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Interrelationship between cotton parameters and soil chemical properties in Central Brazil

Inter-relação entre parâmetros do algodoeiro com atributos químicos do solo no Brasil Central

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ABSTRACT

Classical geostatistical techniques and Geostatistics are important tools to correlate, linearly and spatially, vegetal productivity with the soil properties. Spatial and Pearson correlations between the attributes of the cotton plant and the soil properties were used in Campo Novo do Parecis, State of Mato Grosso, Brazil, in 2015 to determine the variability of plant productivity and soil chemical properties in the Savannah of Mato Grosso. A geostatistical grid was established for collection of data of the soil and plant, with 100 sampling points, in a plot with cotton crop. Soil was classified a Typic Tropustox. The variability expressed by the coefficient of variation was predominantly low to moderate for all soil chemical properties and productive variables of cotton. The absence of spatial dependence for soil chemical properties, except pH, indicated that spatial variations should be considered for soil sampling design. Kriging maps for the productive attributes of cotton showed that they have similar spatial distribution patterns in the crop. The productive attributes of the crop with direct relationship on the productivity of seed cotton were the number of reproductive branches and the boll mass, both linear and spatial.

Keywords: Brazilian agribusiness, geostatistics, *Gossypium hirsutum*, precision agriculture, soil fertility.

RESUMO

Técnicas de estatística clássica bem como da geoestatística são ferramentas importantes para correlacionar, linear e espacialmente, a produtividade vegetal com os atributos do solo. Assim, no ano de 2015, em Campo Novo do Parecis, Mato Grosso, Brasil, foram empregadas correlações, espaciais e de Pearson, entre atributos da planta de algodão e químicos do solo, visando determinar a variabilidade da produtividade vegetal e de atributos químicos do solo no Cerrado mato-grossense. Para tanto, instalou-se a malha geoestatística para a coleta de dados do solo e da planta, com 100 pontos amostrais, num talhão com a cultura de algodão. O solo foi classificado como um Latossolo Vermelho-Amarelo distrófico. A variabilidade expressa pelo coeficiente de variação foi predominantemente baixa a média para todas as variáveis de química do solo e produtivas do algodoeiro. A ausência de dependência espacial para os atributos químicos do solo, excetuando-se o pH, indicou que as variações espaciais devem ser consideradas para o planejamento de coleta de amostras de solo. Os mapas de krigagem para os atributos produtivos do algodoeiro revelaram que estes possuem semelhantes padrões de distribuição espacial na lavoura. Os atributos produtivos da lavora com relação direta na produtividade de algodão em caroço foram o número de ramos reprodutivos e a massa do capulho, tanto linear, quanto espacial.

Palavras-chave: agricultura de precisão, agronegócio brasileiro, fertilidade do solo, geoestatística, *Gossypium hirsutum*.

INTRODUCTION

The favorable climatic conditions, the topography that allows the mechanization of agriculture, the governmental programs to encourage cotton cultivation, and especially, the intensive adoption of modern technologies, are the major factors that have driven the cultivation of cotton in the Brazilian Savannah, so that this biome has provided the highest national crop yields under dry conditions (Zonta *et al*., 2014).

According to data from CONAB (2017), it is estimated that the national production of seed cotton in the 2016/17 growing season will total 3550 thousand tons (10% higher than the 2015/16 crop), and the State of Mato Grosso will participate with 75.8%, or 2334 thousand tons (6% higher than the previous harvest). The national area cultivated in Brazil will occupy 673.5 thousand hectares, with average yield estimated at 3922 kg ha^{-1}, while that of the State of Mato Grosso will be 3943 kg ha^{-1}.

Information obtained through research has been decisive in providing technological support to agricultural development, ensuring better yields and competitive economic returns. Among the various technologies developed, the proper choice of the cultivar to the site of cultivation is one of the main components of the crop production system. The increase in crop productivity still necessarily requires mineral nutrition and the correct supply of essential elements that meet the requirements required in its phenological cycle (Dalchiavon *et al*., 2015).

Allied to the nutritional requirement of the crop, the application of inputs in general, which should be carried out with varied rates, is actually done in large areas in a homogeneous way, whether in Brazil, the United States of America (USA) or the rest of the world, disregarding the existence of spatial variability, which directly impacts the final cost of the crop, since among the main factors that define the profitability of a crop stand out productivity and production costs, in which the maximization of the efficiency of use of available resources allows the economic sustainability of the productive system (Stewart *et al*., 2005; Sana *et al*. 2014; Zonta *et al*., 2014), although according to Mooney *et al*. (2010), in cotton crops in 16 states in the USA, precision farming tools are used by 63% producers, but only 2% use productivity monitoring.

In support of these questions, the farmer has geostatistics at disposal, a tool that analyzes the spatial dependence of georeferenced data by the semivariogram adjustment, represented by the semivariance graph as a function of the distances between observations. Once the semivariance is obtained, the kriging map can be made for each attribute searched (soil and/or plant), which represents the spatial variability of the data. However, given the affinity between spatial dependencies of any two attributes, modeled by the cross-semivariogram, it can be obtained the cokriging map for the main attribute, usually difficult to obtain and of greater interest, according to a secondary attribute, usually easier to determine (Molin *et al*., 2007; Montanari *et al*., 2010; Dalchiavon *et al*., 2011). It would be possible, then, from the secondary attribute, to obtain spatially the estimates for the primary attribute as well as to suggest possible management interventions aiming at the primary attribute.

Currently, several studies have been carried out with the purpose of investigating the relationship between soil chemical properties (secondary) and crop productivity (principal), among them Dalchiavon *et al*. (2011, 2013 a, b, 2015) and Montanari *et al*. (2013), with the crops of beans, sugarcane, rice and sunflower, respectively. However, there is a shortage of studies on the cotton crop. Thus, it is essential that the research seeks to correlate cotton development with the chemical characteristics of the soil, focusing on the regions where the crop is intensively grown, such as is the case of the Savannah of Mato Grosso. In this context, the goal of this work was to determine the variability of cotton yield and soil chemical properties in the Savannah of Mato Grosso.

MATERIAL AND METHODS

The study was developed in 2015 at the Federal Institute of Mato Grosso (IFMT), Campo Novo do Parecis (State of Mato Grosso, Brazil), at 13º40'31"South latitude, 57º53'31" West longitude and 574 m altitude. The climate is A_w (tropical humid with rainy season in summer and dry in winter). Figure 1 shows the values of rainfall and temperatures during the cultivation period.

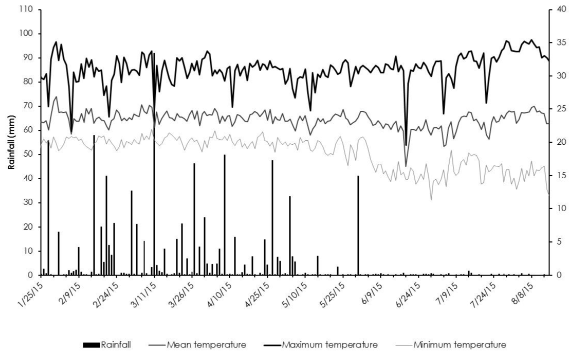

Figure 1 - Data on air temperature and cumulative rainfall in the experimental area during the conduction of the experiment (Campo Novo do Parecis, MT, 2015).

The soil was classified as Typic Tropustox, whose particle size at the 0-0.20 m layer was 506 g kg^{-1} clay, 134 g kg^{-1} silt and 360 g kg^{-1} sand. The initial chemical characterization of the soil at the 0-0.20 m layer showed the following values: pH (H_2O) = 5.7; P (resin) = 6.1 mg dm^{-3}; K = 2.4 mmol dm^{-3}; Ca = 25 $mmol_c$ dm^{-3}; Mg = 10 $mmol_c$ dm^{-3}; Al = 0 $mmol_c$ dm^{-3}; H + Al = 46 $mmol_c$ dm^{-3}; Organic matter = 35.8 g dm^{-3} and V% = 44.8%.

In succession to soybean, in a plot of 10000 m^2 (100 x 100 m), cotton (cultivar FM 940GLT, medium cycle, with 150 to 180 days) was sown on January 29, 2015, with 0.45 m between rows and seven seeds per meter, using as basal fertilization 200 kg ha^{-1} Monoammonium Phosphate (MAP: 12% N and 52% P_2O_5). On 06/03/2015 and 06/04/2015, 300 and 200 kg ha^{-1} of the formulation 20-00-20 (N-P_2O_5-K_2O) was applied as complementary fertilizer, respectively. The control of pests, diseases and weeds was carried out as recommended for the crop, whenever necessary, through constant monitoring.

A grid was set up for data collection on July 25, 2015, and it consisted of 10 transects (NS direction), 10 m spaced apart, with 10 sampling points each, 8.5 m spaced apart, totaling 100 points distributed in an area of 91 x 76 m, the remainder was the border area. Between 25/07/2015 and 15/08/2015, the attributes (soil and plant) were collected at each sampling point.

The soil properties, at the 0-0.20 m, were collected between the rows of the central point, being the levels of phosphorus (P), organic matter (OM), pH values ($CaCl_2$), content of potassium (K), Calcium (Ca), magnesium (Mg), potential acidity (H + Al), sum of bases (SB), cation exchange capacity (T) and base saturation (V%) determined, according to Raij *et al*. (2001), at the Laboratory of Physics and Soil Fertility of the Faculty of Engineering of Ilha Solteira (SP)/UNESP.

Plant attributes, seed cotton yield (CY, in kg ha^{-1}), plant population (PP, plants ha^{-1}), final plant height (PH; m), stem diameter (SD), number of reproductive branches (RB), number of bolls per plant (BP), boll mass (BM; g), fiber mass of the boll (FM; g), seed mass of the boll (SM; g), percentage of fiber (%F) and mass of 100 seeds (M100; g), were determined from the data collected in four rows of the culture with 1.80 m, around each point.

CY for each point was estimated based on 3.24 m^2 (1.8 x 1.8 m), as well as for PP, with manual harvesting of bolls at physiological maturity (90% open bolls), manual detachment of fibers and weighing. PH and SD were measured in a sample of five continuous plants of the useful area, from the base to the apex of the plant (PH), with a ruler and 5 cm from the ground (SD), with digital caliper, at the moment of the harvest. RB was determined by the reproductive nodes; BP, by counting the total number of bolls in the plant; BM by the mean of 30 bolls of the seed cotton; FM by BM minus SM; SM by BM minus FM; % F by the relative mass of the fiber after the separation of the samples into FM and SM; and M100, obtained by the mass of 100 seeds (13% moisture).

Statistical analysis was performed with SAS and Excel spreadsheet, following the procedures of Dalchiavon *et al*. (2012a). The descriptive analysis of the attributes was performed, calculating the mean, median, minimum and maximum values, standard deviation, coefficient of variation, kurtosis, asymmetry and frequency distribution analysis by the Shapiro-Wilk test. A correlation matrix was constructed between all the attributes studied, containing all paired combinations possible, aiming to check for significant Pearson correlations between the attributes (dependent variables x independent variables). Then, simple and multiple linear regressions of CY were performed according to the variables of the soil and/or plant, in order to determine which could serve as a quality indicator (s), when the objective was to increase CY.

For the geostatistical analysis, the Gamma Design Software 7.0 was used, following the procedures of Dalchiavon and Carvalho (2012). For each attribute, the spatial dependence was analyzed by the semivariogram, where adjustments were made primarily by the initial selection of: (a) the smallest sum of the squares of the deviations (RSS); (B) higher coefficient of determination (r^2); and (c) the highest spatial dependence evaluator (SDE). The interpretation proposed for SDE was also performed according to Dalchiavon and Carvalho (2012): a) SDE < 20% = spatial variable of very low dependence (MB); b) 20% ≤ SDE < 40% = low dependence (BA); c) 40% ≤ SDE < 60% = intermediate dependence (ME); d) 60% ≤ SDE < 80% = high dependence (AL), and e) 80% ≤ SDE < 100% = very high dependence (MA). Cokrigings procedures were carried out, mainly those between CY and soil and/or plant attributes. The objective was to validate the existence of an attribute (soil and/or plant) that could spatially serve as an indicator of quality, that is, when the goal was to increase the seed cotton productivity.

RESULTS AND DISCUSSION

Because it is the typical representative of plant data, the normal (NO) frequency distribution (DF) is ideal for a statistical study (regression and/or geostatistical analysis). If this is not the case, normality is sought by logarithmic transformation (Molin *et al*., 2007). Table 1 illustrates that all attributes, except PH (IN) and M100 (TN), presented normal frequency distribution, whose coefficients of kurtosis and asymmetry ranged from -0.564 to 0.442 and -0.362 to 0.468, respectively, which was expected as they are biological attributes (Montanari *et al*., 2010, 2013; Dalchiavon & Carvalho, 2012; Dalchiavon *et al*., 2012, 2013a,c). Dalchiavon *et al*. (2015), studying the relationships of sunflower productivity with soil chemical properties by geostatistical techniques, have also found a DF of the type IN for PH, which indicates that, for the attribute in question, it is common in studies of this nature.

There was low (FM, %F and M100), intermediate (PP, PH, SD, BM and SM), high (CY and RB) and very high (BP) data variability, analyzed by coefficient of variation (Table 1), differing from the data found by Carvalho *et al*. (2001) for the attributes PH, RB, BP, BM and CY, which may be related to

Table 1 - Descriptive analysis of production attributes of *Gossypium hirsutum* L. on a Typic Tropustox under no-till system. Campo Novo do Parecis (MT), 2015

Attribute [(a)]	Descriptive statistical measures									
	Mean	Median	Value		Standard deviation	Coefficient			Probability of the test[(b)]	
			Minimum	Maximum		Variation (%)	Kurtosis	Asymmetry	Pr<w	DF
CY (kg ha^{-1})	3096.0	3220.5	1263.4	4643.8	817.0	26.4	-0.564	-0.362	0.042	NO
PP	142463	143519	94444	181482	17244	12.1	-0.069	-0.334	0.411	NO
PH (m)	1.16	1.20	0.67	1.59	0.19	16.1	0.227	-0.623	1.10^{-4}	IN
SD (mm)	12.23	12.36	7.60	15.73	1.74	14.2	-0.099	-0.303	0.383	NO
RB	3.89	3.70	1.60	7.30	0.99	25.5	0.442	0.387	0.187	NO
BP	4.84	4.65	1.70	8.70	1.55	32.2	-0.227	0.468	0.052	NO
BM (g)	4.06	4.06	3.15	5.15	0.42	10.4	-0.248	0.075	0.773	NO
FM (g)	2.13	2.12	1.66	2.66	0.21	9.9	-0.349	0.048	0.856	NO
SM (g)	1.93	1.93	1.46	2.50	0.23	11.7	-0.169	0.174	0.589	NO
%F	52.58	52.40	50.50	55.10	1.02	2.0	-0.214	0.289	0.106	NO
M100 (g)	7.36	7.33	6.30	8.97	0.48	6.5	1.088	0.487	0.023	TN

[(a)] CY, PP, PH, SD, RB, BP, BM, FM, SM, %F and M100 are, respectively, the productivity of seed cotton, plant population, plant height, stem diameter, number of reproductive branches, number of bolls per plant, boll mass, fiber mass per boll, seed mass per boll, percentage of fiber and mass of one hundred seed; [(b)] DF = frequency distribution, in which NO, IN and TN respectively of the types normal, indeterminate and tending to normal.

the fact that these authors used nitrogen and potassium fertilization in cotton, while for % F, data were similar. However, data were close to those obtained by Henrique and Laca-Buendía (2010), when they studied the morphological and agronomic characteristics of cotton, reporting low (SM, M100, % F and BM), intermediate (SD and PP), high (PH and BP) and very high (CY) CV. On the other hand, in a study carried out in eight cotton crops in the State of Texas (USA), the CV of CY varied between 8 and 32% (Guo *et al*., 2012), consistent with the present study.

CY (3096 kg ha^{-1}; Table 1) was low when compared to the 4000.0 kg ha^{-1} reported by Sana *et al*. (2014) and to the 6285 kg ha^{-1} of Santos *et al*. (2012) in Savannah soil, but was superior to CY reported by Kaneko *et al*. (2014) of 2507 kg ha^{-1}. These data demonstrate that CY can vary widely, depending on several factors, such as genotype and management, even within a single biome. The low CY obtained in this study is related both to the difficulty of weed control at post-emergence, which caused competition for the available environmental resources, and the low water availability at specific moments (Figure 1) due to the delay in crop sowing, which for the region is recommended until January 5th.

The other mean values of the attributes of the plants were, respectively, 142463 plants ha^{-1}; 1.16 m; 12.23 mm; 3.86; 4.84; 4.06 g, 2.13 g, 1.93 g; 52.58% and 7.36 g for PP, PH, SD, RB, BP, BM, FM, SM, %F and M100 (Table 1). These data are similar to those observed by Teixeira *et al*. (2008), with PP of 130000 plants ha^{-1}, with PH of 1.20 m and M100 of 9.2 g, of Henrique and Laca-Buendía (2010), with SD of 10.8 mm, BP of 3.81, FM of 2.21 g, SM of 3.07 g, % F of 41.36 and BM of 5.35 g of Motomiya *et al*. (2011), with PH of 1.20 m and PP of 122663 plants ha^{-1}.

For the soil properties (Table 2), it was observed DF in NO (OM, pH, K, Ca, Mg, SB, T and V%) and IN (P and H+Al), agreeing with the data observed by Zonta *et al*. (2014) and Dalchiavon *et al*. (2015). In general, the coefficients of variation were between low (OM, pH and T), moderate (Ca, H+Al, SB and V%), high (Mg) and very high (P and K), consistent with Motomiya *et al*. (2011) and Dalchiavon *et al*. (2015) for P and K and with Sana *et al*. (2014) for soil pH when they analyzed the variability of soil properties and their effects on cotton productivity.

The coefficients of kurtosis between -0.377 and 0.518 and those of asymmetry between -0.140 and 0.352 (Table 2), resemble those of DF and coefficients of variation mentioned by Dalchiavon *et al*. (2012, 2013a,b) and Montanari *et al*. (2013). In relation to soil fertility, and considering the mean/median values of its chemical properties, it can be verified that these presented low (K), moderate

Table 2 - Descriptive analysis of chemical properties of a Typic Tropustox cultivated with *Gossypium hirsutum* L. under no-till system. Campo Novo do Parecis (MT), 2015

Properties [(a)]	Descriptive statistical measures									
	Mean	Median	Value		Standard deviation	Coefficient			Probability of the test [(b)]	
			Minimum	Maximum		Variation (%)	Kurtosis	Asymmetry	Pr<w	DF
P (mg dm^{-3})	17.1	16.0	10.0	48.0	6.5	38.0	8.160	2.626	1.10^{-4}	IN
OM (g dm^{-3})	27.8	28.0	23.0	34.0	2.2	7.9	-0.235	0.099	0.066	NO
pH	5.4	5.4	4.8	6.0	0.3	5.0	-0.093	-0.054	0.050	NO
K ($mmol_c$ dm^{-3})	1.4	1.4	0.4	2.7	0.5	32.4	-0.377	0.338	0.069	NO
Ca ($mmol_c$ dm^{-3})	23.0	23.0	12.0	34.0	4.4	19.0	0.138	0.021	0.581	NO
Mg ($mmol_c$ dm^{-3})	16.1	16.3	7.0	28.0	3.9	24.1	0.518	0.337	0.124	NO
H+Al ($mmol_c$ dm^{-3})	29.7	28.0	18.0	42.0	5.8	19.4	-0.271	0.219	0.002	IN
SB ($mmol_c$ dm^{-3})	40.3	41.0	20.0	60.0	8.0	19.8	0.218	0.134	0.425	NO
T ($mmol_c$ dm^{-3})	70.3	70.8	58.0	85.0	5.3	7.5	0.402	0.352	0.385	NO
V% (%)	57.6	57.5	34.0	80.0	9.6	16.6	0.087	-0.140	0.676	NO

[(a)] P, OM, pH, K, Ca, Mg, H+Al, SB, T and V% are, respectively, phosphorus, organic matter, potential of hydrogen, potassium, calcium, magnesium, potential acidity, sum of bases, cation exchange capacity and base saturation; [(b)] DF = frequency distribution, with IN and NO, respectively, of the types indeterminate and normal.

(P, OM, pH, V%) and high (Ca, Mg, SB) values/contents, according to the limits mentioned in Raij *et al*. (1997) and in Alves *et al*. (2009), also justifying, and partly, this CY. These values of soil chemical properties (K, OM, V%, Ca and Mg) were in accordance with those presented by Dalchiavon *et al*. (2012), when investigated the spatial variability of fertility attributes of a Typic Acrustox under no-till system in Selvíria (MS) and Zonta *et al*. (2014), when evaluating the spatial variability of soil fertility in the area planted with cotton in the Brazilian Savannah.

Pearson's significant correlations (plant x plant; plant x soil), and of interest, for the pairs of attributes were: 1) CY x PP (r = 0.309**), 2) CY x SD (r = 0.306**), 3) CY x RB (r = 0.553**), 4) CY x BP (r = 0.558**), 5) CY x BM (r = 0.334**), 6) CY x FM (r = 0.275**), 7) CY x SM (r = 0.369**), 8) RB x PH (r = 0.425**), 9) BP x PH (r = 0.426**), 10) %F x PH (r = -0.253*), 11) BP x RB (r = 0.951**), 12) CY x OM (r = 0.503**), 13) CY x T (r = 0.238*), 14) PH x P (r = 0.225*), 15) RB x OM (r = 0.312**), 16) BP x OM (r = 0.290**), 17) FM x H+Al (r = -0.206*), 18) M100 x H+Al (r = -0.208*). It was observed that 83% of the correlations showed a direct cause-effect behavior, that is, any change in the values of the independent variables (X) promoted a change of the same nature in the response or dependent variable (Y).

The correlation coefficients between the plant attributes were high (p <0.01) and positive, except for % F x PH, denoting an appreciable direct relationship between the attributes involved. OM and T were the only soil properties significant with CY, with low correlation coefficients, however positive, due basically to the fact that it is a classic example of a dependent variable (CY) against independent (OM and T) and also due to the high number of observations (n = 100), common in geostatistical studies, as reported by several researchers (Molin *et al*., 2007; Dalchiavon *et al*., 2013a,b; Montanari *et al*., 2013; Dalchiavon *et al*., 2015). Thus, the adjusted regression equations are listed in Tables 3 and 4.

Equations 1, 2, 3 and 4 (plant x plant; Table 3) revealed direct linear influence of PP, SD, RB and BP on CY. Equations 5, 6, 7 and 11, although direct (except for %F x PH), presented potential models between the independent attributes (PH and RB) and the dependent variables (CY, %F, BP and RB). Exponential equations (8 to 10) were observed between CY (dependent) and BM, FM and SM (independent). Among the equations that aim to estimate CY, 4 was the one that provided the best fit (higher *r''*), and is therefore the most recommended for its estimation. Thus, by working in the mentioned equation, it is possible to estimate a CY of 3085.8 kg ha^{-1}, when BP is 4.84 g (Table 1), that is, with the increase in the number of bolls in the plant, because of larger viability, in this population and crop spacing, it can be estimated the seed cotton yield in a linear way.

On the other hand, 12 and 13 were linear equations (plant x soil; Table 4). However, quadratic (14),

Table 3 - Simple linear regression equation and adjustment coefficients between production attributes of *Gossypium hirsutum* L under a Typic Tropustox under no-till system. Campo Novo do Parecis (MT), 2015

Mathematical model [(a)]	Coefficient of adjustment [(b)]					Equation number
	a	b	c	r	r^2	
CY = a + b . PP	1004.252	$1.468.10^{-2}$**	-	0.310**	-	(1)
CY = a + b . SD	1336.535	143.846**	-	0.307**	-	(2)
CY = a + b . RB	1324.727	455.819**	-	0.552**	-	(3)
CY = a + b . BP	1678.835	293.114**	-	0.558**	-	(4)
CY = a . PH^b	4.058	$9.007.10^{-1}$**	-	0.473**	-	(5)
%F = a . PH^b	52.785	$-2.918.10^{-2}$**	-	0.261**	-	(6)
BP = a . RB^b	0.923	1.211**	-	0.962**	-	(7)
CY = a . $EXP^{BM.b}$	1090.907	$2.470.10^{-1}$**	-	0.346**	-	(8)
CY = a . $EXP^{FM.b}$	1222.804	$4.178.10^{-1}$**	-	0.292**	-	(9)
CY = a . $EXP^{SM.b}$	1131.942	$4.996.10^{-1}$**	-	0.376**	-	(10)
RB = a . PH^b	3.422	$6.900.10^{-1}$**	-	0.455**	-	(11)

[(a)] CY, PP, PH, SD, RB, BP, BM, FM, SM and %F are, respectively, the productivity of seed cotton, plant population, plant height, stem diameter, number of reproductive branches, number of bolls per plant, boll mass, fiber mass per boll, seed mass per boll and percentage of fiber; [(b)] ** = significant at 1%

Table 4 - Simple linear regression equation and adjustment coefficients between production attributes of *Gossypium hirsutum* L and properties of a Typic Tropustox under no-till system. Campo Novo do Parecis (MT), 2015

Mathematical model [(a)]	Coefficient of adjustment [(b)]					Equation number
	a	b	c	r	r^2	
CY = a + b . OM	-2086.903	186.236**	-	0.503**	-	(12)
CY = a + b . T	494.354	36.997	-	0.238*	-	(13)
PH = a + b . P + c . P^2	$7.375.10^{-1}$	$3.619.10^{-2**}$	$5.829.10^{-4*}$	-	0.103**	(14)
RB = a . OM^b	$1.073.10^{-1}$	1.070**	-	0.322**	-	(15)
BP = a . OM^b	$5.619.10^{-2}$	1.325**	-	0.317**	-	(16)
FM = a . $EXP^{HAl.b}$	2.357	$-3.631.10^{-3*}$	-	0.210*	-	(17)
M100 = a . HAl^b	9.376	$-7.231.10^{-2*}$	-	0.221*	-	(18)

[(a)] CY, PH, BP, FM, M100 P, OM, H+Al, and T are, respectively, the productivity of seed cotton, plant height, number of bolls per plant, boll mass, fiber mass per boll, 100-seed mass and content of phosphorus, organic matter, pot ential of hydrogen and cation exchange capacity; [(b)] ** and * = significant at 1% and 5%, respectively.

potential (15, 16 and 18) and exponential (17) equations were also modeled. OM and T, as mentioned above, were the only soil properties indicated to estimate CY, which would be 3096 and 3095 kg ha^{-1} when OM and T contents were, respectively, 27.83 g dm^{-3} and 70.3 $mmol_c$ dm^{-3} (Table 1). In this way, conservationist soil management, such as no-till systems, which aim to increase organic matter contents, and will directly and positively implicate their T, are necessary to obtain higher seed cotton yields, by increasing fertility through nutrient cycling (OM) and the maintenance of exchangeable bases available in soils usually dependent on T by increase in OM contents, since the other colloids in Savannah soils have low expressiveness in T values and are very dependent on pH.

The geostatistical analysis (Table 5) revealed, for the plant attributes that did not result in pure nugget effect, that the decreasing order of the spatial correlation coefficients (r^2) was: 1) PH (0.888), 2) %F (0.851), 3) SD (0.818), 4) FM (0.596), 5) BM (0.587), 6) SM (0.521), 7) #CY (0.508) and 8) RB (0.504). The PH derived in a very high spatial correlation coefficient (r^2), very high spatial dependency (SDE) (87.2%) and angular coefficient (b) of the cross-validation near 1 (1.022), denoting high quality of the experimental semivariogram of spherical type, thus agreeing with the semivariographic model reported by Motomiya *et al*. (2011), who proposed a diagnosis for the localized management of the cotton crop, and mentioned high r^2 (0.640) and high SDE (68.0%).

In relation to the pure nugget effect for BP and M100 (Table 5), this is relatively common because they are productive attributes related to cotton maturity, which are heavily influenced by the environment (Johnson *et al*., 2002).

#CY, attribute of greater agronomic interest, presented semivariographic spherical model, intermediate r^2 (0.508), very high SDE (99.8%) and angular coefficient of cross validation of 0.983 (Table 5). Motomiya *et al*. (2011) obtained spherical model, intermediate r^2 (0.500) and high SDE (70.0%), while Sana *et al*. (2014) reported spherical model, intermediate r^2 and very high SDE, therefore, both studies corroborate the data of the present research.

Regarding soil properties, only pH showed spatial dependence (Table 5). The pure nugget effect for the other soil properties indicated that the behavior of these regionalized variables was totally random, revealing the semivariogram discontinuity for distances smaller than those sampled, indicating the need to rethink this distance, which was evidenced in the study by Dalchiavon *et al*. (2013b). Motomiya *et al.* (2011) also found no spatial dependence for P and Mg, denoting that the spatial dependence of soil properties can also vary according to the area and the management applied. Typically, in areas under no-till system, as nutrient application vary from spreading and in-row, in crops with different spacings, combined with high or low nutrient mobility, heterogeneity becomes common, and semivariogram adjustments do not always have quality because of lower ranges.

pH (Table 5), with a Gaussian semivariogram model, had a low spatial correlation coefficient (0.399), intermediate spatial dependence (57.3%) and an angular coefficient of 0.881, demonstrating

Table 5 - Parameters of the simple and cross semivariograms adjusted for productive attributes of *Gossypium hirsutum* L. and chemical properties of a Typic Tropustox under no-till system. Campo Novo do Parecis (MT), 2015

Attribute[(a)]	Adjustment parameters										
	Model[(b)]	C_o	C_o+C	A_o (m)	r^2	SQR[(c)]	SDE[(d)]		Cross-validation		
							%	Class	a	b	r
γ(h) simple – plant											
#CY	esf (136)	$1.10.10^{3}$	$4.43.10^{5}$	26.4	0.508	$6.54.10^{10}$	99.8	MA	-9.45	0.983	0.764
#PP	epp	$2.99.10^{8}$	$2.99.10^{8}$	-	-	-	-	-	-	-	-
PH	exp (126)	$3.77.10^{-4}$	$2.95.10^{-2}$	31.8	0.888	$2.02.10^{-5}$	87.2	MA	$-2.00.10^{-2}$	1.022	0.554
SD	exp (137)	$2.86.10^{-1}$	2.14	17.7	0.818	$4.58.10^{-2}$	86.6	MA	$8.50.10^{-1}$	0.933	0.303
RB	exp (126)	$1.19.10^{-1}$	$7.55.10^{-1}$	20.1	0.344	$6.74.10^{-2}$	84.2	MA	1.64	0.576	0.219
BP	epp	2.38	2.38	-	-	-	-	-	-	-	-
BM	esf (133)	$7.32.10^{-2}$	$1.47.10^{-1}$	30.9	0.587	$1.43.10^{-3}$	50.3	ME	$7.40.10^{-1}$	0.816	0.377
FM	exp (130)	$3.55.10^{-3}$	$3.49.10^{-2}$	17.1	0.596	$3.93.10^{-5}$	89.8	MA	$9.00.10^{-2}$	0.955	0.363
SM	exp (138)	$3.80.10^{-3}$	$4.19.10^{-2}$	21.3	0.521	$1.52.10^{-4}$	90.9	MA	$1.90.10^{-1}$	0.899	0.415
%F	exp (121)	$1.29.10^{-1}$	1.07	19.5	0.851	$1.52.10^{-2}$	87.9	MA	7.55	0.857	0.316
M100	epp	$2.30.10^{-1}$	$2.30.10^{-1}$	-	-	-	-	-	-	-	-
γ(h) *simple – soil*											
#P	epp	3.79.10	3.79.10	-	-	-	-	-	-	-	-
OM	epp	4.87	4.87	-	-	-	-	-	-	-	-
pH	gau (130)	$2.24.10^{-2}$	$5.25.10^{-2}$	13.6	0.399	$1.57.10^{-4}$	57.3	ME	$6.40.10^{-1}$	0.881	0.333
K	epp	$2.06.10^{-1}$	$2.06.10^{-1}$	-	-	-	-	-	-	-	-
Ca	epp	1.90.10	1.92.10	-	-	-	-	-	-	-	-
Mg	epp	1.50.10	1.50.10	-	-	-	-	-	-	-	-
H+Al	epp	3.31.10	3.31.10	-	-	-	-	-	-	-	-
SB	epp	6.36.10	6.36.10	-	-	-	-	-	-	-	-
T	epp	2.75.10	2.75.10	-	-	-	-	-	-	-	-
V%	epp	9.14.10	9.14.10	-	-	-	-	-	-	-	-
γ(h) crossed – plant x soil											
#CY=f(PH)	gau (116)	$1.00.10^{-1}$	3.60.10	22.9	0.328	$1.83.10^{3}$	99.7	MA	8.65	0.989	0.792
#CY=f(SD)	esf (120)	$1.00.10^{-1}$	$3.05.10^{2}$	30.7	0.431	$7.22.10^{4}$	100.0	MA	5.45	0.916	0.726
#CY=f(RB)	gau (2015)	1.51.10	$2.93.10^{2}$	28.9	0.629	$3.20.10^{4}$	94.8	MA	5.83	0.958	0.753
#CY=f(BM)	gau (53)	3.22.10	$1.42.10^{2}$	33.6	0.776	$3.84.10^{3}$	77.4	AL	-2.84	0.943	0.752
#CY=f(%F)	esf (130)	$-1.00.10^{-1}$	$-2.73.10^{2}$	27.5	0.819	$7.48.10^{3}$	100.0	MA	-1.43	1.000	0.783

[(a)] #CY = seed cotton productivity, #PP = plant population, PH = plant height, SD = stem diameter, RB = number of reproductive branches, BP = number of bolls per plant, BM = boll mass, FM = fiber mass per boll, SM = seed mass per boll, %F = percentage of fiber, M100 = 100-seed mass, #P = phosphorus, OM = organic matter, pH = potential of hydrogen, K = potassium, Ca = calcium, Mg = magnesium, H+Al = potential acidity, SB = sum of bases, T = cation exchange capacity and V% = base saturation; # = attribute worked with the data residue; parentheses after the model = number of pairs in the first lag; [(b)] esf = spherical, epp = pure nugget effect, exp = exponential and gau = Gaussian; [(c)] SQR = sum of squared residuals; (d) SDE = spatial dependence evaluator, where MA = very high, ME = intermediate and AL = high.

substantial quality. Its geostatistical range (13.6 m) indicated that, for the property in question, soil samples should be taken in grids of 185 m² (13.6 x 13.6 m). The low value of the parameter is associated with the extrinsic variability, related to the practices of soil management, which contributed to the reduction of the range (Silva *et al*., 2007). The geostatistical data for the pH behaved similarly, except for the spherical models, to the results evidenced by Johnson *et al*. (2002) and Motomiya *et al*. (2011), where the latter obtained a low spatial correlation (0.330) and intermediate spatial dependence (40.0%), as well as the spherical model described by Sana *et al*. (2014) and by Zonta *et al*. (2014).

In general, the semivariogram ranges were between 13.6 (pH) and 31.8 m (PH), indicating that for specific and localized management, the reference values used in precision agriculture should not be less than 13.6 m (Table 5), because they represent the distance within which the values of a given property have a spatial correlation with each other, since the range value can influence the quality of the estimate, since it determines the number of values used in the interpolation. Thus, estimates obtained by kriging interpolation using the highest range values tend to be more reliable, presenting maps that better represent reality (Dalchiavon *et al*., 2011). On the other hand, the smaller the ranges, the more important will be the interpolation and, therefore, semivariograms should be more precise, especially at small distances (Vieira *et al*., 2010). Another aspect to be mentioned is that all the obtained ranges exceeded the values of the spacings between the samplings, suggesting that the samples are correlated with each other, allowing interpolations (Vieira *et al*., 2007).

The kriging maps obtained from modeling the semivariograms and illustrated in Figures 2 and 3, although some have intricate aspects, are directly similar to each other (except for %F), that is, in regions where the values are smaller for £CY, for example, are the same regions where the lowest values are found for the other evaluated attributes, as well as for the regions of higher values between them. This behavior trend concentrated, with some exceptions, the highest values in the central regions and partly on the sides of the map, while the lowest values were present in the marginal regions of the maps, where the yields were lower than the average of the crop. This fact can also be

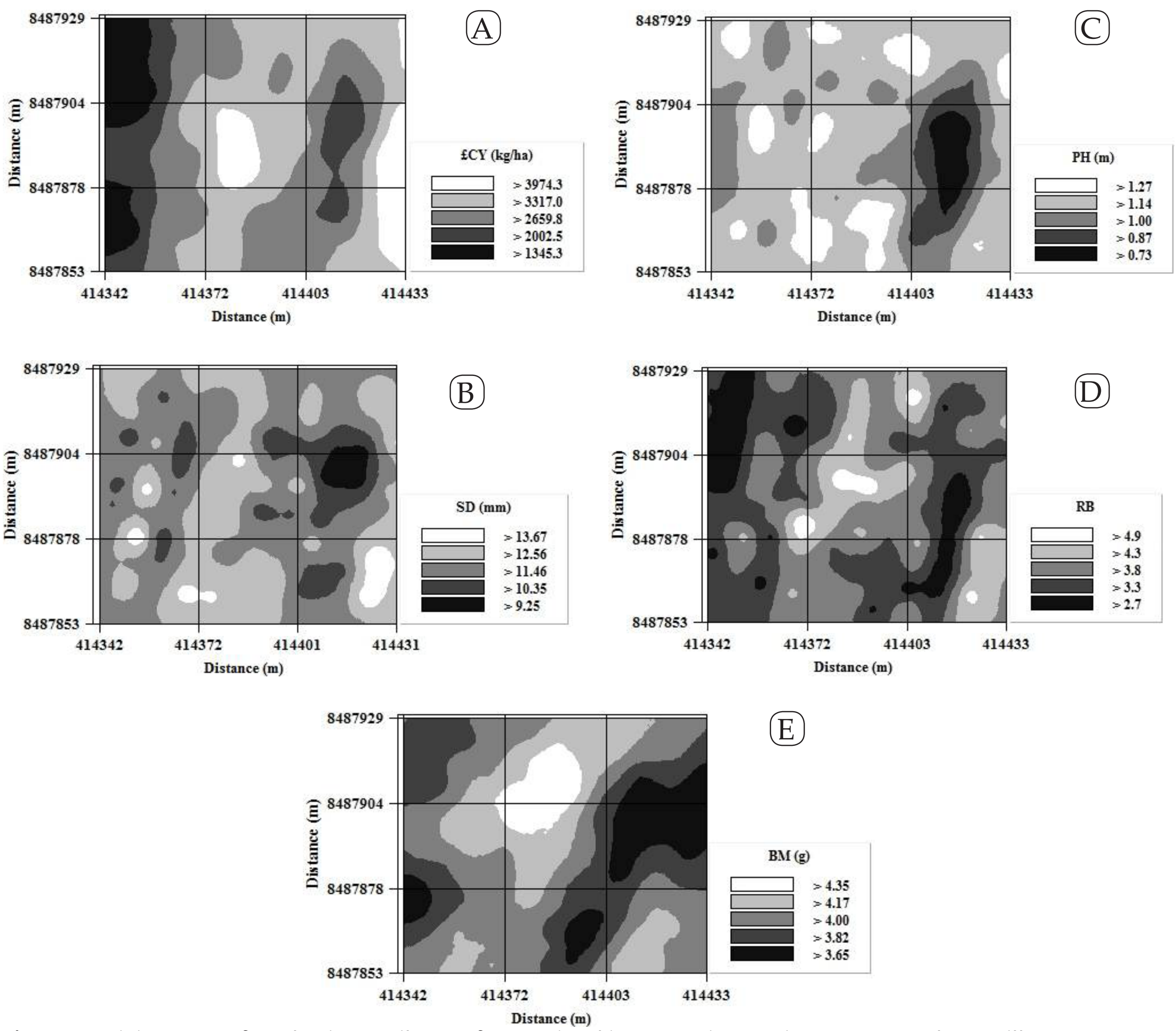

Figure 2 - Kriging maps of production attributes of *Gossypium hirsutum* L. in a Typic Tropustox under no-till system. Campo Novo do Parecis (MT), 2015.

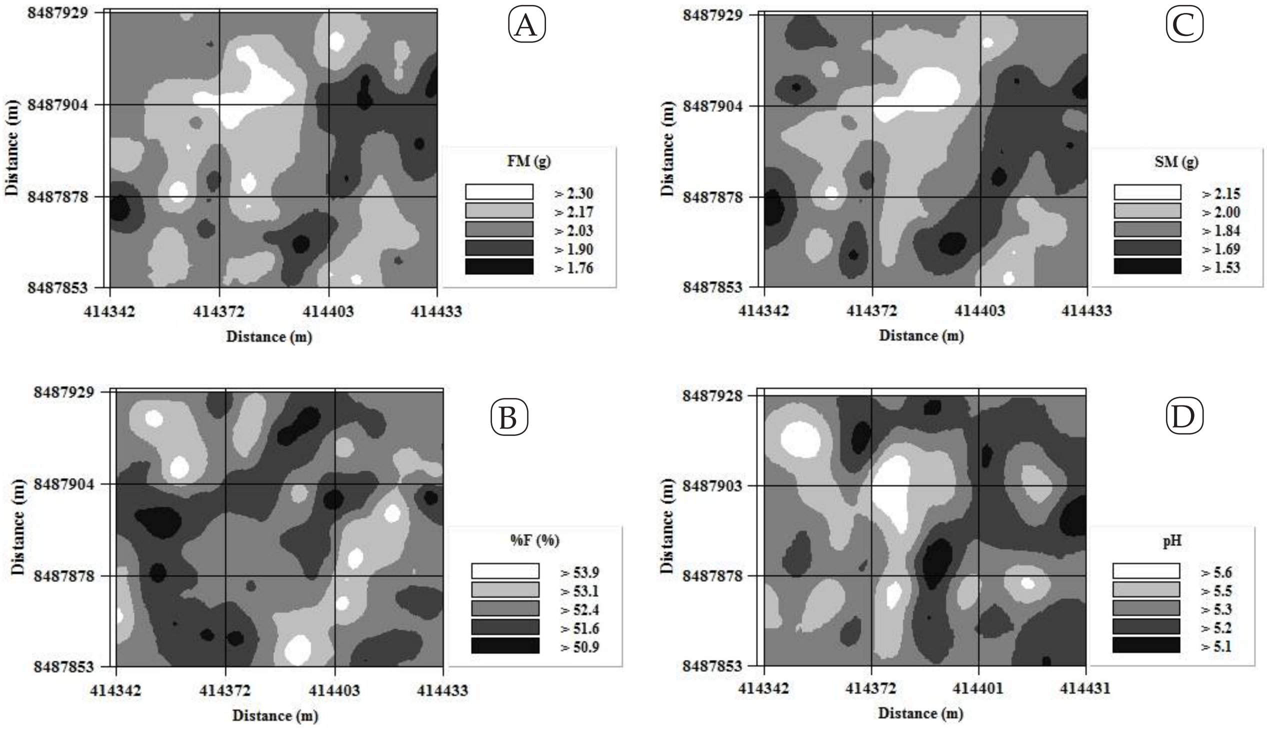

Figure 3 - Kriging maps of production attributes of *Gossypium hirsutum* L. and of properties of a Typic Tropustox under no-till system. Campo Novo do Parecis (MT), 2015.

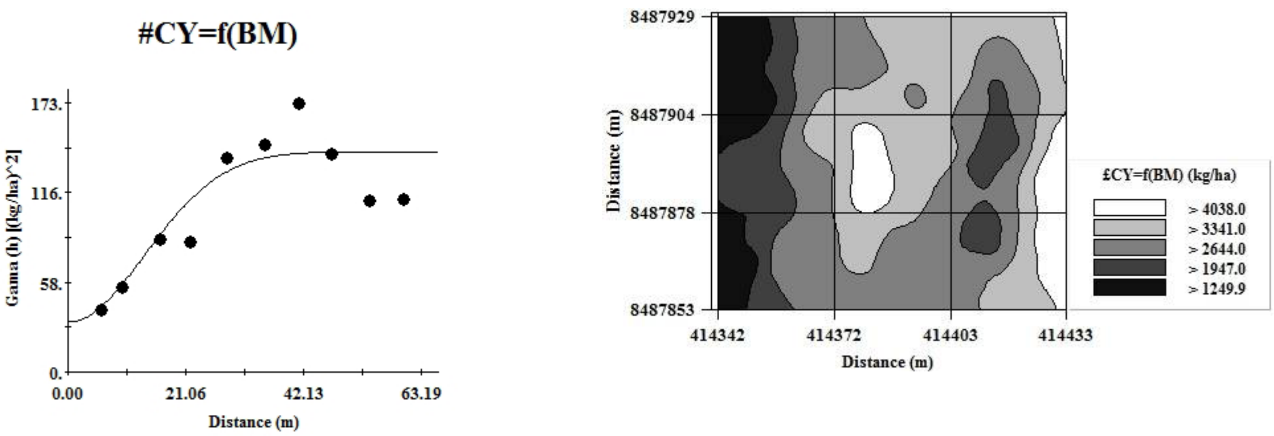

Figure 4 - Cross semivariogram and cokriging map of £CY according to BM of a Typic Tropustox under no-till system. Campo Novo do Parecis (MT), 2015.

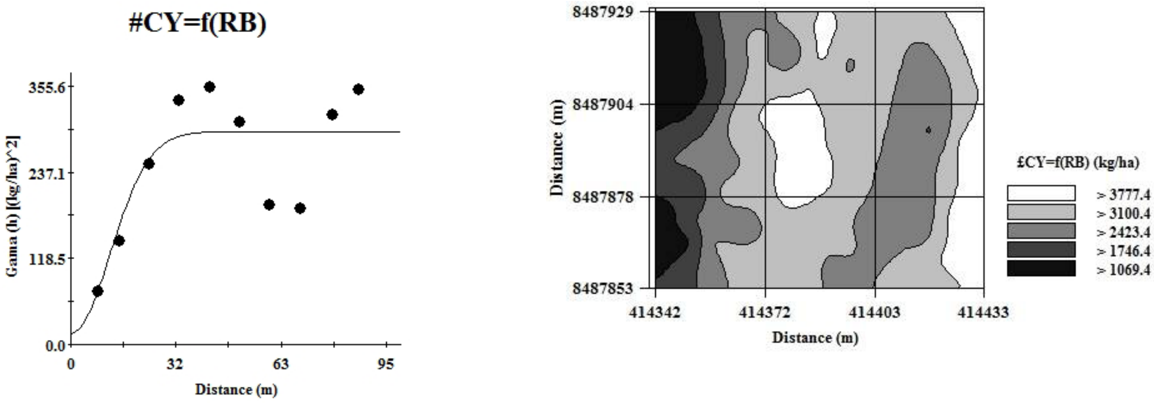

Figure 5 - Cross semivariogram and cokriging map of £CY according to RB of a Typic Tropustox under no-till system. Campo Novo do Parecis (MT), 2015.

observed in Figures 4 and 5, which present, by means of the existing direct relationship, the cross semivariograms and their respective cokriging maps between the £CY and the BM and RB.

In this context, we recommend to investigate the factors that affect crop productivity, beginning with the history of management, fertilization, crop rotation and productivity obtained in each crop. Thus, when heterogeneous behavior is identified, applications of inputs, or regionalized management of soil and crop, can be made with variable rates. Nevertheless, when factors that alter productivity cannot be corrected due to the intrinsic characteristics of the soil, it is advisable to create management zones and treat them differently, according to the productive potential of each site (Torbett *et al*., 2007; Walton *et al*., 2008; Sana *et al*., 2014). Following these recommendations, it was possible to verify that in the left vertical third, where there were the lowest yields, it was precisely where rainwater accumulated (Figure 1), because it is border, during the establishment phase of the crop, which reflected in the death of a significant amount of plants. This may have contributed to the lack of spatial dependence of PP data (Table 5).

In relation to the soil pH, in more than 50% of the area pH was less than 5.5 (Figure 3). This may represent a problem since Carvalho *et al.* (2011) reported that soil acidity negatively affects root development and growth of the cotton plant, directly affecting productivity. There are evidences of reduced productivity in soils with pH below this threshold.

However, it was not possible to model the cross-semivariogram between the #CY and the pH, although cross-semivariograms were obtained between the productive attributes of cotton, as previously mentioned (Table 5, Figures 4 and 5). The decreasing order of their spatial correlation coefficients (r^2) was: 1) #CY =f(%F) (0.819), 2) #CY =f(BM) (0.776), 3) #CY =f(RB) (0.629), 4) #CY =f(SD) (0.431) and 5) #CY =f(PH) (0.328). From these, the numbers 2 to 5 could be perfectly used to estimate the seed cotton productivity quickly due to the great ease in determining the independent variables (PH, SD, RB and BM) still in the field. In this context, the two cross-linked semivariograms with higher r^2 [#CY =f(BM) and #CY =f(RB)] were Gaussian, both with high coefficient of spatial determination (0.776 and 0.629, respectively), as observed in Table 5 and Figures 4 and 5. Thus, from the spatial point of view, there was a direct spatial correlation of #CY with BM and RB.

In Figures 2 and 4, cokriging #CY =f(BM) showed, in sites with lower values of BM (3.65-4,00), the lowest £CY (1345.3-2659.8 kg ha^{-1}). Conversely, in regions with higher BM values (> 4.00), the highest £CY (2659.8-3974.3 kg ha^{-1}) were found. Similarly, in Figures 2 and 5, it was observed that regions with the lowest values of RB (2.7-3.8) were precisely the sites with the lowest £CY values (1345.3-2659.8 kg ha^{-1}). Higher values of £CY (> 2659.8 kg ha^{-1}) were mapped where RB was above 1.00. Such behavior addresses the direct relationship between these production attributes, the result of their interdependence. In this sense, when the intention is to increase the productivity of seed cotton, agronomic management that stimulates the production of branches and reproductive bolls must be adopted in the property, since this study clearly demonstrates the implication of BM and RB on the productivity of seed cotton.

CONCLUSIONS

The variability expressed by the coefficient of variation was predominantly low to moderate for all soil chemical properties and cotton production variables.

The absence of spatial dependence in soil chemical properties, except for pH, indicated that spatial variations should be considered for soil sampling design.

The kriging maps for the production attributes of cotton revealed that these variables have similar patterns of spatial distribution in the crop.

The productive attributes of the direct relationship, both linear and spatial, with the productivity of seed cotton were the number of reproductive branches and the boll mass.

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