemical attributes are close together, indicating a normal distribution of data and proven by the Kolmogorov-Smirnov (KS) test at 5%, which probably occurs because the application of fertilizers and the correctives is performed at variable rate. Carneiro *et al.* (2016a) investigated the spatial distribution of chemical attributes in a soil managed with application of a fixed rate of correctives and fertilizers. The authors found that P, K⁺, Mg²⁺, Al³⁺ and m% (aluminum saturation) had no normal

distribution of data and indicated the conventional management as the main cause of the absence of normality in the area of production.

The coefficient of variation (CV) can be used to classify the chemical attributes of the soil. The pH, CEC, and V% are classified with low CV (<12%) and the other attributes with medium CV (> 12% <60%). The absence of the CV classified as high (> 60%) is due to the application in the previous crop year (2017/2018) of soil correctives and fertilizers in a varied rate based on software and equipment, which was before the soil sampling in May 2018.

The skewness coefficient (C_s) was negative for pH, V%, and OM, which means that large amount of the data are above the sample mean. The other soil properties had positive asymmetric distribution. The skewness coefficient measures the asymmetry of the frequency distribution of a variable. Thus, if data are left-skewed, skewness is negative, when it is right-skewed it is positive, and if a distribution is symmetric, then the skewness

coefficient is zero, respectively (ZANÃO JUNIOR *et al.*, 2010).

In addition to the CV and C_s , the Coefficient of kurtosis (CK) is also used to assess whether the data follows a normal distribution. The kurtosis values of the normal distribution should be zero, however, the values in the range +2 to -2 are acceptable (NEGREIROS NETO *et al.*, 2014). Of the Ck values in this analysis, only the chemical attributes P (2.869) and Zn (4.015) did not fit the acceptance interval, exceeding the positive limit.

The best models adjusted to the semivariogram (Table 2) were spherical (pH, V%, SB, K⁺, Mg, Cu and Fe), Gaussian (CEC, H + Al, P, and S) and exponential (OM, B, Mg, and Zn). None of the chemical attributes fitted the linear model. According to Druck *et al.* (2004), the main difference between the exponential and the spherical models is that the exponential reaches the sill only asymptotically, while the spherical model reaches the sill in the range value.

All the variables in the study exhibited good spatial dependence and most were classified as

strong, being only CEC, P, and S classified as moderate. The spatial dependence degree (SDD) influences the kriging method, as the larger the SDD, the better the kriging estimation for non-sampled sites (LIMA *et al.*, 2010). Alencar *et al.* (2016) assessed the spatial distribution of soil attributes and pasture and similarly found high SDD values classified as strong and moderate.

Different ranges were obtained from the analysis of the semivariogram, and these values varied from 286 m (Fe) to 1277 m (pH), which represent the rays of areas considered homogeneous for each soil chemical attribute (LIMA *et al.*, 2014). In this case, the range is crucial, because it indicates the maximum distance that a particular characteristic is correlated spatially and delimits the spatial correlation between the sample points (DALCHIAVON *et al.*, 2012).

The range is directly correlated with the management adopted and mainly with the application of correctives and fertilizers in the area, since the goal is to make it as unvarying as possible. Precision agriculture deals with each sample spot

Table 2. Models and parameters estimated from semivariograms fitted to the data of chemical properties, macro, and micronutrients of the Red Latosol in the Cerrado of Tocantins, in the Santa Helena farm, Municipality of Santa Rosa - TO

Variable	Parameter							
	¹ Mod	² C ₀	³ C0+C ₁	⁴ A (m)	⁵ SDD _(%)	⁶ Clas.	⁷ R ²	⁸ SSD
pH H ₂ O	Sph.	0.0033	0.0220	1277.00	84.90	Str.	0.99	4.43x10 ⁻⁷
H+Al	Gau.	0.0248	0.1186	1271.32	79.10	Str.	0.99	3.25x10 ⁻³
P	Gau.	16.310	32.6400	1193.38	50.00	Mod.	0.94	5.06
K ⁺	Sph.	79.200	379.000	702.00	79.10	Str.	0.80	4951.00
S	Gau.	16.200	56.4900	1196.84	71.30	Mod.	0.99	1.04
Ca ²⁺	Exp.	0.0104	0.0874	516.00	88.10	Str.	0.95	1.68x10 ⁻⁵
Mg ²⁺	Esf.	0.0011	0.0152	766.00	92.80	Str.	0.82	1.31x10 ⁻⁵
B	Exp.	0.0001	0.0009	579.00	83.50	Str.	0.64	2.70x10 ⁻⁸
Cu	Sph.	0.00001	0.0227	304.00	100.00	Str.	0.39	1.18 x10 ⁻⁵
Fe	Sph.	0.0100	14.840	286.00	99.90	Str.	0.39	2.95
Mn	Exp.	0.0680	0.3760	405.00	81.90	Str.	0.81	8.04x10 ⁻⁴
Zn	Exp.	0.0262	0.2334	315.00	88.80	Str.	0.37	1.00x10 ⁻³
SB	Sph.	0.0351	0.1632	665.00	78.50	Str.	0.92	3.10x10 ⁻⁴
CEC _(T)	Gau.	0.0601	0.1952	878.14	69.20	Mod.	0.99	1.35x10 ⁻⁵
V%	Sph.	6.750	32.8100	924.00	79.40	Str.	0.98	2.31
OM	Exp.	0.0164	0.1168	666.00	86.00	Str.	0.59	5.12x10 ⁻⁴

Source: Authors

¹Mod: Model (Exp.: Exponential; Gau.: Gaussian; Sph.: Spherical; Lin.: Linear); ²C₀: nugget effect; ³C0+C₁: Sill; ⁴A: Reach; ⁵SDD_(%): spatial dependence degree; ⁶Clas.: Class (W.: Weak; Mod.: Moderate; Str.: Strong); ⁷R²: coefficient of determination; ⁸SSD: sum of squared deviations; CEC_(T): total cationic exchange capacity; V%: Base saturation; SB: Sum of bases; H + Al: potential acidity; OM: Organic matter; P: Phosphorus; K⁺: Potassium; S: sulfur; Ca²⁺: Calcium; Mg²⁺: Magnesium; B: Boron; Cu: Copper; Fe: Iron; Mn: Manganese; Zn: Zinc

differently to reduce heterogeneity, standardize the area, and increase the range (CARNEIRO *et al.*, 2016b). Liming possibly influenced attributes such as pH and H+Al (Table 2), which was done at a varied rate, since both have close ranges, besides the congruence of the maps.

CEC, pH, H+Al and S produced the highest coefficients of determination with $R^2 = 0.99$, while the lowest $R^2 = 0.37$ occurred for the micronutrient Zn, which were rated as strong and moderate, respectively (DANTAS, 1998).

The several semivariograms fitted for each variable assessed confirms spatial dependence, by estimating non sampled spots using the geostatistic interpolation method of ordinary kriging and disclosing the variability of the chemical attributes studied, according to the values estimated in the isoline maps in Figures 1, 2, and 3. The isoline maps generated using ordinary kriging consider the spatial dependence of points with similar values, enabling the estimation of values with the least variation and the highest precision within the study area (CORÁ *et al.*, 2006).

The fitting of semivariograms allowed the creation of isoline maps by interpolation of the sample points throughout the study area using ordinary kriging, an essential tool for soil fertility study. Thus, these maps help to create specific zones of management and adopt precision agriculture technologies for the application of fertilizers and correctives at different rates. These practices aim at making the cultivation area uniform, reducing costs and variability of soil fertility, and providing conditions to increase productivity (CARNEIRO *et al.*, 2016a).

To deliver a more detailed evaluation of the soil fertility in the production area, the contents of the chemical attributes, macro, and micronutrients were listed according to the agronomic classification recommended by Sousa and Lobato (2004) and Ribeiro *et al.* (1999). The attribute levels were rated as very low, low, moderate, good (high), or very good (very high), correlating them with the five color shades in the maps, from lighter colors for the lower concentrations to more saturated hues for higher concentrations.

The pH (Figure 1a) has approximately half of the area falling into the range 4.5 to 5.4, with the ideal pH being a level above this (5.5 to 6.0 = good). Equally, V% (Figure 1C) presented similar spatial distribution, with the need to be increased to “good”, from 60% to 80%. CEC (Figure 1B)

and SB (Figure 1D) of the almost the entire area falls into moderate levels (4.31 - 8.60 $\text{cmol}_c \text{dm}^{-3}$ and 1.81 - 3.60 $\text{cmol}_c \text{dm}^{-3}$, respectively). H+Al (Figure 1E) are rated as “low” (1.01 - 2.50 $\text{cmol}_c \text{dm}^{-3}$) and are reduced to “too low” (<1.0 $\text{cmol}_c \text{dm}^{-3}$). OM (Figure 1F) was rated as “low” for most of the area, ranging from 0.71 to 2.0 dag kg^{-1} (RIBEIRO *et al.*, 1999).

Soybean has been cultivated in the crop season, after corn grown in the off-season. This management is currently sufficient to increase OM levels in the soil. In this context, the introduction of forage crop with a high biomass contribution is essential to promote an increase in OM contents over the course of time with successive crops in this production system and positively influence CEC, which is presently at low concentrations.

P levels in Figure 2a show that a small portion of the area was rated as “good” (12.1 - 18 mg dm^{-3}) and “very good” (> 18.0 mg dm^{-3}), and most of the area was rated as “moderate” (8.1 - 12.0 mg dm^{-3}), thus, correction of fertility is required for phosphorus, according to the recommendations of Sousa *et al.* (2016). Figure 2B shows that most of the area has above 70 mg dm^{-3} of K levels, which is rated as “good” (71 - 120 mg dm^{-3}). The S levels in Figure 2C are in the range considered “good”. However, Ca and Mg in Figures 2D and 2E are rated as “moderate” (1.21 - 2.4 and 0.46 - 0.90 $\text{cmol}_c \text{dm}^{-3}$, respectively), requiring the correction of these nutrients in order to raise V%, balance the pH, and neutralize the soil H+Al levels (RIBEIRO *et al.*, 1999).

The micronutrients are evenly distributed in the area, except for zinc. However, the concentrations of B (Figure 3a) and Mn (3D figure) are “low”. Cu (Figure 3B) and Fe (Figure 3C) are at levels rated as “good”. Zn (Figure 3E) distribution in the area was highly uninform, with great variation of concentrations. Retention and availability of micronutrients are influenced by several factors such as soil parent material, texture, pH, Fe and Al oxides, organic matter, moisture, among other soil characteristics (CAMARGO, 2019), which can explain the high Zn variability.

OM influences the availability of soil micronutrients in two main ways: the first results from the increase in CEC, which prevents nutrients from leaching to deeper soil layers; and the second, by the formation of chelated complexes that reduces the availability of micronutrients and regulates their release (KURIHARA, 2019).

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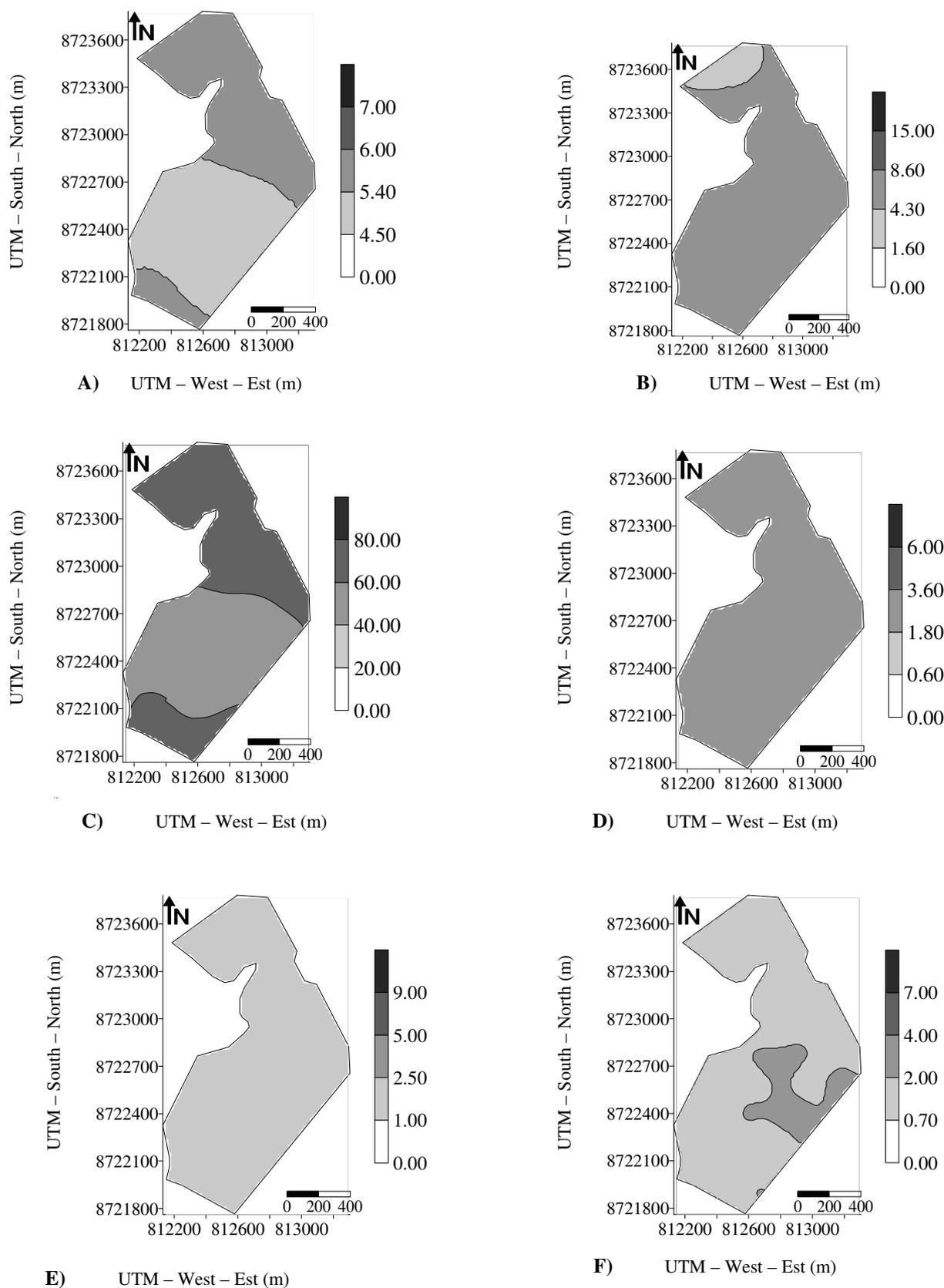


Figure 1. Isolines maps of the spatial distribution of the levels of soil chemical attributes: (A) pH H_2O ; (B) $CEC_{(T)}$ ($cmolc\ dm^{-3}$); (C) V%; (D) SB ($cmolc\ dm^{-3}$); (E) H+Al ($cmolc\ dm^{-3}$); (F) OM ($dag\ kg^{-1}$). Santa Helena Farm, Municipality of Santa Rosa - TO (2019)

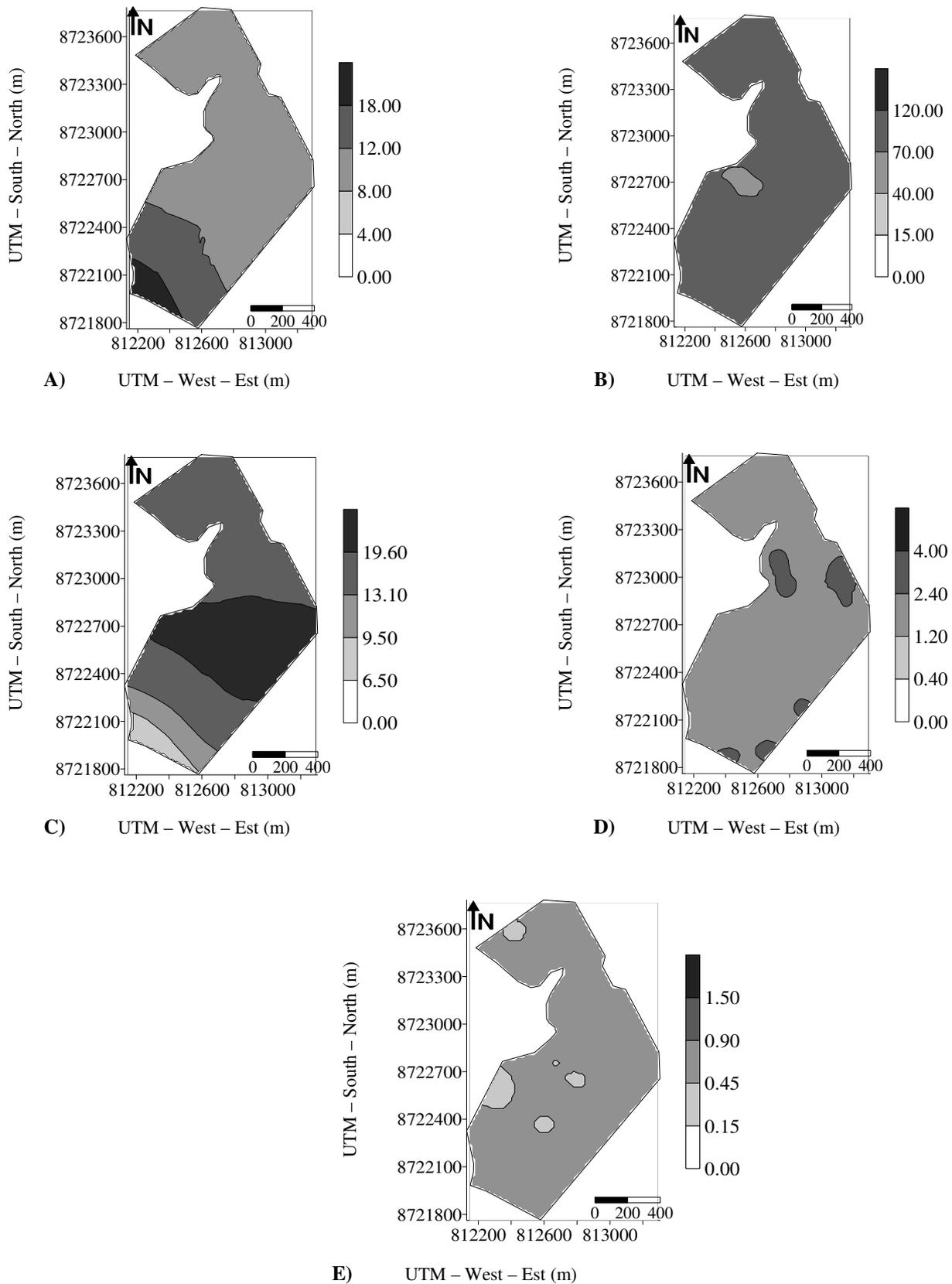


Figure 2. Isoline maps of spatial distribution of the contents of macronutrients in the soil: (A) P (mg dm^{-3}); (B) K (mg dm^{-3}); (C) S (mg dm^{-3}); (D) Ca (cmolc dm^{-3}); (E) Mg (cmolc dm^{-3}). Santa Helena Farm, Municipality of Santa Rosa - TO (2019)

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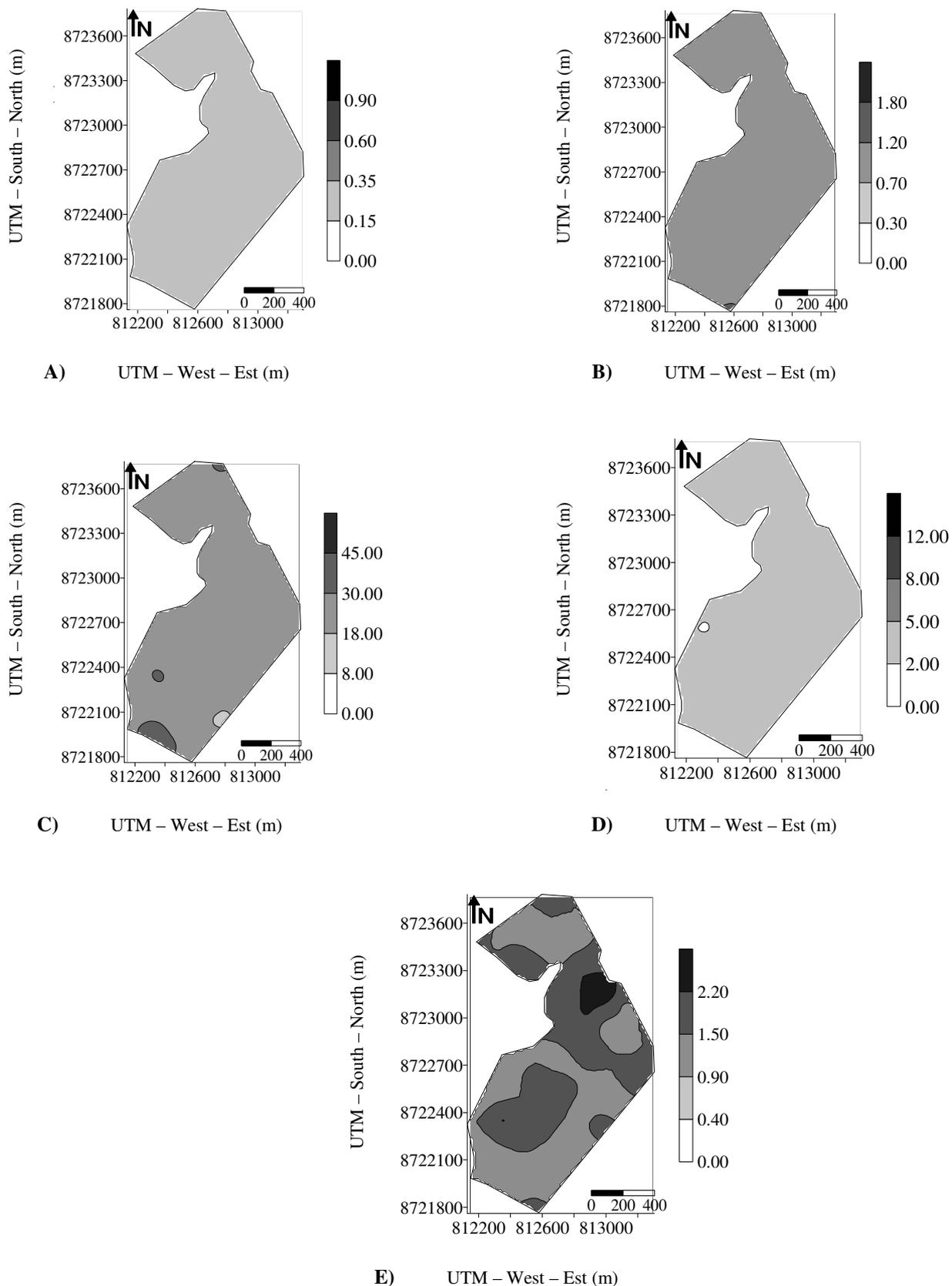


Figure 3. Isolines maps of spatial distribution of micronutrients in the soil: (A) B (mg dm^{-3}); (B) Cu (mg dm^{-3}); (C) Fe (mg dm^{-3}); (D) Mn (mg dm^{-3}); (E) Zn (mg dm^{-3}). Santa Helena Farm, Municipality of Santa Rosa - TO (2019)

The maps of spatial distribution and soil fertility evaluation, as presented in Figures 1, 2, and 3, enable the agricultural technician or farmer to perform site-specific management to meet precisely the needs of the production area. In addition, these maps allow the use of precision farming, the ideal tool for agriculture management, aiming to respond to variability in the fields, according to the variability of soil attributes, applying the right amount of inputs to reduce costs and increase productivity and sustainability of the agricultural production.

CONCLUSION

- The study area presented substantial variations in chemical and macronutrient attributes and low variation in soil micronutrients, except for Zn. Thus, these results demonstrate differences in the spatial behavior of the soil attributes and reveal the need for correction according to each attribute's characteristics and the requirements of the crop production.
- In this way, the use of geostatistics for the spatial evaluation of the chemical attributes of the soil is essential to the adoption of precision agriculture, promoting the correct soil fertilization, according to the nutrient availability and the productivity expected for the crops.

AUTHORSHIP CONTRIBUTION STATEMENT

FERREIRA JÚNIOR, O.J.: Conceptualization, Data curation, Formal Analysis, Project administration, Writing – original draft; **SANTOS, A.C.:** Conceptualization, Funding acquisition, Project administration, Software, Supervision; **NAVES JÚNIOR, C.H.:** Conceptualization, Methodology, Visualization, Writing – original draft, Writing – review & editing; **MENDES, F.C.:** Conceptualization, Methodology, Validation, Visualization, Writing – original draft; **RAMALHO, T.A.Q.:** Conceptualization, Formal Analysis,

Methodology, Software, Validation, Writing – original draft; **SOUSA, W.L.:** Conceptualization, Data curation, Project administration, Validation; **TEIXEIRA, M.M.:** Investigation, Resources, Visualization, Writing – original draft, Writing – review & editing; **AGUIAR, G.R.:** Investigation, Resources, Visualization, Writing – original draft, Writing – review & editing; **FLOR, M.V.C.:** Resources, Validation, Visualization, Writing – review & editing.

DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

- ALENCAR, N. M.; MELO, J. C.; DOS SANTOS, A. C.; CUNHA, O. F. R.; DE PAULA NETO, J. J. Distribuição espacial das propriedades do solo, produção do capim-marandu com a intensidade de pastejo. **Engenharia na agricultura**, Viçosa - MG, v.24, n.4, p. 338-349, 2016.
- BOTTEGA, E. L.; QUEIROZ, D. M. D.; PINTO, F. D. A. D. C.; SOUZA, C. M. A. D. Variabilidade espacial de atributos do solo em sistema de semeadura direta com rotação de culturas no cerrado brasileiro. **Revista Ciência Agronômica**, v.44, n. 1, p. 1-9, 2013.
- CAMARGO, O. A. Infobibos. Reações e interações de micronutrientes no solo. Available in: <http://www.infobibos.com/Artigos/2006_3/micronutrientes/Index.htm>. Access on: 29 de jul. 2019.
- CARNEIRO, J. S. S.; DE FARIA, Á. J. G.; FIDELIS, R. R.; DA SILVA, S. P.; NETO, A. C. D. S.; DA SILVA, R. R. Diagnóstico da variabilidade espacial e manejo da fertilidade do solo no cerrado. **Revista Scientia Agraria**, v.17, n. 3, p. 38-49, 2016b.

- CARNEIRO, J. S. S.; DOS SANTOS, A. C. M.; FIDELIS, R. R.; DA SILVA NETO, S. P.; DOS SANTOS, A. C.; DA SILVA, R. R. Diagnóstico e manejo da variabilidade espacial da fertilidade do solo no cerrado do Piauí. **Revista de Ciências Agroambientais**, v.14, n. 2, p. 10-21, 2016a.
- CORÁ, J. E.; ARAÚJO, A. V.; PEREIRA, G. T.; BERALDO, J. M. G. Variabilidade espacial de atributos do solo para adoção do sistema de agricultura de precisão na cultura de cana-de-açúcar. **Revista Brasileira de Ciência do Solo**, Viçosa, v.28, n.6, p.1013-1021, 2004.
- DALCHIAVON, F. C.; CARVALHO, M. D. P.; ANDREOTTI, M.; MONTANARI, R. Variabilidade espacial de atributos da fertilidade de um Latossolo Vermelho Distroférico sob sistema plantio direto. **Revista Ciência Agronômica**, v.43, n.3, p. 453-461, 2012.
- DANTAS, R. A. Engenharia de Avaliações: uma introdução à metodologia científica. São Paulo: Pini, 1998.
- FAPTO. Perfil do agronegócio Tocantinense (versão final P6). Contrato nº 034/ 2015. Fundação de Apoio científico e tecnológico do Tocantins - FAPTO. Palmas – TO, 2016.
- GOLDEN SOFTWARE. Surfer for Windows version 8.0. Colorado: Golden, 2002.
- GOOVAERTS, P. Geostatistics for natural resources evaluation. New York: Oxford University Press, 1997.
- KURIHARA, C.H. Agência EMBRAPA de Informação Tecnológica (AGEITEC). Micronutrientes. Available in: < http://www.agencia.cnptia.embrapa.br/gestor/sistema_plantio_direto/arvore/CONT000fwuzxobr02wyiv807fiqu92hyld8y.html>. Access on: 29 jul. 2019.
- LIMA, G. C.; SILVA, M. L.; OLIVEIRA, M. S. D.; CURTI, N.; SILVA, M. A. D.; OLIVEIRA, A. H. Variabilidade de atributos do solo sob pastagens e mata atlântica na escala de microbacia hidrográfica. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v.18, n. 5, p.517–526, 2014.
- NEGREIROS NETO, J. V.; DOS SANTOS, A. C.; GUARNIERI, A.; SOUZA, D. J. D. A. T.; DARONCH, D. J.; DOTTO, M. A.; DOS SANTOS ARAÚJO, A. Variabilidade espacial de atributos físico-químicos de um Latossolo Vermelho-Amarelo distrófico em sistema plantio direto. **Semina: Ciências Agrárias**, v.35, n. 1, p. 193-204, 2014.
- RIBEIRO, A. C.; GUIMARÃES, P. T.; ALVAREZ V, V. H. Recomendação para o uso de corretivos e fertilizantes em Minas Gerais: 5ª aproximação. Viçosa: Comissão de Fertilidade do Solo do Estado de Minas Gerais. 1999.
- ROBERTSON, G.P. GS+: Geostatistics for the environmental sciences – GS+ User’s guide. Plainwell, Gamma Design Software, 2008.
- SANA, R. S.; ANGHINONI, I.; BRANDÃO, Z. N.; HOLZSCHUH, M. J. Variabilidade espacial de atributos físico-químicos do solo e seus efeitos na produtividade do algodoeiro. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v.18, n.10, p.994-1002, 2014.
- SANTOS, H. G.; JACOMINE, P. K. T.; DOS ANJOS, L. H. C.; DE OLIVEIRA, V. A.; LUMBRERAS, J. F.; COELHO, M. R.; CUNHA, T. J. F. Sistema Brasileiro de Classificação de – 5. ed., rev. e ampl. – Brasília, DF: Embrapa, 2018.
- SENAR. Mapas de variabilidade. In.: Introdução à Agricultura de Precisão. Serviço Nacional de Aprendizagem Rural de Goiás – SENAR/AR-GO. Goiânia – GO. 2015a.
- SENAR. Variabilidade espacial e temporal no campo. In.: Introdução à Agricultura de Precisão. Serviço Nacional de Aprendizagem Rural de Goiás – SENAR/AR-GO. Goiânia – GO. 2015b.
- SILVA, S. D. A.; LIMA, J. S. D. S.; SOUZA, G. S. D.; OLIVEIRA, R. B. D.; SILVA, A. F. D. Variabilidade espacial do fósforo e das frações granulométricas de um Latossolo Vermelho Amarelo. **Revista Ciência Agronômica**, v. 41, n. 01, p. 1-8, 2010.

SOUSA, D. M. G.; REIN, T.; SANTOS JUNIOR, J. Manejo da Adubação Fosfatada para Culturas Anuais no Cerrado. **EMBRAPA**. Circular Técnico 33, Planaltina-DF, 2016.

SOUSA, D. M. G.; LOBATO, E. Cerrado: correção do solo e adubação/ Editores técnicos Djalma Martinhão Gomes de Sousa, Edson Lobato. 2 ed. Brasília, DF: Embrapa Informação Tecnológica, 2004.

SRIVASTAVA, R. M. Describing spatial variability using geostatistics analysis. In: ROUHANI, S.; SRIVASTAVA, R. M.; DESBARATS, A. J.; CROMER, M. V.; JOHNSON, A. I. (Ed.). Geostatistics for environmental and geotechnical applications. West Conshohocken: ASTM, 1996.

VIEIRA, S.R. Geoestatística em estudos de variabilidade espacial do solo. In: NOVAIS, R.F.; ALVAREZ V.V.H.; SCHAEFER, G.R. (Ed.). Tópicos em ciência do solo. Viçosa: Sociedade Brasileira de Ciência do solo, 2000.

ZANÃO JÚNIOR, L. A.; LANA, R. M. Q.; CARVALHO-ZANÃO, M. P.; GUIMARÃES, E. C. 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.

ZARONI, M. J.; SANTOS, H. G. ESPECIAL – Agencia EMBRAPA de Informação Tecnológica (AGEITEC). 2019. Available in: < http://www.agencia.cnptia.embrapa.br/gestor/solos_tropicais/arvore/CONTAG01_2_2212200611536.html>. Access on: 28 junho 2019.

ZONTA, J. H.; BRANDÃO, Z. N.; MEDEIROS, J. D. C.; SANA, R. S.; SOFIATTI, V. Variabilidade espacial da fertilidade do solo em área cultivada com algodoeiro no Cerrado do Brasil. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v.18, n.6, p.595–602, 2014.