

SPATIAL VARIABILITY OF RESISTANCE TO PENETRATION IN SOIL UNDER SUGARCANE CROPS WITH DIFFERENT HARVEST METHODS¹

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ABSTRACT - The objective of this work was to evaluate the spatial variability of resistance to penetration in soil under sugarcane crops subjected to different harvest methods in the North Coast microregion of the state of Paraíba, Brazil. The study was conducted in a Typic Hapludult under sugarcane crops, at the farms Santa Emília-II and Maria da Luz-I of the company Miriri Food and Bioenergy S/A, in the municipalities of Rio Tinto and Capim, respectively, state of Paraíba, Brazil. Three sugarcane areas with different harvest methods (manual, mechanized, and manual/mechanized) were selected. The sampling was done in plots of 100 × 100 m, using a grid of 20 × 20 m, covering planting rows and interrows; each intersection point of the grid was georeferenced, and the soil mechanic resistance to penetration was evaluated with the aid of an impact penetrometer (IAA/Planalsucar-Stolf) up to the depth of 0-0.6 m. Soil disturbed and undisturbed samples from the 0.0-0.1 and 0.1-0.2 m layers were collected for analyses of soil moisture, texture, clay dispersed in water, flocculation degree. A pure nugget effect was found in the 0.0-0.1 and 0.4-0.5 m soil layers in the rows of the areas with manual/mechanized harvest. The spherical model was found for most conditions evaluated. The results for the areas were similar, with amplitude of 25-49 m, indicating that the harvest management had no effect on the soil resistance to penetration. No compacted areas were found, and the spatial dependency of the resistance to penetration was characterized as moderate to strong.

Keywords: Soil compaction. Controlled traffic. Geostatistics.

VARIABILIDADE ESPACIAL DA RESISTÊNCIA A PENETRAÇÃO EM SOLO SOB DIFERENTES CONDIÇÕES DE COLHEITA DE CANA-DE-AÇÚCAR

RESUMO - O objetivo deste trabalho foi avaliar a variabilidade espacial da resistência a penetração em solo sob diferentes condições de colheita de cana-de-açúcar na microrregião do Litoral Norte paraibano. O estudo foi realizado em Argissolo Acinzentado cultivado com cana-de-açúcar, nas fazendas Santa Emília II e Maria da Luz I, pertencentes à Usina Miriri e Bioenergia S/A, nos municípios de Rio Tinto e Capim, estado da Paraíba no Brasil. Selecionou-se três áreas: Colheita manual; Colheita mecanizada e; Colheita manual e mecanizada. As coletas se procederam em parcelas de 100 x 100 m, sob grid de amostragem de 20 x 20 m, contemplando linhas e entrelinhas de plantio, sendo cada ponto de cruzamento da malha amostral georreferenciado, e levantada a sua resistência mecânica à penetração com auxílio de um penetrômetro de impacto modelo IAA/Planausucar-Stolf na profundidade de 0-0,6 m. Foi procedida coleta de amostra deformadas e indeformadas nas profundidade de 0-0,1 e 0,1-0,2 m para análises das seguintes variáveis: Umidade do solo, Textura, Argila dispersa em água, Grau de floculação. Observou-se efeito pepita puro nas camadas de 0-0,1 e 0,4-0,5 m na linha da área de colheita manual e mecanizada. Na maioria das condições analisadas constatou-se o modelo esférico. Os alcances foram semelhantes para áreas, com amplitude de 25 a 49 m, indicando que o manejo de colheita, no período estudado, não exerceu influência para a resistência à penetração. Não foram observadas áreas compactadas e a dependência espacial da resistência à penetração foi caracterizada como moderada a forte.

Palavras-chave: Compactação do solo. Tráfego controlado. Geoestatística.

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¹Received for publication in 06/12/2019; accepted in 03/09/2020.

Paper extracted from the master dissertation of the first author.

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INTRODUCTION

Sugarcane is an important crop for the economy of many countries, and is a source of food and bioenergy. Brazil is the largest sugarcane producing country, with approximately 39% of world's production, followed by India, Thailand, and Pakistan (FAO, 2014).

According to the Brazilian National Food Supply Company (CONAB), the state of Paraíba is the third largest sugarcane producing state in the last ten years in the Northeast region, after Pernambuco and Alagoas, with a planted area of 110,300 hectares and a production of 4,856,100 Mg in the 2016/2017 crop season (CONAB, 2017).

In the 1990's, the Brazilian sugar-energy sector focused on increasing technologies for a greater competitiveness in the market, implementing the use of mechanized harvesters for sugarcane crops; moreover, soil management in sugarcane crops is one of the most aggressive practices, considering the large number of machinery operations throughout the crop stages (CASTRO et al., 2013).

The sugarcane mechanized harvest system requires the use of load-transfers and harvesters with total weights of 20-30 Mg, whose frequent traffic during several crop cycles and under several soil hydrological conditions results in soil physical changes, mainly in increasing soil compaction, which decreases crop yield (BRAUNACK et al., 2006).

Understanding and measuring the effects of soil use and management are essential for the development of sustainable agricultural systems to conserve and improve soil quality, avoiding soil

degradation and increasing crop yield. The development of sugarcane crops increases the concern on problems of soil compaction resulted from the intense heavy machinery traffic (SILVA; CABEDA, 2006).

Considering the heterogeneity of soils, monitoring and analysis of the soil physical quality over the crop stages are strategies for conducting management systems focused on the mitigation of structural soil degradation (CAVALIERI et al., 2011). Geostatistics is a tool indicated for the study of soil attributes that vary in the space, which enables the development of information and maps that evidence the distribution of these attributes in the field, providing subsidies for an adequate soil management (SOUZA et al., 2009).

Therefore, the objective of this work was to evaluate the spatial variability of resistance to penetration in soil under sugarcane crops subjected to different harvest methods in the North Coast microregion of the state of Paraíba, Brazil.

MATERIAL AND METHODS

The study was conducted in three sugarcane producing areas of the Miriri Food and Bioenergy S/A, two of them in the Santa Emília-II farm, in the municipality of Rio Tinto, and one in the Maria da Luz-I farm, in the municipality of Capim, state of Paraíba, Brazil (Figure 1). These municipalities are in the Zona da Mata region, whose climate is As', tropical rainy with dry summer, according to the Köppen classification, presenting mean annual rainfall depth of 1,600 mm year⁻¹ and mean annual temperature of 26 °C.

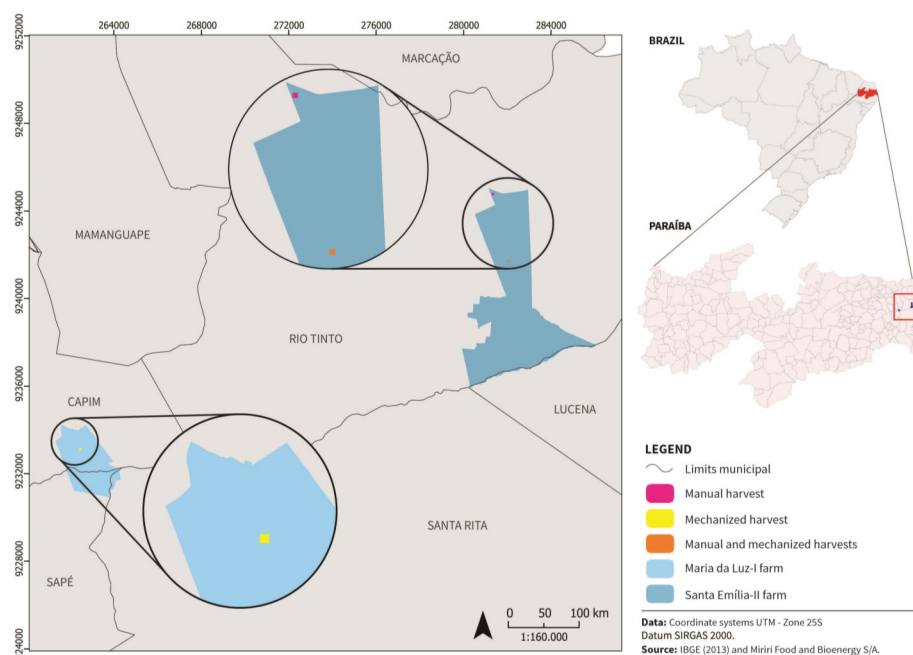


Figure 1. Location of the sampling areas in the Maria da Luz-I farm and Santa Emília-II farm, in the municipalities of Capim and Rio Tinto, respectively, state of Paraíba, Brazil.

The soil of the three areas was classified as Typic Hapludult (Argissolo Acinzentado; SANTOS et al., 2018). The areas had been subjected to two manual harvest (MAH)(6°49'42.36"S, 34°58'43.48"W); two mechanized harvest (MEH)(6°55'59.29"S, 35°8'59.30"W); or manual/mechanized harvest (two manual and two mechanized harvests) (MMH) (6°51'21.39"S, 34°58'20.39"W) (Figure 1).

The sampled areas are part of a commercial sugarcane crop, which were systematized in double rows for mechanized harvest with spacing of 0.80 m between rows and 1.60 m between interrows. The areas were determined with a GNSS receptor (GPSMAP®76CSx; Garmin), using the Sirgas 2000 Datum, Zone 25 South. The samples were collected using a regular grid spacing 20 × 20 m in plots of 100 × 100 m (1 ha). Trenches were opened in the center of each plot and soil samples were collected in every 0.10 m layer up to 0.60 m to determine soil moisture. Each intersection point of the grid was georeferenced and the soil resistance to penetration

(SRP) was determined in the planting row and interrow, totaling 50 sampling points per area.

The soil granulometry was assessed through the Bouyoucos densimeter method (GEE; BAUDER, 1986), using sodium hydroxide (NaOH 1 mol L⁻¹) as chemical dispersant, and mechanical agitation as physical dispersant (Table 1). The clay dispersed in water was evaluated using the same procedure used for the granulometry analysis, but without the use of chemical dispersant (TEIXEIRA et al., 2017). The total and water dispersed clay data were used to calculate the soil flocculation degree (Equation 1):

$$Df = \left[\left(\frac{Clay - Clay_{H_2O}}{Clay} \right) \times 100 \right] \quad (1)$$

where *Df* is the degree of flocculation (%), *Clay* is the clay dispersion in NaOH (g kg⁻¹), and *Clay_{H₂O}* is the clay dispersion in water (g kg⁻¹).

Table 1. Soil granulometry, clay dispersed in water (CDW), soil textural classification and flocculation degree for sugarcane areas under manual, mechanized, and manual/mechanized harvests.

Soil layer (m)	Soil granulometry			CDW	Textural Class	Flocculation degree
	Sand	Silt	Clay			
-----g kg ⁻¹ -----						
Manual harvest						
Planting row						
0.0 – 0.1	884	55	61	0	Loamy Sand	100
0.1 – 0.2	878	51	71	0	Loamy Sand	100
Planting interrow						
0.0 – 0.1	896	57	47	0	Sand	100
0.1 – 0.2	899	49	52	8	Sand	84.6

Mechanized harvest						
Planting row						
0.0 – 0.1	865	44	91	0	Loamy Sand	100
0.1 – 0.2	847	40	113	0	Loamy Sand	100
Planting interrow						
0.0 – 0.1	864	59	77	0	Loamy Sand	100
0.1 – 0.2	864	43	93	5	Loamy Sand	94.6

Manual/mechanized harvest						
Planting row						
0.0 – 0.1	899	32	68	0	Sand	100
0.1 – 0.2	888	25	87	0	Loamy Sand	100
Planting interrow						
0.0 – 0.1	901	32	67	0	Sand	100
0.1 – 0.2	903	32	65	0	Sand	100

The soil resistance to penetration was determined in each sample point up to 0.60 m depth, with the aid of an impact penetrometer (IAA/Planalsucar-Stolf). The number of impacts was counted, and the penetration depth reached by the rod into the soil layers was recorded and converted to MPa units, according to (Equation 2):

$$SRP = \left[\frac{Mg + mg + \left(\frac{M}{M+m} \times \frac{Mg \times h}{X} \right)}{A} \right] \times 0.098 \quad (2)$$

where *SRP* is the soil resistance to penetration, *M* is

the weight of the piston (4.03 kg), g is the gravity acceleration (9.8 m s^{-2}), m is the weight of the device without the piston (3.24 kg), h is the height ran by the piston (0.56 m), x is the penetration of the rod into the soil (cm per impact), and A is the basal area of the rod (m^2).

The dataset of soil resistance to penetration was characterized and summarized through descriptive statistics before the geostatistical analysis, by calculating the maximum value, minimum value, mean, median, standard deviation, coefficient of variation, coefficient of asymmetry, and kurtosis value. The coefficient of variation (CV) was evaluated according to Warrick and Nielsen (1980), classifying as low (<12%), moderate (12% to 60%), and high (>60%).

The geostatistical analysis was done in two phases, using the Surfer[®] 13 program. The first phase was done through empirical semivariograms, evaluating the spatial dependency of the variable in each layer of the plantin grow and planting interrow. The semivariograms were estimated by the intrinsic hypothesis theory, which assumest hat measurements separated by small distances are more similar to each other than those separated by longer distances (OLIVEIRA et al., 2013). The semivariance was obtained using (Equation 3):

$$\hat{\gamma}(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i) - Z(x_i+h)]^2 \quad (3)$$

where $\hat{\gamma}(h)$ is the semivariance value for the distance h ; $N(h)$ is the number of pairs involved with the calculation of semivariance; $Z(x_i)$ is the Z value in the position x_i ; $Z(x_i+h)$ is the Z value separated by a distance h in the position x_i . The theoretical models of the empirical semivariograms were adjusted by interaction and visual inspection. The semivariograms used were omnidirectional, considering the isotropies.

In the second phase, the spatial dependency index (SDI) was calculated considering the parameters nugget effect (C_0) and sill (C_0+C_1) of the semivariograms, according to the expression $[C_1/(C_0+C_1)*100]$, classifying it as very low (SDI<20%), low (20<SDI<40%), moderate (40%<SDI<60%), high (60%<SDI<80%), and very high

(80%<SDI<100%) (DALCHIAVON; CARVALHO, 2012).

RESULTS AND DISCUSSION

The data of soil resistance to penetration (SRP) were close to a normal distribution (Table 2), since the mean and median values were similar in all sugarcane areas, soil layers, and positions studied. According to Cressie (1991), normality is not required for evaluations of spatial dependency when avoiding elongated tails in distribution curves, which can be found in the present work by the number of coefficients of asymmetry close to zero.

The CVs for the 0.0-0.1 and 0.1-0.2 m soil layers in the planting rows, and for the 0.0-0.1 m soil layer in the interrows in the MAH area were classified as high, indicating a high variation of the data when compared to the other areas and respective soil layers, which presented moderate CVs.

The MAH area showed decreases in CV, as the depth of the analyzed soil layer was increased. According to Cancian (2015), it can be due to the greater effect of the furrower mechanism of the seeders on the soil surface layers, which causes higher disaggregation, in addition to the constant moistening and drying cycles and biological activity that also affect the soil surface layers. The CVs of the MMH and MEH areas had not the same decreasing pattern.

The MAH area presented higher absolute values of SRP than the other areas (Table 2). According to Otto et al. (2011), SRPs above 2 MPa limit root growth in most crops, including sugarcane.

The MEH and MMH areas presented low SRP in surface layers (0.0-0.3 m) and increasing SRP in deeper layers. The higher SRP values in the subsurface layers can be explained by the management or cohesion conditions of the soil due to low moisture content in the sampling point.

The MEH and MMH areas presented higher SRP in the planting interrow due to the passing of the harvester wheels, which causes intense soil compression. The MAH area presented higher SRP in the planting row, with mean of 4.06 MPa, which was not expected and can be limiting for root growth.

Table 2. Descriptive statistics of data of soil resistance to penetration (SRP; MPa) in areas with manual harvest, mechanized harvest, and manual/mechanized harvest of sugarcane crops grown in a Typic Hapludult.

Layer (m)	Minimum	Mean	Median	Maximum	SD	CV	CA	CC
Manual harvest								
Planting row								
0.0 – 0.1	0.26	1.43	1.13	5.09	1.19	82.77	1.63	5.08
0.1 – 0.2	1.07	3.17	2.45	9.48	2.38	75.04	1.28	3.57
0.2 – 0.3	1.22	3.76	3.00	8.83	2.01	53.41	0.91	2.91
0.3 – 0.4	1.83	4.06	3.19	9.26	1.92	47.16	1.07	3.32
0.4 – 0.5	1.65	3.95	3.66	7.29	1.63	41.38	0.51	2.09
0.5 – 0.6	1.65	3.85	3.77	7.29	1.52	39.39	0.34	2.27
Planting interrow								
0.0 – 0.1	0.26	1.32	1.01	5.24	1.15	87.53	2.24	7.61
0.1 – 0.2	0.98	2.46	2.32	4.94	1.23	50.27	0.38	1.94
0.2 – 0.3	1.35	2.83	2.67	5.38	1.13	39.83	0.77	2.82
0.3 – 0.4	1.24	2.64	2.38	4.58	0.81	30.72	0.93	3.20
0.4 – 0.5	1.28	2.38	2.14	5.09	0.82	34.64	1.65	6.01
0.5 – 0.6	1.39	2.68	2.72	4.21	0.86	32.19	0.18	2.03
Mechanized harvest								
Planting row								
0.0 – 0.1	0.26	0.34	0.26	0.69	0.12	33.74	1.29	4.43
0.1 – 0.2	0.53	1.13	1.02	1.97	0.35	31.21	0.63	3.00
0.2 – 0.3	0.80	1.59	1.57	3.19	0.45	28.50	1.56	7.63
0.3 – 0.4	0.61	1.43	1.42	2.16	0.33	23.29	0.10	3.52
0.4 – 0.5	0.55	1.16	1.13	1.87	0.30	26.25	0.28	3.04
0.5 – 0.6	0.61	1.15	1.13	2.31	0.40	34.69	0.91	3.91
Planting interrow								
0.0 – 0.1	0.52	1.01	1.13	1.57	0.24	24.12	0.02	2.82
0.1 – 0.2	1.34	2.16	2.14	2.63	0.31	14.50	-0.77	3.36
0.2 – 0.3	1.79	2.25	2.23	2.97	0.33	14.63	0.51	2.20
0.3 – 0.4	1.15	1.67	1.68	2.16	0.28	16.86	0.17	2.21
0.4 – 0.5	0.80	1.22	1.24	1.57	0.22	17.81	-0.26	2.01
0.5 – 0.6	0.69	1.17	1.18	1.72	0.27	23.17	0.25	2.27
Manual/mechanized harvest								
Planting row								
0.0 – 0.1	0.26	0.31	0.26	0.50	0.08	25.48	1.32	3.40
0.1 – 0.2	0.26	0.65	0.65	1.12	0.20	31.39	0.23	2.88
0.2 – 0.3	0.26	0.98	1.04	1.57	0.34	34.77	0.06	2.46
0.3 – 0.4	0.63	1.05	1.03	1.57	0.28	26.71	0.33	2.10
0.4 – 0.5	0.65	1.01	0.99	1.68	0.26	25.67	0.76	3.12
0.5 – 0.6	0.42	0.91	0.85	1.87	0.26	28.64	1.85	8.63
Planting interrow								
0.0 – 0.1	0.26	0.62	0.59	1.28	0.23	36.57	1.32	4.99
0.1 – 0.2	0.82	1.35	1.39	2.09	0.32	23.68	0.21	2.68
0.2 – 0.3	1.21	1.74	1.76	2.45	0.28	16.37	0.13	3.02
0.3 – 0.4	1.06	1.69	1.72	2.60	0.31	18.50	0.63	4.50
0.4 – 0.5	0.83	1.37	1.40	1.72	0.21	15.47	-0.81	3.15
0.5 – 0.6	0.63	1.02	1.06	1.35	0.19	18.23	-0.41	2.37

SD = standard deviation; CV = coefficient of variation; CA = coefficient of asymmetry; CC = coefficient of kurtosis.

The higher SRP in the MAH area is due to the soil moisture in this area, which varied from 0.02 to 0.04 kg kg⁻¹ and was lower than that found in the other areas (Table 3). The result is consistent with those of Carvalho Filho et al. (2004), who reported that SRP tends to vary inversely to soil water content. Lima et al. (2013) evaluated soils under

different textures and found increases in SRP as the soil moisture was decreased, which is explained by the higher presence of water acting as lubricant of particles, hindering penetrometer rod penetration.

The moisture was distributed uniformly in the soil profile and presented free water percolation, indicating that there were no compacted layers.

Table 3. Soil gravimetric moisture in areas with manual harvest, mechanized harvest, and manual/mechanized harvest of sugarcane crops grown in a Typic Hapludult.

Layer (m)	Soil gravimetric moisture (kg kg ⁻¹)	
	Planting row	Planting interrow
Manual harvest		
0.0 – 0.1	0.02	0.02
0.1 – 0.2	0.02	0.02
0.2 – 0.3	0.02	0.03
0.3 – 0.4	0.03	0.04
0.4 – 0.5	0.04	0.04
0.5 – 0.6	0.04	0.04
Mechanized harvest		
0.0 – 0.1	0.07	0.07
0.1 – 0.2	0.07	0.08
0.2 – 0.3	0.09	0.09
0.3 – 0.4	0.11	0.11
0.4 – 0.5	0.12	0.13
0.5 – 0.6	0.13	0.14
Manual/mechanized harvest		
0.0 – 0.1	0.08	0.11
0.1 – 0.2	0.08	0.10
0.2 – 0.3	0.07	0.10
0.3 – 0.4	0.08	0.11
0.4 – 0.5	0.08	0.10
0.5 – 0.6	0.08	0.10

The maps shown in Figures 2, 3 and 4 are the kriging of the areas. This interpolated surface presents the spatial distribution of each variable, comparing the SRP in the planting row and in the

planting interrow in the different soil layers. It allows the identification of location and coverage of extreme values, degree of homogeneity of the area, and greater gradient directions.

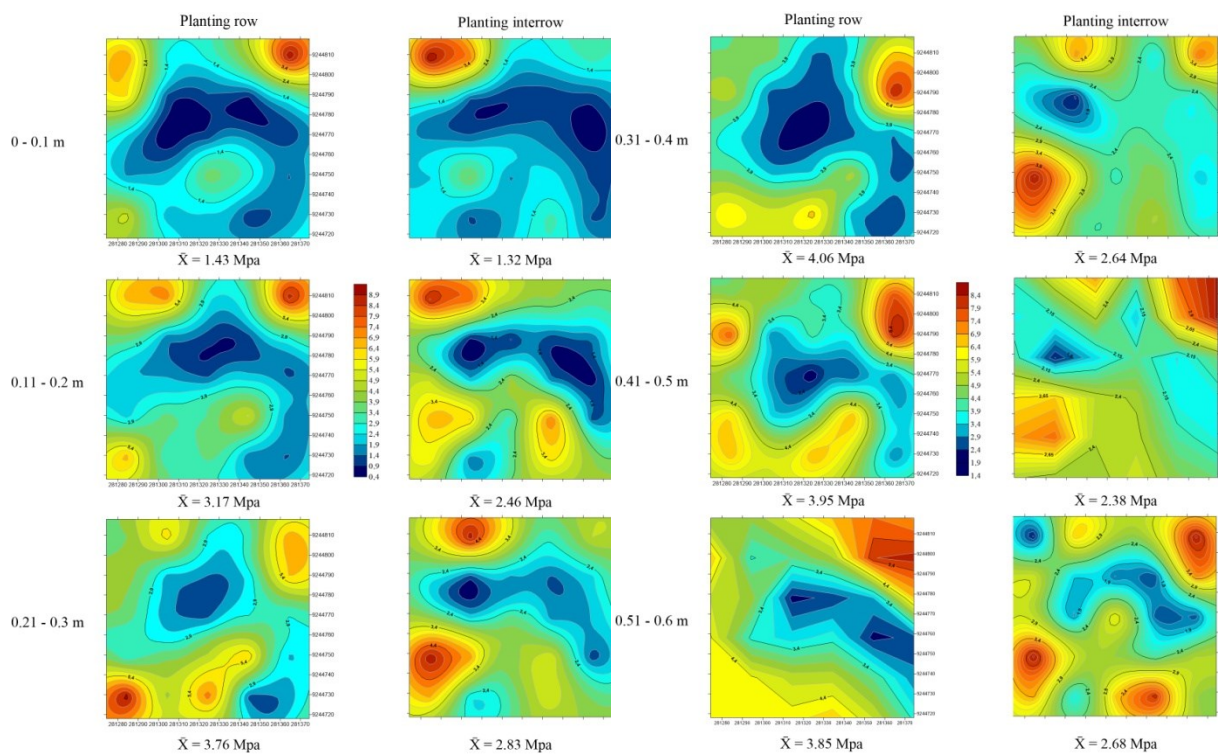


Figure 2. Kriging maps for soil resistance to penetration (SRP) comparing data of planting row and planting interrow in different soil layers (0-0.60 m) in the area with manual harvest (MAH) of sugarcane crops grown in a Typic Hapludult.

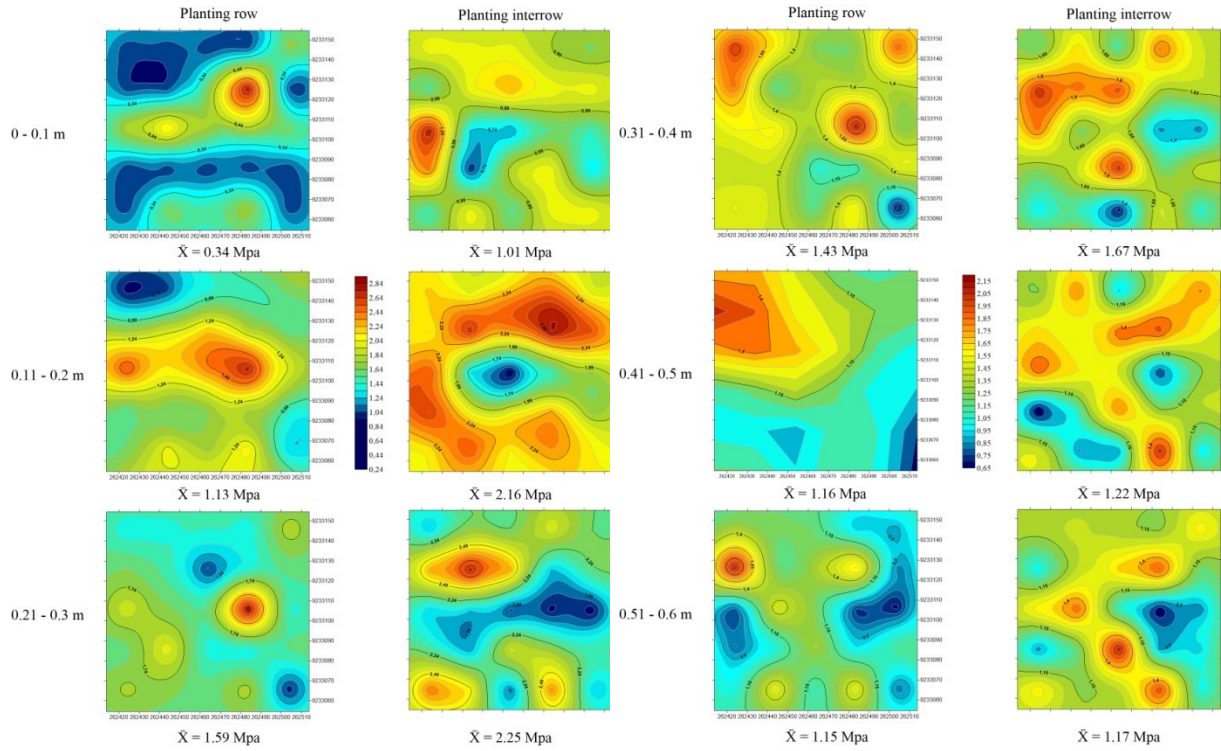


Figure 3. Kriging maps for soil resistance to penetration (SRP) comparing data of planting row and planting interrow in different soil layers (0-0.60 m) in the area with mechanized harvest (MEH) of sugarcane crops grown in a Typic Hapludult.

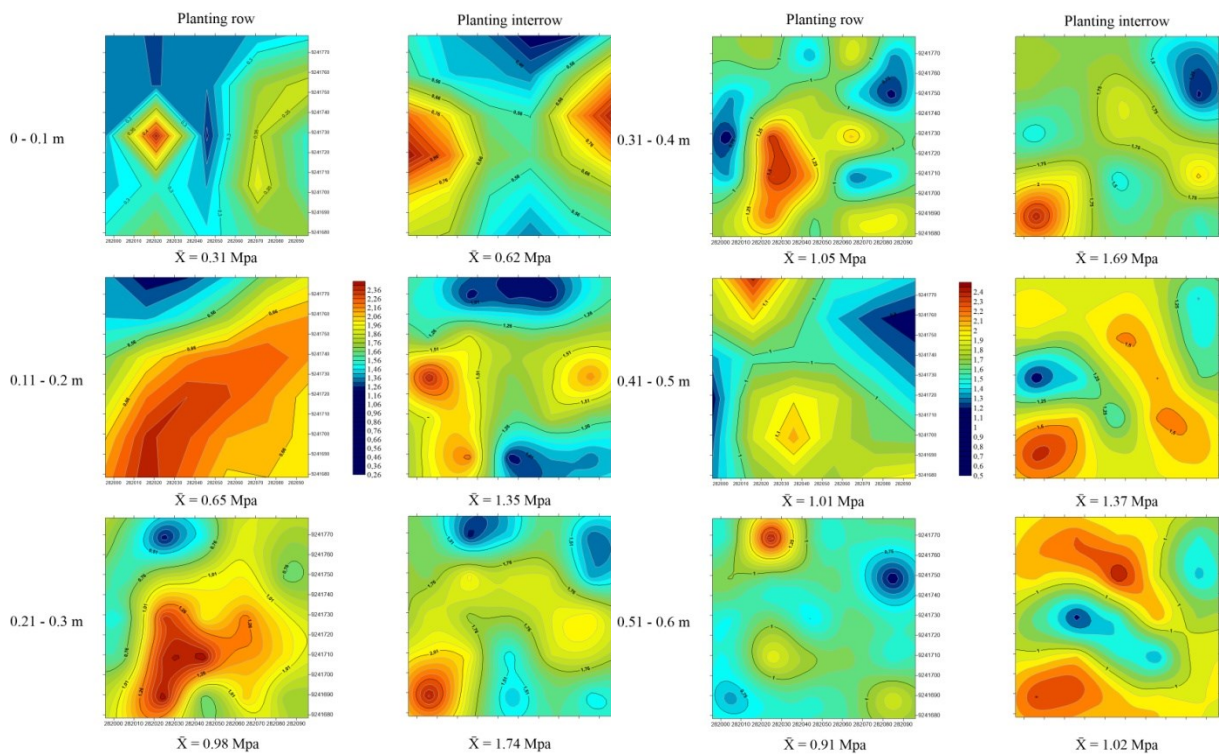


Figure 4. Kriging maps for soil resistance to penetration (SRP) comparing data of planting row and planting interrow in different soil layers (0-0.60 m) in the area with manual/mechanized harvest (MMH) of sugarcane crops grown in a Typic Hapludult.

The variables presented, predominantly, very high spatial dependency index (SDI) (Table 4). Only the 0.1-0.3 m soil layer in the planting row of the MEH area, and the 0.3-0.5 m layer in the planting interrow of the MMH area presented high SDI; and

the 0.1-0.2 m soil layer in the planting row of the MMH area presented intermediate SDI. Thus, the semivariogram explained well the spatial variance of the data for 94% of the variables.

Table 4. Parameters of semivariogram models for soil resistance to penetration (MPa) in areas with manual harvest, mechanized harvest, and manual/mechanized harvest of sugarcane crops grown in a Typic Hapludult.

Layer (m)	C_0	$C_0 + C_1$	Range (m)	Model	SDI (%)
Manual harvest					
Planting row					
0.0 – 0.1	0.2	1.22	43	Spherical	84
0.1 – 0.2	0.5	5.00	41	Spherical	90
0.2 – 0.3	0.4	4.00	40	Spherical	90
0.3 – 0.4	0.5	3.60	41	Spherical	86
0.4 – 0.5	0.5	2.75	35	Spherical	82
0.5 – 0.6	0.5	3.21	40	Exponential	84
Planting interrow					
0.0 – 0.1	0.2	1.07	43	Spherical	81
0.1 – 0.2	0.2	1.53	35	Spherical	87
0.2 – 0.3	0.2	1.25	38	Spherical	84
0.3 – 0.4	0.1	0.60	45	Spherical	83
0.4 – 0.5	0.1	0.60	28	Spherical	83
0.5 – 0.6	0.04	0.74	31	Spherical	95
Mechanized harvest					
Planting row					
0.0 – 0.1	0.002	0.0155	29	Spherical	87
0.1 – 0.2	0.04	0.14	46	Spherical	71
0.2 – 0.3	0.05	0.243	25	Spherical	79
0.3 – 0.4	0.01	0.102	28	Spherical	90
0.4 – 0.5	0.012	0.109	30	Exponential	89
0.5 – 0.6	0.02	0.146	27	Spherical	86
Planting interrow					
0.0 – 0.1	0.0105	0.0704	27	Spherical	85
0.1 – 0.2	0.02	0.133	40	Spherical	85
0.2 – 0.3	0.0158	0.1188	29	Spherical	87
0.3 – 0.4	0.01	0.079	27	Spherical	87
0.4 – 0.5	0.005	0.047	27	Spherical	89
0.5 – 0.6	0.0113	0.0883	25	Spherical	87
Manual/mechanized harvest					
Planting row					
0.0 – 0.1	-	-	-	PNE	-
0.1 – 0.2	0.02	0.044	35	Exponential	55
0.2 – 0.3	0.003	0.114	39	Spherical	97
0.3 – 0.4	0.0056	0.0856	31	Spherical	93
0.4 – 0.5	-	-	-	PNE	-
0.5 – 0.6	0.01	0.065	32	Spherical	85
Planting interrow					
0.0 – 0.1	0.0045	0.0695	30	Exponential	94
0.1 – 0.2	0.01	0.115	49	Spherical	91
0.2 – 0.3	0.0033	0.0781	46	Spherical	96
0.3 – 0.4	0.02	0.095	45	Spherical	79
0.4 – 0.5	0.015	0.047	40	Spherical	68
0.5 – 0.6	0.005	0.0427	39	Spherical	88

C_0 = nugget effect; $C_0 + C_1$ = sill; SDI = spatial dependency index; PNE = pure nugget effect.

The range values within the same area and position were similar in the whole soil profile; however, considering the absolute values of the areas studied, they were lower in the MEH area, with mean of 30 m for the planting row and 29 m for the planting interrow.

These ranges were lower than those reported by Mion et al. (2012) for SRP in a Typic Hapludult of sandy texture under pastures (*Bachiaria decumbens* and *Cynodon* sp.) in the state of Ceará, Brazil; they found mean of 310.9 m in a sampling grid of 30 × 30 m. Moreover, Coelho et al. (2012) evaluated SRP in a Typic Hapludert of loamy texture grown with mango and found ranges above 21.6 m in a sampling grid of 10 × 10 m.

The range is affected by the soil type and use, and management applied for its use. According to Coelho et al. (2012), the quantity and distribution of soil samples in the field can also affect the range.

CONCLUSIONS

The soil resistance to penetration presented spatial dependency in all sugarcane areas studied, except for the manual/mechanized harvest area in the 0-0.1 m and 0.4-0.5 m soil layers in the planting rows, which presented pure nugget effect.

The soil moisture was uniform throughout the soil profile, indicating that there were no compacted layers.

The soil resistance to penetration found showed no occurrence of compacted zones that are limiting for root growth.

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