ISSN 2175-6813

Revista Engenharia na Agricultura

Viçosa, MG, DEA/UFV - DOI: 10.13083/reveng.v29i1.9979 V.28, p.425-434, 2020

SPATIAL CORRELATION BETWEEN THE CHEMICAL ATTRIBUTES OF A RED LATOSOL AND THE GRAIN YIELD OF COMMON BEAN

Job Teixeira de Oliveira[1], Cassiano Garcia Roque[2], Monica Resende Zuffo Borges[3], Vagner André Minotto[4] & André Longui Javarez[5]

1 - Professor UFMA, Department Agricultural Engineering, Universidade Federal do Maranhão (UFMA). E-mail: job.oliveira@hotmail.com

2 - Professor UFMS, Universidade Federal do Mato Grosso do Sul, CPCS, Chapadão do Sul, MS.. E-mail: cassiano.roque@ufms.br

3 - Química. Universidade Federal do vale do São Francisco. Petrolina, PE. E-mail: monica.zuffo@univasf.edu.br

4 - Agronomo. Universidade Federal do Mato Grosso do Sul, CPCS, Chapadão do Sul, MS. vagner.minotto@outlook.com

5 - Mestre. Universidade Federal do Mato Grosso do Sul, CPCS, Chapadão do Sul, MS. andrelongui@gmail.com

Keywords:
precision agriculture
geostatistics
soil management
irrigation
soil quality

ABSTRACT

In recent years, common bean in Brazil has become interesting to precede the growing of off-season cotton due to its short cycle. This study was carried out in a Red Latosol in Chapadão do Sul, MS and aimed to select among the attributes of the evaluated soils, those with the best linear and spatial correlation, to explain the variability of grain yield of common bean in the soil layers of 0 - 0.10 m (layer 1) and 0.10 - 0.20 m (layer 2), sampled in a grid of 121 georeferenced points (spacing of 5 meters between points). The soil chemical attributes were determined: pH, carbon (C), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), aluminum (Al), and the sum of bases (SB). The analysis of these data was carried out using statistical and geostatistical techniques that made it possible to verify that for the grain yield of common bean, the multiple regression analysis indicates that approximately 20% of its variation is attributed to the variation in the chemical attributes of the soil presented in the present study. The chemical attributes pH1, pH2, C1, Ca1, Ca2, Mg1a, Mg2, Al2, SB1, and SB2 have spatial dependence classified mostly as moderate. Both linearly and spatially, C1 stood out as a potential indicator of common bean grain yield when grown under no-tillage.

Palavras-chave:
agricultura de precisão
geoestatística
manejo do solo
irrigação
qualidade do solo

CORRELAÇÃO ESPACIAL ENTRE OS ATRIBUTOS QUÍMICOS DE UM LATOSSOLO VERMELHO E A PRODUTIVIDADE DE GRÃOS DO FEIJOEIRO

RESUMO

Nos últimos anos, o feijão comum no Brasil tornou-se interessante para preceder o cultivo do algodão safrinha devido ao seu ciclo curto. Este estudo foi realizado em um Latossolo Vermelho em Chapadão do Sul, MS e teve como objetivo selecionar entre os atributos do solo avaliados, aqueles com melhor correlação linear e espacial, para explicar a variabilidade da produtividade de grãos do feijoeiro nas camadas do solo. de 0 - 0,10 m (camada 1) e 0,10 - 0,20 m (camada 2), amostrados em uma malha de 121 pontos georreferenciados (espaçamento de 5 metros entre os pontos). Foram determinados os atributos químicos do solo: pH, carbono (C), fósforo (P), potássio (K), cálcio (Ca), magnésio (Mg), alumínio (Al) e soma de bases (SB). A análise desses dados foi realizada por meio de técnicas estatísticas e geoestatísticas que permitiram verificar que para a produtividade de grãos do feijão, a análise de regressão múltipla indica que aproximadamente 20% de sua variação é atribuída à variação dos atributos químicos do feijão. Os atributos químicos pH1, pH2, C1, Ca1, Ca2, Mg1a, Mg2, Al2, SB1 e SB2 apresentam dependência espacial classificada principalmente como moderada. De forma linear e espacial, C1 se destacou como potencial indicador da produtividade de grãos do feijão quando cultivado em sistema plantio direto.

Recebido para publicação em 08/04/2020 • Aprovado em 31/08/2020 • Publicado em 08/12/2020

INTRODUCTION

In recent years, common bean in Brazil, specifically in the region of Chapadão do Sul-MS, has become interesting to precede the growing off-season cotton due to its short cycle. From the 2019/2020 harvest, it was estimated that the total area of common bean would increase to 2,909 thousand hectares, 0.6% greater compared to the previous harvest. Domestic common bean production is expected to be 3,022,800 tons, 0.6% higher than last season (CONAB, 2020).

The use of precision agriculture techniques, such as their use in localized management of soil fertility, has been widely used. The dosages of inputs are applied in a variable way, aiming to meet the specific needs of each location, optimizing the production process, and reducing the environmental impacts caused by agricultural practices. Therefore, it is essential to characterize the spatial variability of the chemical and physical attributes of the soil through sampling capable of representing such variations (BOTTEGA *et al*., 2013).

As a result of both the short cycle and the characteristics of the root system, the common bean is considered a nutrient-demanding plant, and they must be properly placed, in time and space, at their disposal (MONTANARI *et al*., 2013a).

In order to keep the increase of yield in the crop production system, fertilizers and correctives can be classified as the most important inputs due to their ability to influence crop yield. An alternative to optimize the system is adopting precision agriculture, which promotes knowledge of soil variability (CAMARGO *et al*., 2013).

Geostatistics which is one of the tools of precision agriculture, which allows the study of the spatial variability of soil attributes and the study of the technique helps the computer programs used in precision agriculture; that is, the data generated and adjusted for simple data interpolation (kriging) and cross interpolation (cokriging) between plant versus soil attributes serve as a basis for estimating the spatial variability of a given variable through another with ease of determination (MONTANARI *et al*., 2015).

We aimed with this paper to select, among the evaluated soil attributes, those with the best linear and spatial correlation, to explain the variability in the grain yield of common bean and the possible creation of specific management zones.

MATERIAL AND METHODS

The study was carried out in 2015, at the Federal University of Mato Grosso do Sul, in Chapadão do Sul (MS), located at 18°46’18” S and 52°37’25” W, with an average altitude of 820 m. According to Köppen, the region’s climate is classified as humid tropical (Aw-type), with a rainy season in summer and a dry season in winter and an average annual rainfall of 1850 mm, and an annual average temperature of 25 ºC. The soil in which the experimental grid was installed was classified as a Red Latosol, with a homogeneous slope of 0.055 m $m^{-1,}$ according to (EMBRAPA, 2018).

The studied soil had 34.5, 10.6, and 54.9 g kg^{-1} of sand, silt, and clay. The area has been cultivated with soybean and corn in the first and second harvest, respectively. For the past two years, the soil has been fallow. The crop was implanted in mid-October 2012. The test plant used was the common bean (*Phaseolus vulgaris* L.), cultivar Pérola; the sowing was carried out in the whole area, with a row spacing of 0.45 m and an average plant density of 16 plants m^{-1}. The normal practices of conducting the crop, such as phytosanitary treatment and chemical cultivation, were carried out homogeneously throughout the experimental area, according to the recommendations of Fahl *et al*. (1998).

The experimental area was defined between two terraces, in the x and y directions; thus, an area with 2,500 m^2 (50.0 m x 50.0 m) was restricted, which contained 121 sample points arranged in a regular grid of 5.0 m x 5.0 m as shown in Figure 1.

The following soil chemical attributes, pH, the contents of carbon (g kg^{-1}), phosphorus (mg dm^{-3}), potassium ($mmol_c$ dm^{-3}), calcium ($mmol_c$ dm^{-3}), magnesium ($mmol_c$ dm^{-3}), aluminum ($mmol_c$ dm^{-3}), and the sum of bases ($mmol_c$ dm^{-3}) were determined. The soil attributes were individually collected around each sample point at the soil layers: 1) 0 - 0.10 m and 2) 0.10 - 0.20 m. The plant traits and grain yield (YLD) were individually collected

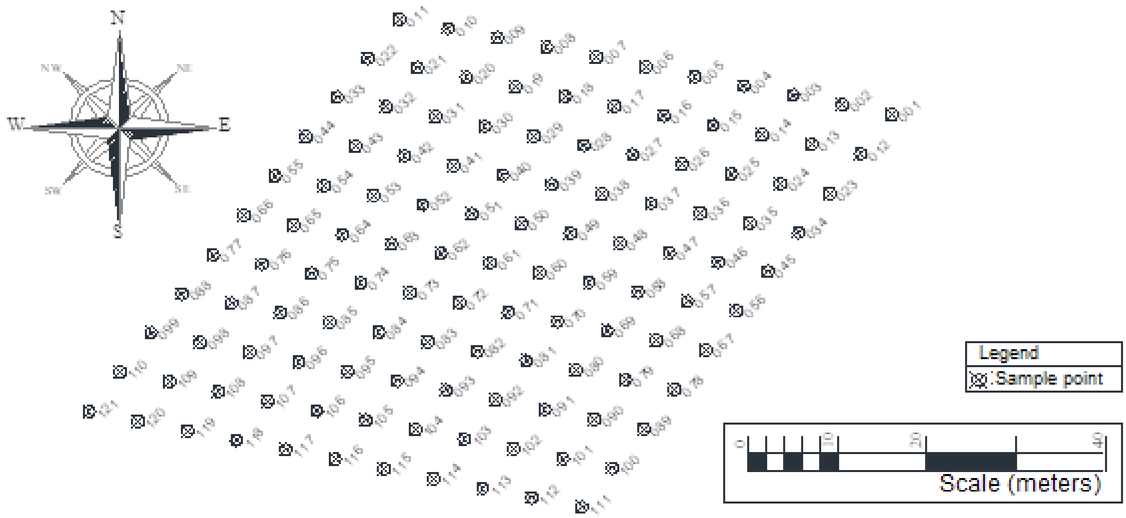

Figure 1. Sampling grid and details of sampling performed in Chapadão do Sul (MS)

around each sampling point, with a useful area of 3.24 m^2 (1.8 x 1.8 m) in four rows. The common bean was harvested between the phenological stages R7 and R8, with humidity between 13 and 15%.

For the studied attributes, the initial descriptive analysis, linear regression, and geostatistical analysis were performed. With the aid of the statistical software Rbio (biometrics in R), version 17, the mean, minimum and maximum values, standard deviation, coefficient of variation, kurtosis, asymmetry, and frequency distribution were calculated. The Shapiro-Wilk (1965) statistic at 5% was used to test the hypothesis of normality,

Pearson's correlation matrix was set up, aiming to perform simple linear regressions for the combinations, from two to two, between all the studied attributes (soil and plant), in order to study the linear correlation between them, in an attempt to try to select those that would probably provide cross-semivariogram and, therefore, cokriging; for that, the Excel software was used.

The spatial dependence analysis of the chemical attributes of the soil was made using the *Gamma Design Software* GS$^+$ (2004). The adjustments of the simple semivariograms, depending on their models, were made primarily by the initial selection of a) the smallest sum of the squares of the deviations (SSD), b) the highest determination coefficient (r2), and c) the highest grade of spatial dependence evaluation (SDE). The final decision of the model that represented the adjustment was made by cross-validation and the definition of the neighborhood size that provided the best grid of kriging.

The analysis of the Spatial Dependence Evaluation (SDE) was performed according to equation 01:

$$SDE = \left[\frac{C}{C+Co}\right] x\ 10 \qquad (1)$$

where:
SDE is the spatial dependence evaluation; C, the structural variance; and C+C$_o$, the landing. The proposed interpretation for the SDE was as follows: a) SDE < 25% = spatial variable of low dependence; b) 25% ≤ SDE < 75 % = moderate dependence, and c) 75% ≤ SDE < 100% = strong dependence (DALCHIAVON *et al*., 2012).

RESULTS AND DISCUSSION

According to Pimentel-Gomes and Garcia (2002), the coefficient of variation (CV) can be classified according its magnitude as low (CV < 10%), medium (10% < CV < 20%), high (20% < CV <30%) and very high (CV > 30%).

From the attributes presented in Table 1, we verified that the grain yield presented high variability (27.4%), similar to the results obtained by Dalchiavon *et al*. (2011). They worked with a grid of 135 points of 2.5 m x 2.5 m between points; the authors also found high variability (20.3%) for common bean grain yield. Still, different from those found by Montanari *et al*. (2013a), who work with a 5.0 m x 5.0 m grid, found average variability (18.3%).

From the soil attributes, it is observed that pH1, pH2 presented low variability, 3.1%, and 3.5%, respectively. Such data are following results obtained by Montanari *et al*. (2013a), working in a Latossolo Vermelho distrófico obtained 4.4% and 4.3% for the soil layers of 0.00 - 0.10 m and 0.10 - 0.20 m; Matias *et al*. (2015) who also found low pH variability (2.58%) and also in agreement with Carvalho *et al*. (2002), where the author also found that for the no-till system, the pH also obtained low variability (5.34%); also in line with data from Dalchiavon *et al*. (2012) where the author found low variability for the two soil layers in this study, 0.0 - 0.10 m and 0.10 - 0.20 m, with 7.8% and 6.91%, respectively.

The results for soil attributes C1 and C2 showed medium variability, 14.9%, and 15.3%, respectively. The phosphorus in the soil layer P1, 0.00 - 0.10 m, showed high variability (25.6%), and in the soil layer P2, 0.10 - 0.20 m, medium variability (17.7 %). Discordant results from those were found by Montanari *et al*. (2013a) (43.4% and 43%) and Lima *et al*. (2013) (32.1% and 48.0%), where the authors obtained very high variability for phosphorus at both soil layers. This discrepancy in the data obtained can be explained by the adsorption of this nutrient to the oxides of Fe and Al (ALVES *et al*., 2014).

About potassium, K1 and K2a presented medium variability with values of 17.5% and 19%, respectively, different from those obtained by Dalchiavon *et al*. (2011), where the author found for K, very high variability (38.5%). The authors report that the high variability of K may indicate that it may have been interfered with by the predecessor crop (corn) due to fertilization, which did not occur in this work because the soil was fallow in the last two years as previously described.

Also, in Table 1, calcium showed very high

Table 1. Initial descriptive statistics of grain yield of common bean and some chemical attributes of a Latossolo Vermelho in Chapadão do Sul, (MS)

Attribute [(a)]	Average	Minimum	Maximum	Standard deviation	Variation (%)	Kurtosis	Asymmetry	Pr<w	FD [(b)]
YLD	2278.70	482.30	3453.30	625.20	27.4	-0.423	-0.232	0.084	NO
pH1	4.75	4.40	5.23	0.15	3.1	0.943	0.335	0.048	NO
pH2	4.63	4.16	5.11	0.16	3.5	0.550	0.273	0.146	NO
C1	6.35	2.50	8.05	0.95	14.9	2.212	-0.943	$2x10^{-4}$	UN
C2	5.13	2.88	6.89	0.79	15.3	0.617	-0.645	0.001	UN
P1	10.58	5.74	21.29	2.71	25.6	3.945	1.365	$1x10^{-4}$	UN
P2	8.99	5.74	12.62	1.60	17.7	-0.128	0.008	0.111	NO
K1	0.58	0.37	0.81	0.10	17.5	-0.565	0.071	0.328	NL
K2	0.51	0.26	0.77	0.10	19.0	0.034	0.030	0.702	NL
Ca1	12.12	8.00	30.80	4.33	35.8	7.269	2.711	$1x10^{-4}$	UN
Ca2	10.66	4.30	25.30	3.65	34.2	6.022	2.221	$1x10^{-4}$	UN
Mg1	0.88	0.51	1.35	0.17	19.0	-0.627	0.158	0.035	TL
Mg2	6.52	0.01	17.53	3.16	48.5	0.501	0.399	0.010	UN
Al1	1.32	0.70	1.95	0.22	16.5	0.013	0.184	0.581	NL
Al2	2.25	0.01	10.00	1.36	60.4	9.367	2.313	$1x10^{-4}$	UN
SB1	24.31	16.34	46.10	6.46	26.6	2.122	1.510	$1x10^{-4}$	UN
SB2	20.45	8.58	39.19	5.86	28.7	1.324	0.939	$1x10^{-4}$	UN

[(a)] YLD = grain yield, (kg ha^{-1}), pH1 and pH2 = hydrogen potential, C1 and C2 = soil carbon content, (g kg^{-1}), P1 and P2 = phosphorus content, (mg dm^{-3}), K1 and K2 = potassium content, ($mmol_c$ dm^{-3}), Ca1 and Ca2 = calcium content, ($mmol_c$ dm^{-3}), Mg1 and Mg2 = magnesium content, ($mmol_c$ dm^{-3}), Al1 and Al2 = active soil acidity, (mmolc dm^{-3}), SB1 and SB2 = sum of bases, ($mmol_c$ dm^{-3}). a = data transformed into log, b = data transformed into log (x*10). (b) FD = frequency distribution, NO = normal, UN = undetermined, NL = normal log, and TL = tending to normal log.

variability with values of 35.8% and 34.2%, consistent with those obtained by Alves *et al.* (2014), where the author working with a grid of 230 m x 228 m in two soil layers obtained 44.81% and 43.39% respectively. For magnesium, values of Mg1a and Mg2 of 19.0% and 48.5% respectively were observed. Cavalcante *et al.* (2007) verified the values of magnesium in a no-tillage system of 35% and for the conventional tillage of 49%. These results are analogous to those found for magnesium in the deepest layer (0.10 - 0.20 m); these same variabilities were also found by Lima *et al.* (2013), where the actors also found very high variability (39.2%) for the deepest layer assessed. The medium variability found for Mg1a differs from those found by the authors mentioned above and can be explained since the Mg1a data in this study were normalized by the log.

Bottega *et al.* (2013) also found very high variability for aluminum, as found in this work for Al2 (60.4%). From this high variability arises the need for more refined techniques such as precision agriculture that precisely consider this effect of the sampling error in soil collection (DALCHIAVON *et al.*, 2011).

High variability was observed for SB1 and SB2, 26.6%, and 28.7%, respectively (Table 1). Matias *et al.* (2015) also found high variability (20.58%) working in a Latossolo Amarelo distrófico cultivated with soy in a conventional tillage system with georeferenced points in two areas with 50 points each. Dalchiavon *et al.* (2011) found very high variability (30.4%) working with common bean irrigated with a center pivot, in a Latossolo Vermelho distroférrico under a no-tillage system, different from those obtained in this work.

According to Cavalcante *et al.* (2007), a variation coefficient greater than 35% reveals that the series is heterogeneous, and the mean has little meaning. If it is greater than 65%, the series is very heterogeneous, and the average has no meaning. However, if it is less than 35%, the series is homogeneous, and the mean has meaning, and it can be used as representative of the series from which it was obtained; this indicates in this work that Ca1, Ca2, Mg2, and Al2 presented heterogeneous and average data series with little significance. According to Silva *et al.* (2003), even finding low coefficients of variation of Ca, Mg, and Al, surface applications followed by soil tillage for incorporation can generate variability in the soil, thus being able to indicate the high value of the coefficient of variation of Ca1, Ca2, Mg2, and Al2 obtained in this analysis.

When any statistical variable has a frequency distribution of the normal type, the most suitable central tendency measure to represent it should be the average; in contrast, it will be represented by the median, or by the geometric mean, if it is of the lognormal type (MONTANARI *et al.*, 2010). Therefore, the central tendency average representing the YLD and the soil attributes pH1, pH2, and P2 should be the average due to its normal frequency distribution, in agreement with the data obtained by Dalchiavon *et al.* (2011). For soil attributes C1, C2, P1, Ca1, Ca2, Mg2, Al2, S1, and S2, the frequency distribution was of the indefinite type; for the attributes K1a, K2a, and AL1b, the frequency was of the normal log type; and Mg1 tending to log.

Table 1 shows that the common bean grain yield has an average value of 2,278.7 kg ha^{-1}, close to the values found by Montanari *et al.* (2010) with 2,200.9 kg ha^{-1}, but below the values found by Dalchiavon *et al.* (2011) with an average of 3,044 kg.ha^{-1} and, well above the municipal average reported by Conab (2017), which are around 1,800 kg ha^{-1}.

In the study of Pearson's linear correlations of YLD with the chemical attributes of the soil (Figure 2), YLD established positive and significant correlations with Ca1 (r = 0.200*) and Ca2 (r = 0.260*) presented in Figure 3. The attributes Al1 (r = 0.170*), C2 (r = 0.150*) and SB2 (r = 0.170*) also established positive correlations with YLD, unlike those found by Dalchiavon *et al.* (2011), which obtained a direct relationship to organic matter and pH. In the present study, significant correlations of SB with Ca and Mg were found. Results were also verified by Matias *et al.* (2015), who found significant correlations of SB with Ca and Mg. The negative correlation found between pH and Al was also found by Matias *et al.* (2015), who found a value of r = -0.140.

In the multiple regression analysis of YLD according to all soil attributes in the present

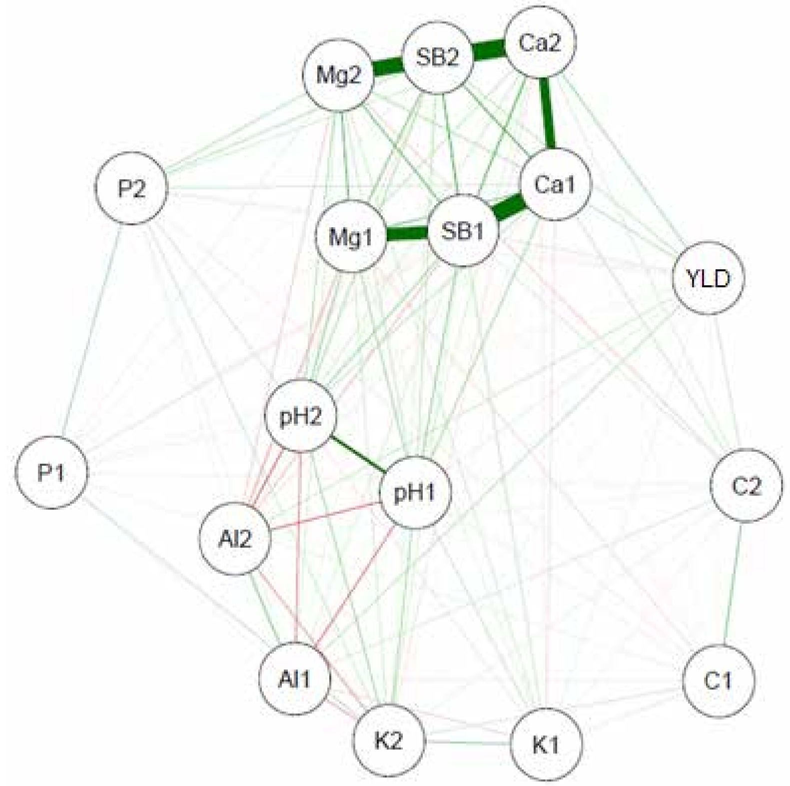

Figure 2. Network of correlations of common bean grain yield and some chemical attributes of a Latossolo Vermelho in Chapadão do Sul (MS)

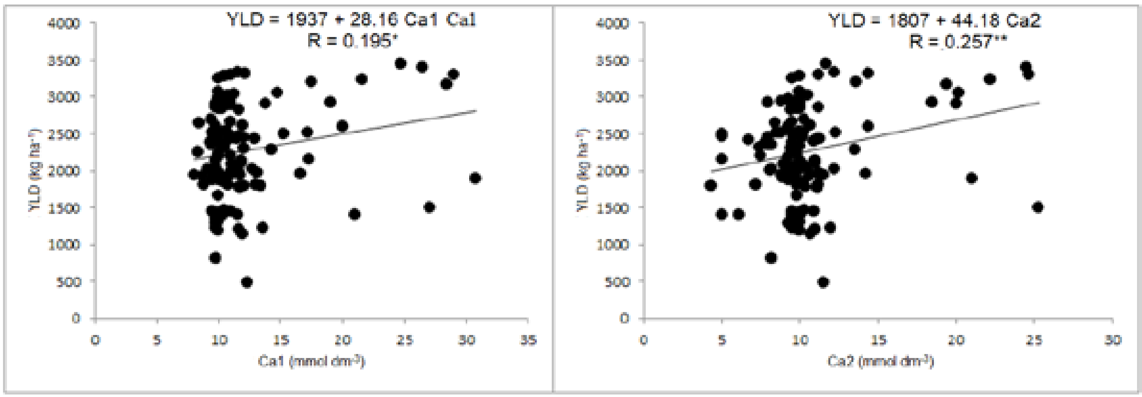

Figure 3. Regression equations of common bean grain yield (YLD) according to Ca1 and Ca2 in a Latossolo Vermelho of Chapadão do Sul (MS)

study, the tested model (Equation 2) explained approximately 20.4% of the variation in common bean grain yield in the soil layer of 0 - 0.20 m (r^2 = 0.204**). Dalchiavon *et al.* (2011) explained with their experiment approximately 22.1% of the variation in the grain yield of irrigated common bean, grown in a no-tillage system, in the soil layer of 0 - 0.20 m, in a Latossolo Vermelho Distroférrico, with georeferenced sample grid with 135 points.

$$YLD = -5901.3 + 878.5\ pH1 + 85.8\ pH2 - 2.6\ C1 + 90.0\ C2 + 16.0\ P1 - 47.6\ P2 + 2083.4\ K1a + 84.3\ K2a + 174.4\ Ca1 + 5.8\ Ca2 + 2815.0\ Mg1a - 37.0\ Mg2 + 780.1\ Al1b + 35.7\ Al2 - 161.6\ SB1 + 27.5\ SB2 \quad (2)$$

Geostatistical analysis (Table 2) showed that there was spatial dependence for the Mg1a attribute semivariogram and PG = f (C1) crossed semivariogram that fit the spherical model, while YLD, C1, and SB1 adjusted to the exponential model, in agreement with Montanari *et al*. (2013b) who say that spherical and exponential models are presented as the most common theoretician models for soil and plant attributes. However, the attributes pH1, pH2, Ca1, Ca2, Al2, and SB2 adjusted to the Gaussian model. For the other soil elements C2, P1, P2, K1a, K2a, and Al1b, the pure nugget effect (pnf) was observed. When the variogram is presented as a pure nugget effect (in which case the points of the variogram would be practically aligned with the abscissa axis), it means that the structuring of the variable, if it exists, cannot be visualized on the scale used; therefore there is no advantage so that the geostatistical method is adopted to study it (ANDRIOTTI, 2010).

In Table 2, the spatial determination coefficients (r^2) was as follows in the simple semivariograms: 1) Ca1 - 0.925, 2) Mg1a - 0.902, 3) SB2 - 0.835, 4) Ca2 - 0.812, 5) Mg2 - 0.768, 6) pH2 - 0.739, 7) SB1 - 0.738, 8) YLD - 0.667, 9) C1 - 0.521, 10) Al2 - 0.512, 11) pH1 - 0.435. The value found (0.738) for the sum of bases in the soil layer of 0.00 - 0.10 m, with SDE classified as medium (53.9%) and the exponential model adjusted with a range of 45.3 m, compared with Alves *et al*. (2014) working in a Latossolo Vermelho Amarelo Distrófico, with the cultivation of sugar cane, in 121 georeferenced sample points, found a lower r^2 value of 0.073 with SDE classified as very high (87.3%), the model adjusted to the exponential type with a range of 51.9 m.

Table 2. Estimated parameters for the simple and crossed semivariogram of the variables

Attribute [a]	Model [b]	Nugget Co	Sill Co+C	Range Ao (m)	r^2	SRS [c]	SDE [d]		Cross Validation		
							%	Classe	a	b	r
					γ(h) Simple						
YLD	exp.	2.12×10^{5}	4.25×10^{5}	32.1	0.667	8.65×10^{9}	50.0	Moderate	6.21	0.999	0.420
					γ(h) Simple						
pH1	gau.	1.23×10^{-2}	2.07×10^{-2}	7.5	0.435	1.44×10^{-5}	40.6	Moderate	3.22	0.322	0.134
pH2	gau.	1.43×10^{-2}	2.61×10^{-2}	7.0	0.739	1.44×10^{-5}	45.1	Moderate	3	0.351	0.145
C1	exp.	4.92×10^{-1}	9.85×10^{-1}	30.6	0.521	9.48×10^{-2}	50.1	Moderate	1.52	0.762	0.279
C2	pnf	-	-	-	-	-	-	-	-	-	-
P1	pnf	-	-	-	-	-	-	-	-	-	-
P2	pnf	-	-	-	-	-	-	-	-	-	-
K1a	pnf	-	-	-	-	-	-	-	-	-	-
K2a	pnf	-	-	-	-	-	-	-	-	-	-
Ca1	gau.	7.00	16.50	18.0	0.925	6.65	57.6	Moderate	-2.13	1.177	0.815
Ca2	gau.	8.00	14.50	59.0	0.812	13.00	44.8	Moderate	-0.06	1.432	0.335
Mg1a	sph	6.50	12.40	24.0	0.902	2.31	47.6	Moderate	0.03	0.996	0.521
Mg2	gau.	4.30	10.20	5.1	0.768	8.57	57.8	Moderate	2.56	0.614	0.226
Al1b	pnf	-	-	-	-	-	-	-	-	-	-
Al2	gau.	1.00	1.79	5.5	0.512	8.91×10^{-2}	44.1	Moderate	0.73	0.688	0.228
SB1	exp.	2.45×10^{1}	48.76	45.3	0.738	1.75×10^{2}	53.9	Moderate	-9.04	1.385	0.620
SB2	gau.	5.00	32.65	6.0	0.835	80.4	84.7	Strong	9.63	0.534	0.226
					γ(h) Cruzader						
YLD=f(C1)	sph	1.00×10^{-1}	1.06×10^{2}	62.3	0.926	7.89×10^{2}	99.9	Strong	324.5	0.961	0.715

[a]YLD = grain yield, (kg ha^{-1}), pH1 and pH2 = hydrogen potential, C1 and C2 = soil carbon content, (g kg^{-1}), P1 and P2 = phosphorus content, (mg dm^{-3}), K1 and K2 = potassium content, ($mmol_c$ dm^{-3}), Ca1 and Ca2 = calcium content, ($mmol_c$ dm^{-3}), Mg1 and Mg2 = magnesium content, ($mmol_c$ dm^{-3}), Al1 and Al2 = active soil acidity, (mmolc dm^{-3}), SB1 and SB2 = sum of bases, ($mmol_c$ dm^{-3}). a = data transformed into log, b = data transformed into log (x*10). [b] sph = spherical, exp = exponential, gau = gaussian, and pnf = pure nugget effect. [c] SRS = sum of the residue square; [d] SDE = spatial dependence evaluation.

About the spatial dependence evaluation (SDE), the highest value was observed in SB2 with 84.7%, followed by Mg2 with 57.8%, Ca1 57.6%, SB1 53.9%, C1 50.1% , YLD 50.0%, Mg1a 47.6%, pH2 45.1%, Ca2 44.8%, Al2 44.1%, and finally pH1 40.6%. The spatial dependency ranges in decreasing order was: Ca2 - 59.0 m, SB1 - 45.3 m, YLD - 32.1 m, C1 - 30.6 m, Mg1a - 24.0 m, Ca1 - 18.0 m, pH1 - 7.5 m, pH2 - 7.0 m, SB2 - 6.0 m, Al2 - 5.5 m, and Mg2 - 5.1 m. Therefore, exclusively based on the present research, as well as aiming to assist future research, in which the same attributes are involved, the values of the spatial dependence ranges to be used in the geostatistical packages, which will feed the computational packages used in the precision agriculture, in general, they should not be less than 5.1 m for soil attributes and 32.1 m for plant traits.

In terms of co-kriging, there was an adjustment between YLD and C1 shown in Figure 4. It was found that 92.6% (C1) of the spatial variability of common bean grain yield could be explained by the spatial variability of C1, so that the highest values of common bean grain yield were found precisely in

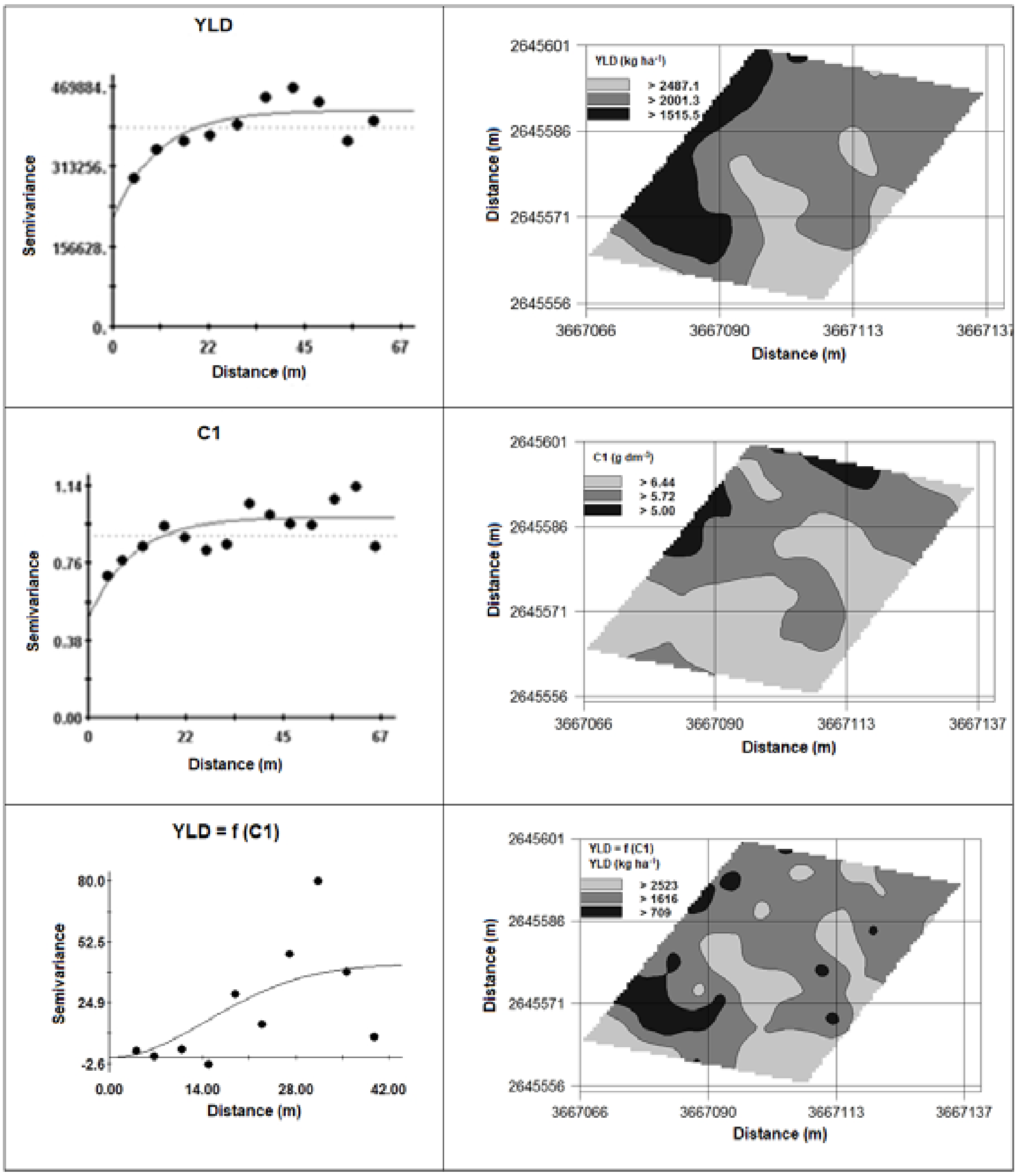

Figure 4. Simple and crossed semivariograms, kriging and co-kriging maps of common bean grain yield, (kg ha^{-1}), and carbon content (C1) of a Latossolo Vermelho in Chapadão do Sul, MS

the central and southern regions, possibly because they are the areas where the highest values of soil carbon were obtained, in the soil layer of 0.00 - 0.10 m. The spatial dependence for this co-kriging was high (SDE = 99.9 (YLD = f (C1)), with the spherical model being adjusted (Table 2; Figure 4).

Thus, it can be inferred that the spatial variability between the soil attribute C1 and the common bean grain yield followed the same linear behavior; therefore, by co-kriging of high significance, one can estimate the common bean grain yield by the direct effect of increasing carbon in the soil.

CONCLUSION

- The multiple regression analysis of the data indicated that approximately 20% of the common bean grain yield is attributed to the variation of all chemical attributes of the soil described in the present work.
- The chemical attributes pH1, pH2, C1, Ca1, Ca2, Mg1a, Mg2, Al2, SB1, and SB2 have spatial dependence classified in the majority as moderate.
- Both linearly and spatially, C1 stood out as a potential indicator of common bean grain yield when grown under a no-tillage system.

REFERENCES

ALVES, V.; MONTANARI, R.; CARVALHO, M.P.; CORREA, A.R.; ROQUE, C.G. Atributos tecnológicos, stand e produtividade da cana-planta correlacionados com aspectos da fertilidade do solo em Chapadão do Céu (GO). **Revista de Agricultura Neotropical**, Cassilândia-MS, v.1, n.1, p.75-91, 2014.

ANDRIOTTI, J.L.; **Fundamentos de Estatística e Geoestatística**. (ed.) Unisinos, São Leopoldo-RS, 2010.

BOTTEGA, E.L.; QUEIROZ, D.M.; PINTO, F.A.C.; SOUZA, C.M.A. Variabilidade espacial de atributos do solo em sistema de semeadura direta com rotação de culturas no cerrado brasileiro. **Revista Ciência Agronômica**, Fortaleza- CE v.44, n.1, p.1-9, 2013.

CAMARGO, L.A.; MARQUES JUNIOR, J.; PEREIRA, G.T. Mineralogy of the clay fraction of Alfisols in two slope curvatures. III - Spatial Variability. **Revista Brasileira de Ciência do Solo,** Viçosa-MG, v.37, n.2, p.295-306, 2013.

CARVALHO, J.R.P.; SILVEIRA, P.M.; VIEIRA, S.R. Geoestatística na determinação da variabilidade espacial de características químicas do solo sob diferentes preparos. **Pesquisa Agropecuária Brasileira**, Brasília-DF, v.37, n.8, p.1151-1159, 2002.

CAVALCANTE, E.G.S.; ALVES, M.C.; SOUZA, Z.M.; PEREIRA, G.T. Variabilidade espacial de atributos químicos do solo sob diferentes usos e manejos**. Revista Brasileira de Ciência do Solo**, Viçosa, MG, v.31, n.2, p.1329-1339, 2007.

CONAB. Companhia Nacional de Abastecimento. Perspectivas para a agropecuária, safra 2016/2017; mar/2017. Brasília: **Conab**, 2017. Disponível em: V.4 - Safra 2016/17 - N.6 - sexto levantamento março 2017.

CONAB. Companhia Nacional de Abastecimento. Perspectivas para a agropecuária, safra 2019/2020; jan/2020. Brasília: **Conab**, 2020. Disponível em: V.7 - Safra 2019/20 - N.4 - quarto levantamento jan. 2020.

DALCHIAVON, F.C., CARVALHO, M.P., FREDDI, O.S., ANDREOTTI, M , MONTANARI, R. Variabilidade espacial da produtividade do feijoeiro correlacionada com atributos químicos de um Latossolo Vermelho Distroférrico sob sistema de semeadura direta. **Bragantia**, Campinas, v.70, n.4, p.908-916, 2011.

DALCHIAVON, F.C.; CARVALHO, M.P.; ANDREOTTI, M.; MONTANARI, R. Variabilidade espacial de atributos da fertilidade de um Latossolo Vermelho Distroférrico sob Sistema Plantio Direto. Revista Ciência Agronômica, Fortaleza-CE, v.43, n.1, p.453-461, 2012.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA – Embrapa. **Sistema brasileiro de classificação de solos**. Embrapa, 2018.

FAHL, J.I.; CAMARGO, M.B.P.; PIZZINATTO, M.A; BETTI, J.A.; MELO, A.M.T; DE MARIA, I.C.; FURLANI, A.M.C. Instruções agrícolas para as principais culturas econômicas. 6. ed. Campinas: Instituto Agronômico, 1998.

GAMMA DESIGN SOFTWARE: **GS+.** Geostatistics for environmental sciences. 7. ed. Michigan: Gamma Desing Software, 2004.

LIMA, S.D.L.; SILVA, S.A.; SILVA, J.M. Variabilidade espacial de atributos químicos de um Latossolo Vermelhor-Amarelo cultivado em plantio direto. **Revista Ciência Agronômica**, Fortaleza-CE, v.44, p.16- 23, 2013.

MATIAS, S.S.R.; BAPTISTEL, A.C.; NOBREGA, J.C.A.; ANDRADE, F.R.; SILVA, J.B.L. Variabilidade espacial dos atributos do solo em duas áreas de manejo convencional no Cerrado piauiense. **Revista de Ciências Agrárias/ Amazonian Journal of Agricultural and Environmental Sciences,** Belém-PA, v.58, n.2, p.217-227, 2015.

MONTANARI R., CARVALHO, M.P., ANDREOTTI, M., DALCHIAVON, F.C., LOVERA, L.H., HONORATO, M.A.O. Aspectos da produtividade do feijão correlacionados com atributos físicos do solo sob elevado nível tecnológico de manejo. **Revista Brasileira de Ciência do Solo**, v.34, p.1811-1822, 2010.

MONTANARI, R.; RODRIGUES, G.G.; DE PASSOS, M.; DALCHIAVON, F.C.; MACHADO, F.C.; GONZALEZ, A.P. Atributos químicos de um Latossolo espacialmente relacionados com a produtividade e componentes de produção do feijão em Selvíria (MS). **Revista de Ciências Agroveterinárias**, Lajes-MG v.12, n.3, p.271-281, 2013a.

MONTANARI R., CARVALHO, M.P., FILHO, M.C.M.T., DALCHIAVON, F.C. Produção de matéria seca da braquiária de acordo com os atributos químicos de um Latossolo em Selvíria, Mato Grosso do Sul. **Revista Ceres**, Viçosa, v.60, n.6, p.772-784, nov/dez, 2013b.

MONTANARI R.; PANACHUKI, E.; LOVERA, L.H.; CORREA, A.R.; OLIVEIRA, I.S.; QUEIROZ, H.Á.; TOMAZ, P.K. Variabilidade espacial da produtividade de sorgo e de atributos do solo na região do ecótono Cerrado-Pantanal, MS. **Revista Brasileira de Ciência o Solo**, Viçosa, MG, v.39, n.2, p.385-96, 2015.

PIMENTEL-GOMES, F. P., GARCIA, C. H. (2002) Estatística aplicada a experimentos agronômicos e florestais. Piracicaba, FEALQ, 2002.

SHAPIRO, S.S.; WILK, M.B. An analysys of variance test for normality: complete samples. **Biometrika**, London, v.52, p.591-611, 1965.

SILVA, V.R.; REICHERT, J.M.; STORCK, L.; FEIJÓ, S. Variabilidade espacial das características químicas do solo e produtividade de milho em um Argissolo Vermelho-Amarelo distrófico arênico. **Revista Brasileira de Ciência do Solo**, Viçosa-MG, v.27, n.6, p.1013-1020, 2003.