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Spatial variability of soil penetration resistance in areas cultivated with sugarcane under different times of mechanized harvesting with controlled traffic

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ABSTRACT

The present study aimed to evaluate the spatial variability of mechanical resistance of the soil to penetration in areas cultivated with sugarcane under different mechanized cutting times with controlled traffic. The study was conducted in an Alfisol under areas of first and third mechanized sugarcane cutting, located in Santa Emília II Farm, belonging to Usina Miriri Bioenergia e Alimentos S/A, in Rio Tinto, State of Paraíba, Brazil. A 20 × 20 m sampling grid was adopted, with points in the row and interrow planting in both areas, totaling 50 georeferenced points, in 1.0 ha plots, where mechanical resistance of the soil to penetration was collected with the aid of an impact penetrometer up to 0.6 m deep. The variability of the resistance was evaluated by descriptive statistics, and the spatial dependence by geostatistics. Mechanical resistance showed a pure nugget effect in the 0-0.1 and 0.2-0.3 m layers in the interrow and the 0.3-0.4 m layer in the row. A Gaussian model was observed in the third cutting area; the spherical, exponential, and Gaussian models presented themselves in both areas. The spatial dependence estimator was rated as very high, with an average range of 27 m for the first cutting area and 49 m for the third cutting. The controlled traffic proved to be efficient, showing less resistance in the lines of both areas, the spatial dependence was very strong and with greater ranges in the area of the third cut.

Keywords: Geostatistics, Sampling grid, Alfisols, *Saccharum oficcinarum* L.

Variabilidade espacial da resistência do solo à penetração em áreas cultivadas com cana-de-açúcar sob diferentes tempos de colheita mecanizada com tráfego controlado

RESUMO

O presente trabalho teve como objetivo avaliar a variabilidade espacial da resistência mecânica do solo à penetração em áreas cultivadas com cana-de-açúcar sob diferentes tempos de cortes mecanizados com tráfego controlado. O trabalho foi conduzido em um Argissolo Acinzentado sob áreas de primeiro e terceiro corte mecanizado de cana-de-açúcar, localizadas na Fazenda Santa Emília II, pertencente à Usina Miriri Bioenergia e Alimentos S/A, município de Rio Tinto (Paraíba). Foi adotada uma malha amostral de 20 × 20 m, com pontos em linha e entrelinha de plantio em ambas as áreas, totalizando 50 pontos georreferenciados, em parcelas de 1,0 ha, onde realizou-se coletas de resistência mecânica do solo à penetração com auxílio de um penetrômetro de impacto na profundidade de 0 a 0,6 m. A variabilidade da resistência foi avaliada pela estatística descritiva e a dependência espacial por meio da geoestatística. A resistência mecânica apresentou efeito pepita puro nas profundidades de 0-0,1 e 0,2-0,3 m na entrelinha e 0,3-0,4 m na primeira linha. Observou-se um modelo gaussiano na área de terceiro corte, os modelos esférico, exponencial e gaussiano se apresentaram em ambas as áreas. O avaliador de dependência espacial, foi classificado como muito alto, com alcance médio de 27 m para a área de primeiro corte e 49 m para o terceiro corte. O tráfego controlado se mostrou eficiente demonstrando menores resistência nas linhas de ambas as áreas, a dependência espacial se mostrou muito forte e com alcances maiores na área de terceiro corte.

Palavras-chave: Geoestatística, Grid de amostragem, Argissolo, *Saccharum oficcinarum* L.

1. Introduction

Sugarcane is a crop that has high economic value both in Brazil and worldwide, used in the production of sugar, electricity, and alcohol (Silva et al., 2014). Mechanized sugarcane harvesting has been established as a way to avoid fire stripping, besides significantly reducing the operational cost of harvesting, but the trafficability of machines in the field can cause changes in the physical attributes of the soil, modifying soil density, porosity, water retention, and enabling the appearance of compacted layers (Souza et al., 2012).

Several studies show that conventional preparation and intense traffic of agricultural machinery are the main tails of the physical degradation of soils in sugarcane plantation areas (Carvalho et al., 2022; Farhate et al., 2022; Luz et al., 2022a; Luz et al., 2022b). In order to mitigate the negative effect of machines in the field, controlled traffic is being adopted, which is based on the premise that the tires of the machines only travel interrows of the crop, favoring the lower appearance of compacted layers with greater resistance to soil penetration (Oliveira Filho et al., 2016).

However, it is necessary to evaluate the effectiveness of this traffic control management through spatial variability studies. For example, a study by Luz et al. (2022b) concluded that reduced tillage associated with controlled machine traffic is essential for improving soil water availability and airflow to subsequent ratoons in sugarcane fields. In this sense, the spatial dependence makes it possible to analyze the crop field in a segmented way, making geostatistics a tool to evaluate how the passage of machines influences the rows and interrows of crop plantings and how they affect their yields (Peluco et al., 2015).

Moreover, the characterization of resource variability through geostatistical analysis is of fundamental importance for the effective use of technologies, visualize or simulate the spatial structure of soil physical attributes (Soares et al., 2023), and contribute to economically viable soil management and environmental protection (Mwendwa et al., 2022). Therefore, the objective of the present study was to evaluate the spatial variability of mechanical resistance of the soil to penetration in areas cultivated with sugarcane under different mechanized cutting times with controlled traffic.

2. Material and Methods

The study was carried out in areas of first cutting (FC) and third cutting (TC) of mechanized sugarcane, located in Santa Emília II Farm (6°50’31” S and 34°58’48” W), belonging to Usina Miriri Bioenergia e Alimentos S/A, in Rio Tinto, State of Paraíba, Brazil (Figure 1). According to the Köppen classification, the region's climate is As-type, tropical rainy with dry summer, average annual precipitation of 1.600 mm, and a temperature of 26 °C. The soil studied was Alfisols (Santos et al., 2018); two areas with 1 and 3 years of sugarcane planting were selected. The particle-size characterization of the soil surface layer is presented in Table 1.

At crop planting, soil corrections were made with 2 tons ha^{-1} of dolomitic limestone applied by broadcasting. Sowing fertilization was conducted with 260 kg ha^{-1} of monoammonium phosphate. As topdressing fertilization, 12 annual fertigation events were conducted, totaling 444 kg of potassium, 829 kg of nitrogen, 379 kg of magnesium, and 44 kg of phosphorus. The corrections and fertilization were repeated annually. The sugarcane variety used was RB 93509 in the FC area, and in the TC, RB 92579. The collections were made three months after the sugarcane was harvested. The cut was made by a John Deere harvester, model 3522, using an automatic pilot of the same brand under traffic controlled by the Apex® system.

The samples were collected in plots with dimensions of 100 × 100 m, in crops systematized for mechanized harvesting, with double row planting lines at 0.80 × 1.60 m spacing. The perimeters of the plots were obtained by a GarmineTrex® 20× handheld GPS survey. For the soil sampling, a regular grid was adopted in the 20 × 20 m spacing, with points in the row and interrow planting in both areas, totaling 50 points, in which mechanical resistance of the soil to penetration (MRSP) was collected up to 0.6 m deep, being georeferenced, adopting a spatial variability.

Additionally, samples were collected in each plot every 0.10 m, up to a maximum depth of 0.60 m, for moisture analysis according to the methodology described by Teixeira et al. (2017). The MRSP was determined with the aid of an impact penetrometer model IAA/Planausucar-Stolf, the transformation of penetration in the unit from cm $impact^{-1}$ to MPa, that is, penetration resistance was proceeded according to Stolf (1991) (Equation 1).

$$MRSP = \left[\frac{Mg + mg + \left(\frac{M}{M+m} \times \frac{Mg \times h}{X} \right)}{A} \right] \times 0.098 \quad (1)$$

where: MRSP - mechanical resistance of the soil to penetration; M - piston mass, 4.03 kg; g - acceleration of gravity; m - mass of the device excluding the piston, 3.24 kg; h - height traveled by the piston, 0.56 m; x - cone penetration into the ground, cm $impact^{-1}$; A -cone basal area (m²).

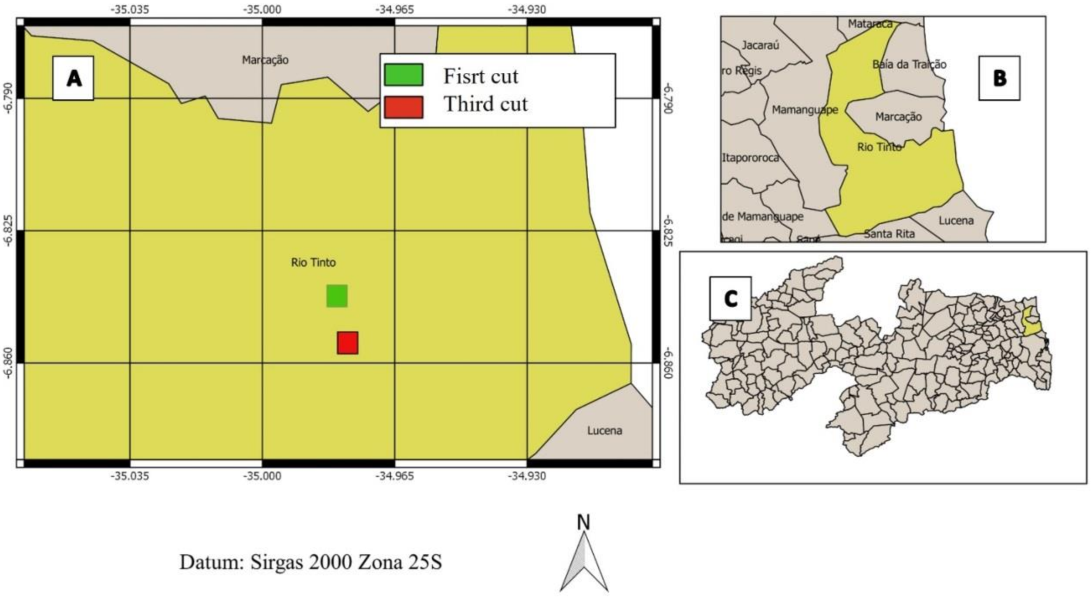

Figure 1. Map of the location of the experiment area (A), municipality of Rio Tinto (B) and Paraiba state (C) in Brazil.

Table 1. Particle-size characterization of the 0-0.2 m layer of Alfisols cultivated with sugarcane with mechanized harvesting under controlled traffic.

Position	Sand		Silt		Clay		Textural Class	
	($g\ kg^{-1}$)							
	Soil layer (m)							
	0-0.1	0.1-0.2	0-0.1	0.1-0.2	0-0.1	0.1-0.2	0-0.1	0.1-0.2
First Cutting (FC)								
Rows	918	928	23	21	59	51	Sand	Sand
Interrows	933	919	31	15	36	66	Sand	Sand
Third Cutting (TC)								
Rows	879	889	9	26	112	85	Loamy sand	Sand
Interrows	870	873	16	13	114	114	Loamy sand	Loamy sand

The variability of MRSP was initially evaluated by the analysis of its descriptive statistics, obtained through the IBM SPSS-statistics© v.24.0 software (Kranzler, 2011), the mean, median, variance, coefficient of variation, asymmetry, kurtosis, and normality was performed by the Shapiro-Wilks test. Spatial dependence was assessed using geostatistics based on the calculation of semivariance and fitted semivariograms obtained by Gamma Design Software GS^+ (2012). The adjustment of the semivariograms was performed by searching for the lowest residual sum of squares (RSS) and the highest spatial dependence estimator (SDE), and it was then possible to determine the parameters nugget effect (Co), plateau (Co+C), and range (Ao). Following the Cambardella et al. (1994) methodology, modified by GS^+ (2004), the spatial dependence was evaluated according to the expression (Equation 2).

$$\text{SDE} = \left[\frac{C}{C+Co}\right]x100 \qquad (2)$$

where: SDE – spatial dependence estimator; C - structural variance; C + Co - plateau. The interpolation of the data was processed by the kriging method, enabling the production of the isoline maps by Surfer© 14 software (GOLDEN SOFTWARE, 2017).

3. Results and Discussion

Table 2 shows the results of the descriptive statistics for the mechanical resistance of the soil to penetration (MRSP) in the row and interrow positions of the first (FC) and third (TC) cutting areas and gravimetric moisture values (Table 3). The Semivariograms of resistance to penetration in Alfisols, in row and interrow positions in the first cutting (FC) area with sugar cane harvested mechanically are presented in Figure 3.

Table 2. Descriptive statistics for mechanical resistance of the soil to penetration (MRSP) in soil profiles from areas under different sugarcane cultivation times under mechanized harvesting.

Positions	Interrow						Row					
	Layer (m)											
	0-0.1	0.1-0.2	0.2-0.3	0.3-0.4	0.4-0.5	0.5-0.6	0-0.1	0.1-0.2	0.2-0.3	0.3-0.4	0.4-0.5	0.5-0.6
First Cutting (FC)												
Mean	0.48	1.47	2.02	2.00	1.59	1.44	0.31	0.95	1.61	1.84	1.82	1.59
Median	0.47	1.35	1.90	1.94	1.57	1.35	0.25	0.94	1.57	1.87	1.72	1.57
Minimum	0.25	0.87	1.21	1.13	0.98	1.13	0.26	0.26	0.55	1.13	1.24	1.13
Maximum	0.91	2.67	3.04	2.89	2.23	2.45	0.51	1.69	2.67	2.67	2.53	2.23
Lower quartile	0.38	1.15	1.77	1.75	1.38	1.22	0.25	0.57	1.25	1.57	1.48	1.33
Upper quartile	0.55	1.69	2.29	2.23	1.75	1.57	0.35	1.21	2.01	2.05	2.12	1.83
Variance	0.01	0.23	0.22	0.18	0.08	0.09	0.01	0.16	0.24	0.16	0.14	0.09
Standard deviation	0.13	0.48	0.46	0.42	0.29	0.30	0.08	0.40	0.48	0.39	0.37	0.30
Kurtosis	2.82	0.89	0.05	0.07	0.38	3.84	0.95	-1.02	0.16	-0.20	-0.7	-0.39
CV (%)	26.99	32.48	22.97	21.00	18.23	21.16	26.34	42.24	30.11	21.65	20.46	18.94
Asymmetry	1.18	1.13	0.40	0.26	0.23	1.64	1.41	0.22	0.25	0.34	0.42	0.45
Shapiro-Wilks	0.07	0.01	0.51	0.56	0.93	0.00	0.00	0.18	0.83	0.66	0.26	0.44
Third Cutting (TC)												
Mean	1.46	2.26	2.27	1.79	1.49	1.43	0.53	1.08	1.43	1.41	1.39	1.40
Median	1.35	2.41	2.09	1.84	1.55	1.46	0.44	1.06	1.41	1.54	1.35	1.46
Minimum	0.33	1.17	1.28	1.28	1.01	0.88	0.26	0.26	0.55	0.77	1.05	0.93
Maximum	2.92	3.11	5.13	2.36	1.90	2.16	1.75	2.19	2.89	1.87	1.94	1.87
Lower quartile	1.13	1.79	1.89	1.57	1.24	1.22	0.26	0.58	0.86	1.11	1.21	1.12
Upper quartile	1.81	2.71	2.67	1.99	1.70	1.57	0.71	1.42	1.71	1.65	1.57	1.62
Variance	0.37	0.37	0.54	0.07	0.07	0.08	0.12	0.33	0.33	0.12	0.05	0.08
Standard deviation	0.61	0.61	0.73	0.28	0.26	0.28	0.35	0.58	0.57	0.34	0.24	0.28
Kurtosis	0.21	-0.78	9.29	-0.55	-0.94	0.87	4.99	1.43	0.25	-0.92	-0.60	-1.16
CV (%)	41.46	26.98	32.19	15.68	17.34	19.69	66.08	53.53	39.88	24.07	17.21	20.54
Asymmetry	0.11	-0.54	2.47	-0.06	-0.15	0.47	1.86	0.43	0.49	-0.46	0.37	0.03
Shapiro-Wilks	0.75	0.07	0.00	0.86	0.25	0.47	0.00	0.14	0.39	0.07	0.35	0.17

Table 3. Gravimetric moisture values found in the soil profile for two areas of mechanized sugarcane harvesting under controlled traffic

Layer (cm)	Row	Interrow
	($kg\ kg^{-1}$)	
First Cutting (FC)		
0-0.1	0.03	0.03
0.1-0.2	0.02	0.03
0.2-0.3	0.03	0.02
0.3-0.4	0.04	0.03
0.4-0.5	0.04	0.03
0.5-0.6	0.05	0.04
Third Cutting (TC)		
0-0.1	0.06	0.06
0.1-0.2	0.07	0.06
0.2-0.3	0.06	0.07
0.3-0.4	0.07	0.08
0.4-0.5	0.07	0.08
0.5-0.6	0.08	0.09

It is observed that the maximum values are above those found in the upper quartile; this condition is more often found in the interrow, but there is no filtering of the data because the MRSP has the characteristic of presenting itself with high peaks in a punctual way in the field, so it is expected high values disturbing the distribution of the variable (Silveira et al., 2010). The MRSP averages are lower in the first 0.1 m of soil with an increase until 0.3 m, a trend seen for the row and interrow positions in both sampled areas, data that corroborates Campos et al., (2013) evaluating soil penetration resistance in area cultivated with sugarcane.

The MRSP presents lower values in the planting rows, with FC having lower penetration resistance in both positions than TC. The results presented in this study show similarity with those obtained by Arcoverde et al. (2020), who verified an increase in soil bulk density according to the machine traffic, finding soil bulk density averages between 1.36 and 1.50 Mg m^{-3}. It is also important to note that Bd is not very sensitive to the effects of traffic, so in some cases, the pressure exerted by machinery cannot modify it (Savioli et al., 2020).

The mean and median values show close magnitudes, tending to similarity, a condition that indicates normal distribution in most of the results found, as can be seen with the Shapiro-Wilks test ($p<0.05$), besides the asymmetry values being close to zero, results that corroborate the statements of Santos et al. (2012), Oliveira et al. (2013), and Tavares et al. (2012). Even though data normality is not a premise for spatial variability analysis, it is recommended that elongated grids in the distribution curve, that is, too much asymmetry, are not verified. Thus, it is observed that the data found are suitable for applying geostatistics.

In most of the results found for kurtosis, the coefficient that indicates the degree of flattening of the distribution, the values were < 2.63, indicating its classification in leptokurtic; this fact infers that the data have less variation and, as they are not high, are close to the normal distribution. A similar value was found by Mion et al. (2012), working in Alfisols, similar to this study, confirming that the data are in accordance with that found in the literature.

The data obtained support the assertion that machine trafficability influences the first 0.3 m of the soil profile and shows that traffic control efficiently maintains the planting row position with lower MRSP, even after three harvest cycles. From 0.3 to 0.6 m depth, there is a tendency for the averages of the row and interrow positions to be similar in the FC and TC areas, and it is possible to state that in this layer, only intrinsic soil characteristics and moisture are responsible for the results found.

According to Camargo and Alleoni (1997), MRSP above 2.5 MPa begins to be considered restrictive to root. Despite the trends exhibited, the penetration resistance values obtained in this study are still below the range between 3.0 and 4.0 MPa, which is considered critical by Betioli Junior et al. (2012). The adjusted semivariograms for the different layers in the row and interrow positions in the FC are shown in Figure 2 and Figure 3, and TC in Figure 4 and Figure 5.

Except for the 0-0.1, 0.2-0.3 m layers of the interrow and the 0.1-0.2 m layer in the row of FC that present pure nugget effect, the MRSP presents spatial dependence in the other layers, positions, and sampled areas. Spherical models of fit are visualized for the semivariograms for the 0.2-0.3 m layer in the interrow of FC, 0.2-0.3 and 0.4-0.5 m layers in the row of FC, 0.1-0.2 and 0.5-0.6 m layers in the interrow of TC, and at 0.5-0.6 m layer in the row of TC, this being the most observed model fit.

The exponential model is verified in the 0.3-0.6 m layer in the interrow of FC, 0.1-0.2 and 0.5-0.6 m layer in the row of FC, 0.2-0.3 and 0.4-0.5 m layer in the interrow of TC, and 0.4-0.5 m layer in the row of TC, besides the Gaussian model in 0.3-0.4 m layer in the interrow of TC and 0-0.4 m layer in the row of TC, therefore, the spherical and exponential models are the most recurrent, a condition that corroborates Souza et al. (2001).

They state that these are the models of greatest occurrence for the soil attributes. The pure nugget effect, found in the semivariograms of the 0-0.1 and 0.2-0.3 m layers of the interrow, as well as in the 0.3-0.4 m layer in the row of FC, indicates that the sampling grid is not sensitive to the detection of dependence in these profile layers, with a random variability. The parameters of the adjusted semivariograms are shown in Table 4.

According to Dalchiavon et al. (2014), we can perform the interpretation of the spatial dependence estimator (SDE), finding that, unlike the 0-0.1 m layer in the interrow and 0.3-0.4 m layer in the row of TC, which show high dependence, the other layers in the row and interrow positions of the different areas show very high SDE, the results indicate greater continuity of the phenomenon in the field, estimated variance, and reliability of the estimate (Bottega et al., 2013). Data found corroborate those seen by Dalchiavon et al. (2014) for Alfisols, finding very high dependence for MRSP, similar to the present study; the same was verified by Mion et al. (2012) evaluating SDE of Alfisols of sandy texture at different depths.

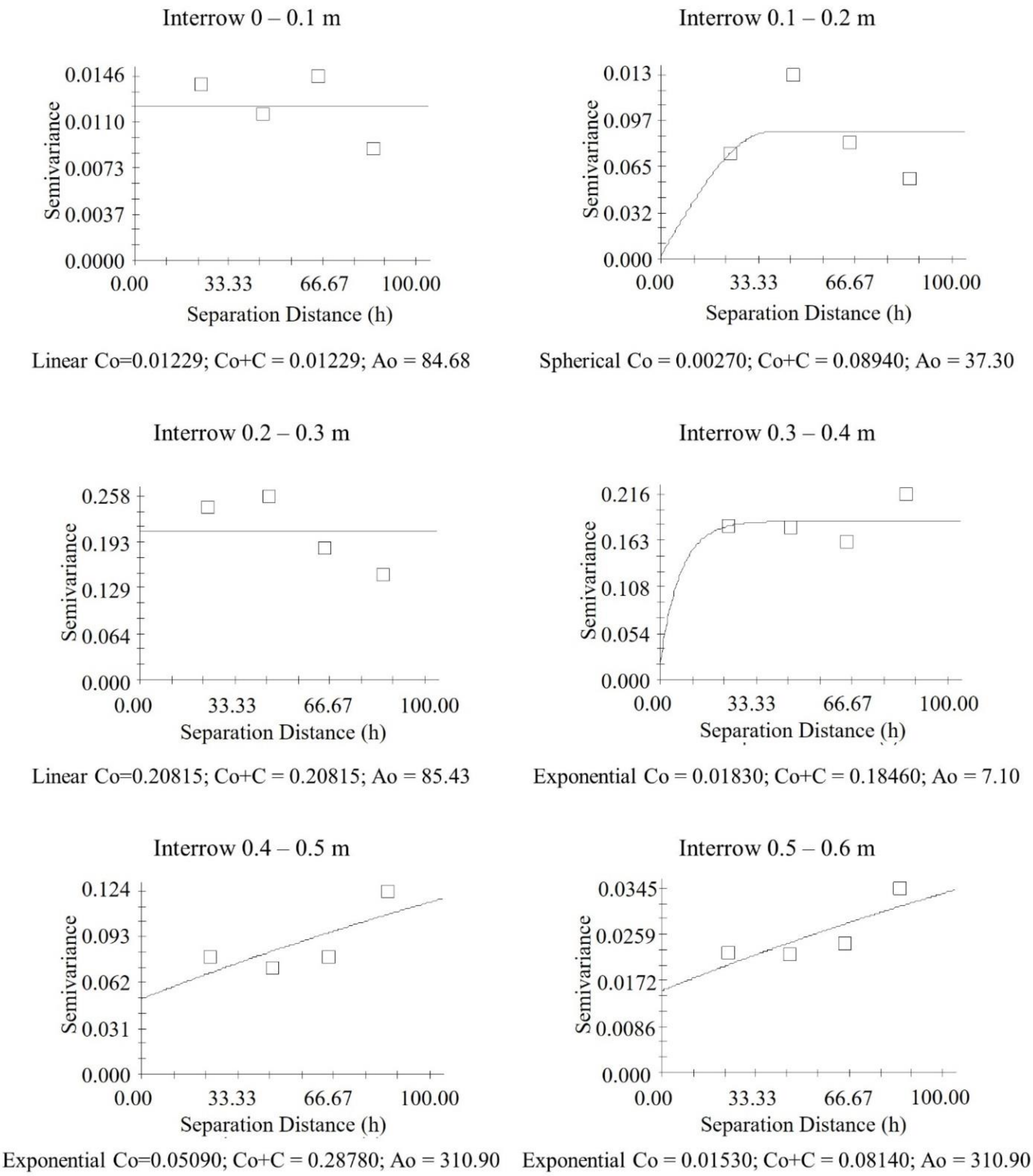

Figure 2. Semivariograms of resistance to penetration in Alfisols, in row and interrow positions in the first cutting (FC) area with sugar cane harvested mechanically

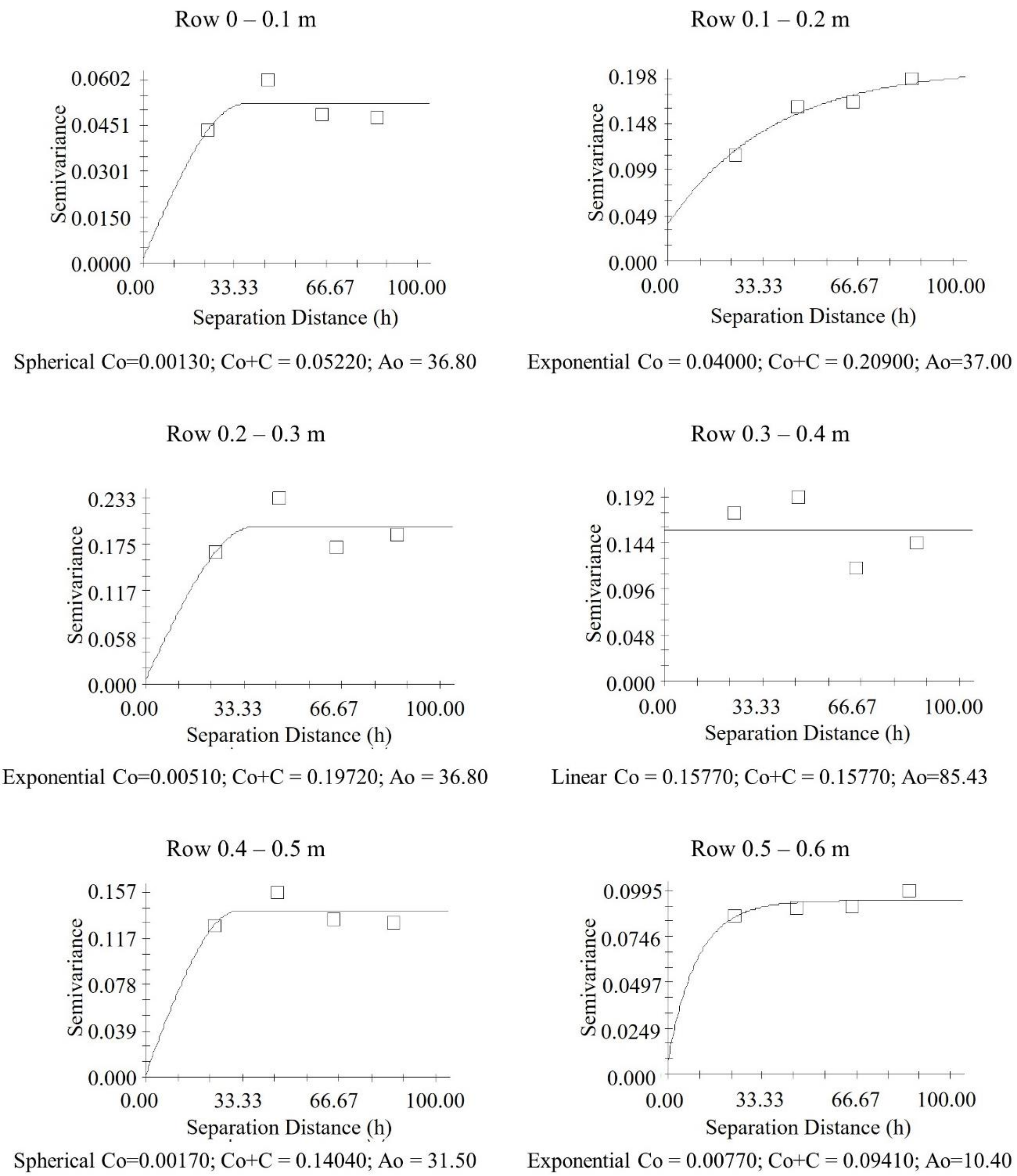

Figure 3. Semivariograms of resistance to penetration in Alfisols, in row and interrow positions in the first cutting (FC) area with sugar cane harvested mechanically

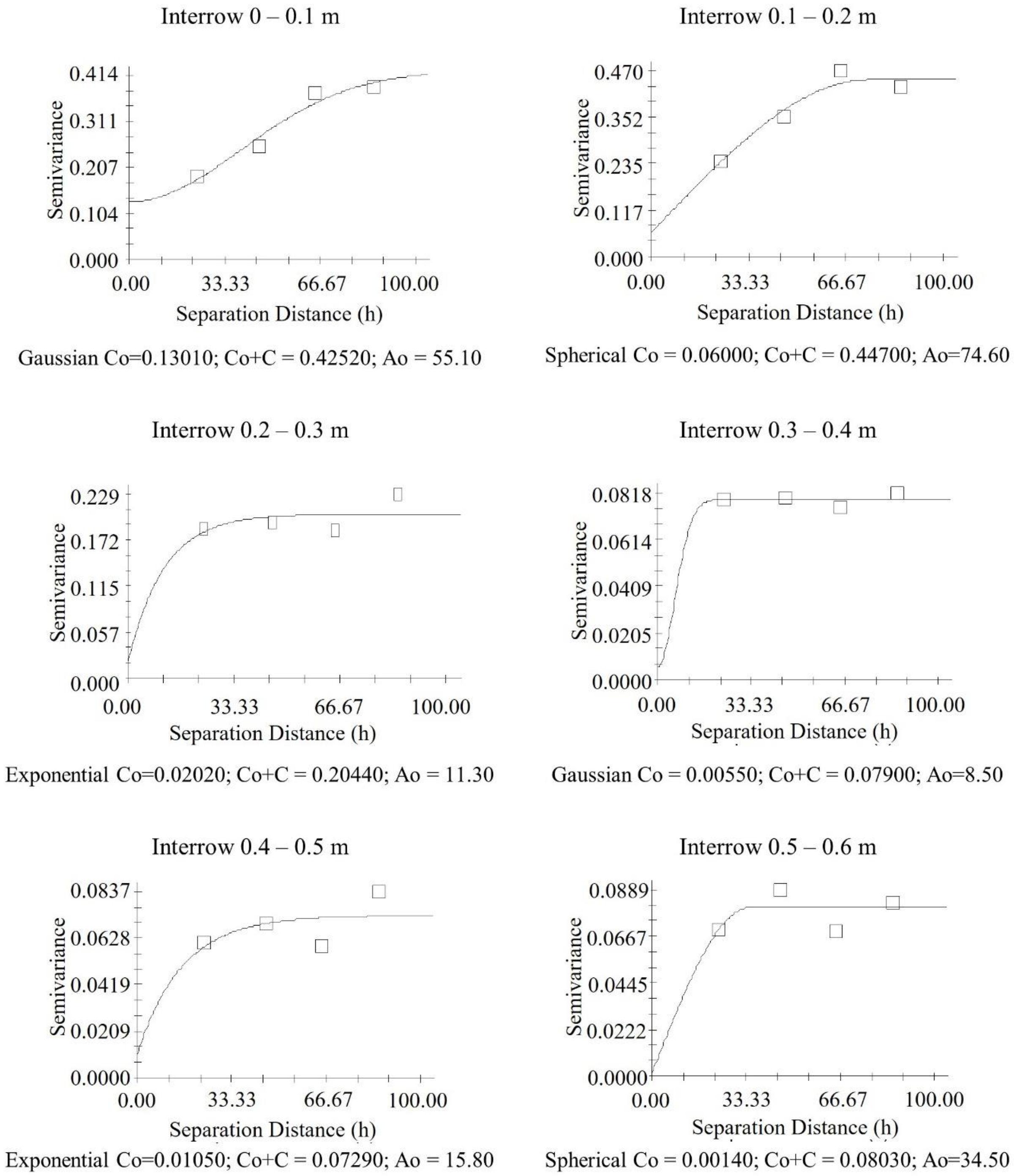

Figure 4. Semivariograms of resistance to penetration in Alfisols, in row and interrow positions in the third cutting (TC) area with sugar cane harvested mechanically

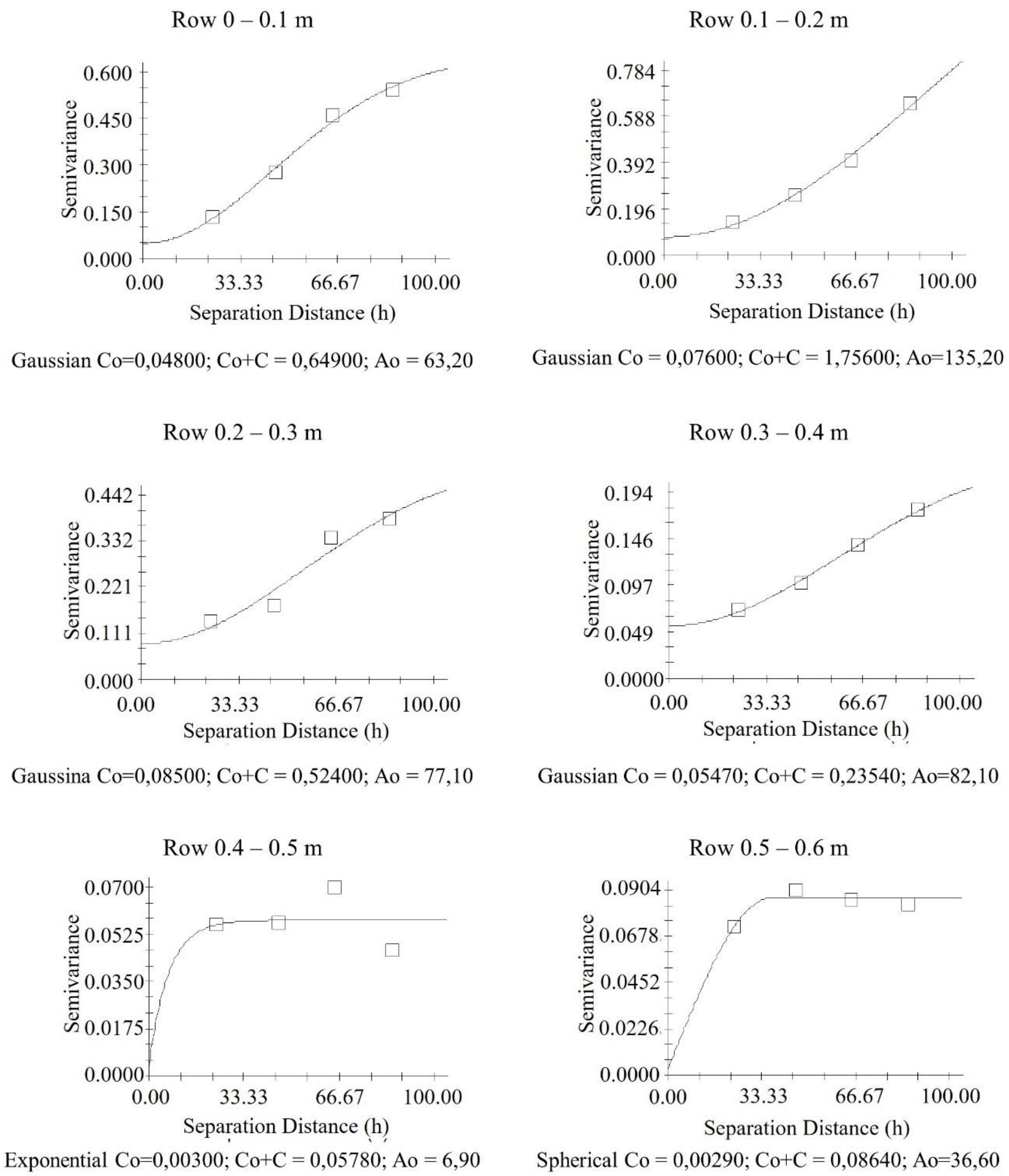

Figure 5. Semivariograms of resistance to penetration in Alfisols, in row and interrow positions in the third cutting (TC) area with sugar cane harvested mechanically.

Table 4. Parameters fitted to the semivariogram of the resistance to penetration (MPa) in soil profiles from areas under different sugarcane cultivation times under mechanized harvesting with controlled traffic

Parameters	Interrow						Row					
	Layers (m)											
	0-0.1	0.1-0.2	0.2-0.3	0.3-0.4	0.4-0.5	0.5-0.6	0-0.1	0.1-0.2	0.2-0.3	0.3-0.4	0.4-0.5	0.5-0.6
	First Cutting (FC)											
Model	PNE	Sph	PNE	Exp	Exp	Exp	Sph	Exp	Sph	PNE	Sph	Exp
Nugget effect	-	0.003	-	0.018	0.051	0.015	0.001	0.040	0.005	-	0.002	0.008
Plateau (Co+C)	-	0.089	-	0.185	0.288	0.081	0.052	0.209	0.197	-	0.140	0.094
Variance (C)	-	0.087	-	0.166	0.237	0.066	0.051	0.169	0.192	-	0.139	0.083
Reach (Ao)	-	37.30	-	7.10	310.90	310.90	36.80	37.00	36.80	-	31.50	10.40
SSR(2)	-	0.003	-	0.002	0.001	0.000	0.000	0.001	0.002	-	0.000	0.000
SDE(3)	-	97.00	-	90.10	82.30	81.20	97.50	80.90	97.40	-	99.10	98.00
Class	-	V.H	-	V.H	V.H	V.H	V.H	V.H	V.H	-	V.H	V.H
	Third Cutting (TC)											
Model	Gau	Sph	Exp	Gau	Exp	Sph	Gau	Gau	Gau	Gau	Exp	Sph
Nugget effect	0.130	0.060	0.0202	0.006	0.011	0.001	0.048	0.076	0.085	0.0547	0.003	0.003
Plateau (Co+C)	0.425	0.447	0.2044	0.079	0.073	0.080	0.649	1.756	0.524	0.2354	0.058	0.086
Variance (C)	0.295	0.387	0.1842	0.074	0.065	0.079	0.601	1.680	0.439	0.1807	0.055	0.084
Reach (Ao)	55.10	74.60	11.30	8.50	15.80	34.50	63.20	135.20	77.10	82.10	6.90	36.60
SSR(2)	0.001	0.002	0.0010	0.000	0.001	0.001	0.001	0.001	0.002	0.0000	0.000	0.0000
SDE(3)	69.40	86.60	90.10	93.00	85.60	98.30	92.60	95.70	83.80	76.80	94.80	96.60
Class	High	V.H	V.H	V.H	V.H	V.H	V.H	V.H	V.H	V.H	V.H	V.H

Note: PNE - Pure nugget effect; Sph - Spherical model; Exp - Exponential model; Gau - Gaussian model; RSS - Residual sum of squares; SDE - Spatial dependence estimator; V.H – Very high.

The range is the parameter that shows the maximum distance where there is a spatial correlation. It can be seen that in the interrow of FC, the range presents higher values in the 0.4-0.6 m layer. In the row it shows constant until the 0.3 m deep with values around 36 m with a decrease at greater depth. In the interrow of TC, greater ranges are seen in the 0-0.2 m layer with a decrease in lower layers, and in the row, there is a tendency for greater ranges at the surface with a subsequent decrease at greater depths.

According to Souza et al. (2020), the ranges in the area of mechanized harvest, in absolute values, were lower than in the other areas studied, a condition that may be an indication that in the course of more harvest cycles, mechanization may affect the spatial dependence of soil penetration resistance. It is also worth mentioning that the results are in agreement with what was observed by Oliveira et al. (2014), analyzing soil under sugarcane cultivation, who observed lower ranges at higher depth.

However, in disagreement with what was verified by Carvalho et al. (2011) in soil with sandy loam to clayey texture profile under mechanized sugarcane harvesting, who found an increase in the range at higher depth. This can be explained by the intrinsic characteristics of the soils studied by these authors since more clayey textures have different trends concerning penetration resistance and its spatial dependence compared to soils with sandier granulometry as the present study.

4. Conclusions

Prominent changes in penetration resistance were observed in the upper soil layers, comprising up to 0.30 m deep, limiting the influence of machine traversability at this depth. Traffic control was efficient in preventing an increase in penetration resistance in the planting rows since the values of this attribute were always lower in this position compared to the interrow, even after three cycles of cultivation.

The semivariograms fitted the spherical, exponential, and Gaussian models, with the occurrence of the pure nugget effect signaling that for these conditions, the sampling grid was not efficient in detecting dependence, except for the 0-0.10 m layer of interrow and 0.30-0.40 m layer in the row in the third cutting area, which were rated as highly dependent. The ranges generally presented a decrease with the increase of soil depth, a fact attributed to the intrinsic characteristics of the soils.

Authors' Contribution

Josevaldo Ribeiro Silva, Carlos Henrique Almeida Farias and Flávio Pereira de Oliveira, conceived the experimental protocol, and were involved in data statistical processing, and in writing the draft and revised the version of manuscript; Pedro Luan Ferreira da Silva, and Milton César Costa Campos were involved in laboratory determinations; Danillo Dutra Tavares collected the samples and contributed to manuscript writing. All authors have read and agreed to the published version of manuscript.

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