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SPATIAL VARIABILITY OF THE STABILITY OF COHESIVE SOIL AGGREGATES UNDER CONSERVATION PRACTICES

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Abstract

The knowledge and characterization of aggregate stability are relevant to select adequate management and to avoid its degradation. Thus, this study aimed to characterize the spatial variability of aggregate stability in cohesive soils under crop conservation systems. The experiment was performed in two different areas of soybean production: no-tillage System (NTS) and livestock farming integration system (LFI), In each production area, a sampling mesh composed of 50 collection points, with a regular spacing of 40 m, at 0.00-0.20 m depth, was carried out. The results were expressed as a percentage of aggregates retained in sieves 2; 1; 0.5 and 0.25 mm, the values obtained were used to calculate the Mean Geometric Diameter (MGD) and Mean Weight Diameter (MWD). In the LFI system, which had a strong degree of spatial dependence (DSD), the attributes showed a moderate DSD, except for MWD. Generally, the reached values of the attributes in the LFI system were lower than those found in the NTS system, showing less variability in the management system with no-tillage. Spatial distribution of the kriging maps demonstrated the LFI system leading to the formation of larger aggregates in the soil when compared to ones to the same attributes in the NTS. All attributes showed a strong to moderate spatial dependence. The soil managed with the LFI system revealed greater aggregate stability when compared to the NTS, which in turn presented less spatial variability than the LFI system and shows a more homogeneous soil.

Keywords: livestock crop integration system; no-tillage; ordinary kriging; spatial variability.

VARIABILIDADE ESPACIAL DA ESTABILIDADE DOS AGREGADOS DE SOLO COESO SOB PRÁTICAS CONSERVACIONISTAS

Resumo

O conhecimento e a caracterização da estabilidade dos agregados são relevantes para selecionar um manejo adequado e evitar sua degradação. Portanto, este estudo teve como objetivo caracterizar a variabilidade espacial da estabilidade de agregados em solos coesos sob sistemas de conservação de culturas. O experimento foi conduzido em duas áreas distintas de produção de soja: sistema de plantio direto (NTS) e sistema de integração pecuária (LFI). Foi realizada uma amostragem de 50 pontos de coleta, com espaçamento regular de 40 m, na profundidade de 0,00-0,20 m, em cada área de produção. Os resultados foram expressos como porcentagem de agregados retidos nas peneiras 2; 1; 0,5 e 0,25 mm, os valores obtidos foram utilizados para calcular o Diâmetro Médio Geométrico (DMM) e o Diâmetro Peso Médio (DMM). No sistema LFI, que possuía alto grau de dependência espacial (DDS), os atributos apresentaram um DSD moderado, exceto para MWD. De maneira geral, os valores de escopo dos atributos no sistema LFI foram inferiores aos encontrados no sistema NTS, apresentando menor variabilidade no sistema de manejo do plantio direto. A distribuição espacial dos mapas de krigagem mostrou que o sistema LFI leva à formação de agregados maiores no solo em comparação com outros com os mesmos atributos no NTS. Todos os atributos apresentaram dependência espacial de forte a moderada. O solo manejado com o sistema LFI revelou maior estabilidade dos agregados em relação ao NTS, que por sua vez apresentou menor variabilidade espacial do que o sistema LFI e apresenta um solo mais homogêneo.

Keywords: sistema de integração pecuária; plantio direto; krigagem comum; variabilidade espacial.

Introduction

From an agricultural point of view, one of the most important soil properties is the structural, since fundamental interactions are attributed to it in the process of soil-plant interrelation (SOUZA *et al.*, 2021). Soil structure is understood as the distribution of solid particles (clay, silt, sand, and organic matter), and porous space (macro and micropores). Besides, it is an important factor for agricultural production, for the management and conservation of soil, implementing practices so that its sustainable use is made (LIMA *et al.*, 2019).

The type of soil particle arrangement defines its structural quality as a result of a dynamic environment, in which the physical, chemical, and biological processes of this soil act in the formation and stabilization of its aggregates, making the soil manifest different behaviors (MARTINS *et al.*, 2022). Size of soil aggregates directly interferes with the structural factor. The larger the average diameter of these aggregates, the less the erosion possibility, the major the amount of carbon fixed to the soil, and the better the moisture retention. These can reflect on the growth of the roots, and consequently, on the productivity of the crops (ROSSI *et al.*, 2016).

The continuous use of the soil associated with inadequate management can alter its physical structure and cause its degradation leaving it more susceptible to erosive processes, and consequently, the loss of organic matter and nutrients (SILVA *et al.*, 2021). The reversal of this degradation can be accomplished through soil conservation practices, such as the no-tillage system and/or crop-livestock integration (LOSS *et al.*, 2011). In these systems, the maintenance of vegetable residues on the surface, added to the absence of soil disturbance, in addition to reducing CO_2, emissions and increasing the carbon stock in the soil, provide further benefits such as the increase in microbial diversity, improving fertility, and soil physical properties (GIONGO *et al.*, 2021).

The knowledge of the spatial and temporal variability of the factors, inherent to the agricultural productivity of the soil, constitutes relevant information for making decision about management practices of the soil physics to be adopted (OLIVEIRA *et al.*, 2018). In this context, several studies have been carried out with the spatialization of the stability of soil aggregates submitted to differentiated management (SOARES *et al.*, 2018). However, in the case of cohesive soils, these studies are still scarce in the literature. Cohesive soils have subsurface compaction horizons, have a significant occurrence in soils in Northeast of Brazil, mainly in the Tertiary coastal plateaus by Barreiras Formation (NUNES *et al.*, 2019). This cohesion provides agricultural limitations, such as the low nutritional potential for plants, limiting root growth, and facilitating the erosion process (RESENDE *et al.*, 2014).

The knowledge and characterization of aggregate stability are relevant to select adequate management and to avoid its degradation, particularly to cohesive soils since there is limited information about it in the literature. Thus, this study aimed to characterize the spatial variability of aggregate stability in cohesive soil under conservation tillage systems.

Materials and Methods

The study was carried out in the municipality of Brejo - MA, at Fazenda Barbosa, located in the eastern mesoregion of Maranhão, Chapadinha microregion – MA, geographically located at the coordinates 3°42'10.4"S e 42°57'09.8"W. According to the Köppen-Geiger climate classification, the climate is of the tropical Aw type, having a dry winter season, with an average temperature of 27.19 ºC and average precipitation of around 1,748 mm. The studied soil was classified as dystrophic cohesive Yellow Latosol, formed by sandy clay sediments of the Barreiras Group, characteristic of the geomorphological unit of coastal plateaus (GEPLAN, 2002).

The experiment was performed in two soybean production areas: one with no-tillage system (NTS) with 15 years of implantation and the other with an livestock farming integration system (LFI), with 5 years of implantation. The chosen areas had different years of implantation, because in the region there were no crops with these types of conservationist management that started with the same year of implantation.

In the No-Tillage area, soybean and corn crop rotation was used. In the livestock farming integration area, corn, brachiaria, and soybean were planted. Corn and brachiaria were planted together. After maize removal, it was used the brachiaria for fattening cattle in three paddocks, which remained for 30 days in each paddock. In each production area, a sampling mesh was carried out, consisting of 50 collection points with a regular spacing of 40 m (Figure 1).

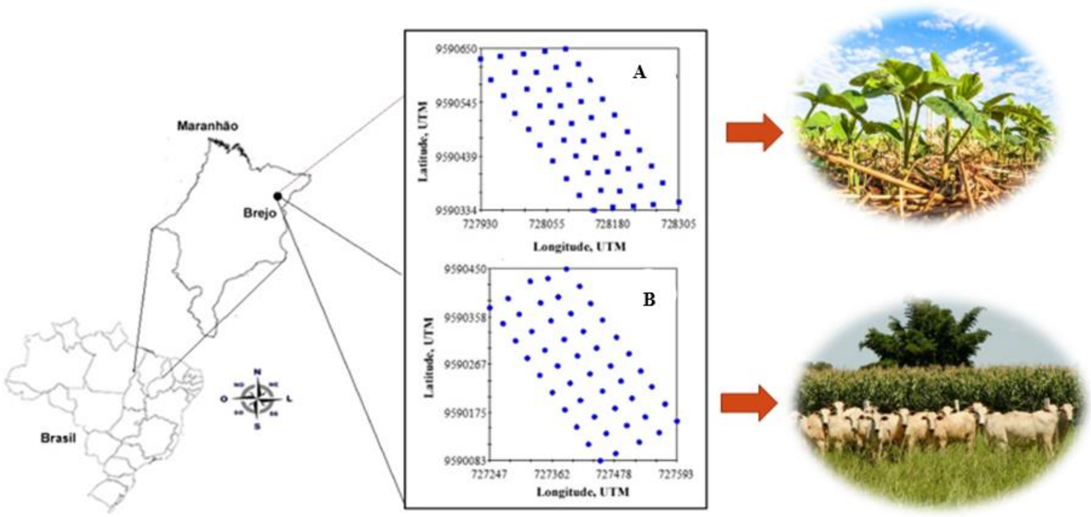

Figure 1. Location of the experimental area and distribution of the sampling points. (A) No-tillage system. (B) Livestock farming integration system.

Soil samples were collected using auger Dutch type, at 0.0-0.2 m depth. Aggregate stability was determined using the wet sieving, using 2.0; 1.0; 0.5; 0.25 mm sieves by the method of Yoder (1936), modified by Kemper and Chepil (1965). The Mean Weight Diameter (MWD), obtained by the formula proposed by Castro-Filho *et al.* (1998), and the Mean Geometric Diameter (MGD), according to Schaller and Stockinger (1953). The equations used were:

$$\text{MWD} = \sum_{i=i}^{n} (ni\ d) \quad (1)$$

$$\text{MGD} = \frac{\text{antilog} \sum (n \log d)}{\sum n} \quad (2)$$

where

ni = percentage of aggregates retained in a given sieve (decimal form); *d* = average diameter of a certain aggregate size range; and *n* = percentage of aggregates retained in a certain sieve.

The variability of attributes was described using descriptive statistics. This type of preliminary exploratory analysis aims to describe the statistical parameters, which help to identify trends, dispersion, and form of data distribution (homogeneity and normality). The results were presented in terms of their descriptive statistics, such as mean, median, standard deviation, minimum, maximum and coefficients of variation, asymmetry, and kurtosis. The coefficient of variation (CV) was classified according to the Warrick and Nielsen (1980) criterion, in which the CV is classified <12% as low, 12- 60%, medium, and above 60% it is considered high.

After the statistical analysis, the geostatistical analysis of the aggregate stability data was performed. The experimental semivariogram modeling followed the principles established by the intrinsic hypothesis (ISAAKS; SRIVASTAVA, 1989), to identify the spatial variability of soil attributes. To determine the experimental semivariogram, the variance was calculated due to the separation distance between samples using the equation:

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

where, $\hat{\gamma}(h)$ is the experimental semi-variance for a separation distance *h*, *z(xi)* is the property value at point *i*, and *N(h)* is the number of pairs of points separated by the distance *h.*

According to the adjustment of the mathematical model, with the calculated values of $\hat{\gamma}(h)$ the parameters of the theoretical model were defined for the semivariogram (the nugget effect, structural variance, C1; threshold, C0 + C1 and the range, a). The choice of theoretical models of the semivariograms and the adjustment of their parameters were defined by the best correlation coefficient obtained by the cross-validation technique and the highest determination coefficient (R^2). The R^2 values closer to one characterize the most efficient model to express the studied phenomenon.

The classification of the degree of spatial dependence (DSP) was based on the ratio between the nugget effect and the threshold (C0/C0 + C1), it is considered weak for DSP> 75%, moderate for DSP between 25% and 75% and strong for DSP <25% (CAMBARDELLA *et al.*, 1994).

After modeling semivariograms, the ordinary kriging technique (KO) was used to interpolate values in locations not shown. This technique is based on a weighted moving average of neighboring samples, obtained by the equation:

$$\hat{z}(x_0) = \sum_{i=1}^{N} \lambda_i z(x_i) \quad , \quad \sum_{i=1}^{N} \lambda_i = 1, \quad \text{with} \quad (4)$$

where $\hat{z}(x_0)$ is the value estimated at point 0; *N* is the number of values used in the estimation; *λ* is the weight associated with each observed value, and *z(xi)* is the value observed in point *i*. The weights *(λi)* of each neighbor are determined using the adjusted semivariogram model, resulting in an estimate of minimum variance (SOARES, 2006).

Results and Discussion

The results referring to descriptive analysis showed normal distribution in the Kolmogorov-Smirnov test at 5% probability only for the aggregate class 2-1 mm and MGD in the LFI and for the aggregate class> 2 mm in the NTS (Table 1). Although the values of asymmetry and kurtosis indicate some asymmetric distributions, the means, and medians of all evaluated attributes are close, pointing out that the data do not show accentuated asymmetry.

It is common in the literature to have data on soil attributes, not showing normal distribution (OLIVEIRA *et al.*, 2018; SOARES *et al.*, 2018). However, the condition of normality is not characterized as a fundamental prerequisite for performing geostatistical analyzes (CAMBARDELLA *et al.*, 1994). Although the values of asymmetry and kurtosis indicate some asymmetric distributions, the means, and medians of all evaluated attributes are close, pointing out that the data do not show accentuated asymmetry (ISAAKS; SRIVASTAVA, 1989). In this way, the information generated by the exploratory analysis allows us to affirm that the variables do not present a distribution with marked asymmetry that compromises the accuracy of geostatistical analyzes.

Table 1. Descriptive statistics of the percentage of aggregates in the class> 2 mm (%), class 2–1 mm (%), Mean Geometric Diameter (MGD, mm), Mean Weight Diameter (MWD, mm), Livestock Farming Integration system, and No-tillage system.

Attributes	N	Average	Media	DP	CV	Min.	Max.	AC.	Curt.	P-value
				Livestock Farming Integration (LFI)						
>2 mm (%)	50	18.31	16.77	13.43	73.35	1.14	57.22	0.70	0.19	0.03
>1-2 mm (%)	50	28.48	27.88	14.46	50.78	5.24	67.37	0.37	-0.15	0.39*
MGD (mm)	50	0.76	0.68	0.29	38.57	0.30	1.97	1.97	6.01	0.01
MWD (mm)	50	1.39	1.32	0.60	43.29	0.56	3.16	0.72	0.32	0.05*
				No-Tillage (NTS)						
>2 mm (%)	50	8.07	8.06	2.34	29.03	3.13	12.74	0.06	-0.69	0.82*
>1-2 mm (%)	50	23.32	17.72	14.61	62.66	9.90	59.30	1.56	0.94	0.01
MGD (mm)	50	0.59	0.57	0.10	17.07	0.44	0.85	1.06	0.78	0.01
MWD (mm)	50	0.99	0.94	0.21	20.97	0.70	1.47	0.68	-0.30	0.01

N = number of samples; DP= standard deviation; CV = Coefficient of variation (%); Min = Minimum; Max = Maximum; AC. = Asymmetry coefficient; Curt. = Kurtosis coefficient; P-value for the Kolmogorov-Smirnov normality test; (*) significant at the 5% level.

The coefficient of variation (CV), with the exception of the aggregate class> 2mm, in the LFI and the class 2-1mm, in the NTS, which presented a high coefficient of variation (> 60%), the other evaluated attributes presented average CV (12 % - 60%) (Table 1). The CV values in LFI showed more accentuated values, indicating higher heterogeneity in the soil for this management. According to Lopes *et al.* (2020), the high content of organic matter, which is distributed discontinuously in the area under study, may cause different behaviors in this type of environment when compared to NTS. The distribution of organic matter in this system tends to have a more uniform distribution, considered a significant agent in the soil aggregation process.

When comparing the averages of the aggregates retained in the >2 mm and 2-1 mm meshes sieves (Table 1), it was found that there was higher retention of LFI aggregates, mainly in the >2 mm mesh. Thus, it indicates this management system presented a soil with a higher degree of the structure compared to the NTS.

According to Garcia (2021) this is explained by the fibrous roots of the grasses used in the LFI system to assist in the formation of macroaggregates, since the roots contribute to the production of recent organic matter in the soil (RESENDE *et al.*, 2021), which corroborates with the results obtained in this work. Furthermore, the bio pores from the decomposition and renewal of these roots (LIMA *et al.*, 2019), added to the intense biological activity and the accumulation of organic matter, imply adequate conditions for the aggregation of soil particles (MOREIRA, 2022).

The lowest aggregation in the NTS is due to its type of vegetation cover. According to SAUER *et al.* (2022), the type of vegetation is a factor in the formation of aggregates. In NTS is implanted, only one grass (corn), while, in LFI, are two (corn and brachiaria). Thus, in this latter system, vegetation will favor the soil aggregation process, which was also reflected in the MGD and MWD values that were superior in the LFI area than those obtained in the NTS area. According to Silva and Mielniczuk (1998), the best development and the best distribution of the root system of grasses in the soil favors the connections of the contact points between mineral particles and aggregates, given that these authors observed a positive correlation between aggregation and root density. MGD indicated a constant and fixed standard, which is possible to determine the most frequent size of aggregates, whose values are 0.76 mm to LFI and 0.59 mm for the NTS.

Soares *et al.* (2018) explain that the MWD is an estimate of the relative amount of soil in each class of aggregates and increases as the percentage of the largest aggregates increases; therefore, it can be deduced that the macroaggregates are more abundant in the more superficial layers (0.0-0.20 m) in the LFI than in the NTS, probably due to the action of the roots of the crops used in this system. Nevertheless, according to the classification of Fialgo (2005), which considers low MWD values below 1.8 mm, sufficient from 1.8 to 2.4 mm and excessive when greater than 2.4 mm; all the MWP values of the soil studied were low, this can be associated with the time, and management conditions in each system. Since in LFI, the implantation is only five years, and although the NTS has 15 years of implantation, the high rates of decomposition provided by the climate of the region do not allow the maintenance of the straw in the soil, thus hindering its aggregation.

All the studied attributes had a spatial dependence structure (Table 2), since there was no random effect on the variables, indicating that the spatial variation was determined from the delimited area. According to Silva *et al.* (2017), geostatistical techniques can explain spatial variability more accurately when compared to the variation coefficient (CV), As the CV characterizes only the variation of the data set (population), while the geostatistical tools are refined techniques that explain the spatial variation distribution of attributes through the scope and degree of spatial dependence (WARRICK; NIELSEN, 1980).

The variograms of the studied attributes were adjusted to the spherical model, and this model was used several times to describe behavioral expressions of soil attributes (OLIVEIRA *et al.*, 2018; SOARES *et al.*, 2018). According to the classification of Cambardella *et al.* (1994), the MWD values, in the NTS system, showed a degree of strong spatial dependence (DSP), different from the other attributes that presented a moderate DSP. These results are similar to those found by Oliveira *et al.* (2018) when studying an oxisol in the same region. For Cambardella *et al.* (1994) the variables that show a strong spatial dependence are more influenced by the intrinsic properties of the soil, that is, by the factors of soil formation, while moderate and low spatial dependence could be due to the soil homogenization.

Table 2. Models and estimated parameters of the experimental semivariograms of the percentage of aggregates in the class> 2 mm (%), class 2–1 mm (%), Mean Geometric Diameter (MGD, mm), Mean Weight Diameter (MWD, mm), Livestock Farming Integration system, and No-tillage system.

Attributes	Model	C0	C0+C	Range	DSP (%)	R²
			Livestock Farming Integration (LFI)			
>2 mm (%)	Spherical	69.20	178.43	184.13	38.78	0.93
>1-2 mm (%)	Spherical	60.84	208.94	173.61	29.12	0.95
MGD (mm)	Spherical	0.04	0.11	112.44	36.41	0.87
MWD (mm)	Spherical	0.07	0.36	149.10	19.42	0.97
			No-Tillage (NTS)			
>2 mm (%)	Spherical	3.05	5.69	146.52	53.58	0.91
>1-2 mm (%)	Spherical	0.08	0.29	186.53	29.28	0.91
MGD (mm)	Spherical	0.01	0.03	176.86	29.74	0.98
MWD (mm)	Spherical	0.02	0.05	221.00	44.49	0.97

C_0= Nugget effect; C_0+C_1= Landing; DSP= degree of spatial dependence (C_0/(C_0+C_1)×100; R^2= Determination coefficient.

The values of the sections related to semivariograms are of considerable importance in determining the limit of spatial dependence, which can also be indicative of the interval between soil mapping units (TRANGMAR *et al.*, 1985), the greater the range, the lesser the variability of the data under analysis. Except for the class >2mm, the values of the range of attributes in the LFI system were lower compared to those found in the NTS system (Table 2), presenting higher variability in the LFI system, this can be attributed to the trampling of animals in this system that alters its structure and contributes to increasing the variability of the analyzed attributes. The values of the determination coefficient (R^2), reveal excellent adjustments, with values above 0.87.

As all attributes presented spatial structure, the parameters of the adjusted semivariograms were used to estimate values in places not sampled through kriging (Figure 2). From the ordinary kriging maps of soil attributes, it was observed that the LFI system provided the formation of larger aggregates in the soil when compared to the same attributes in the no-tillage system. This can be attributed mainly to the use of grasses that have a more voluminous root system, causing a better union of aggregates. Although the NTS revolves the soil less and provides the accumulation of cultural residues on the surface, the high temperatures, characteristic of the region, promote an increase in the rate of decomposition of cultural residues. This fact contributes to little straw remaining in the soil that impairs water retention in the topsoil soil, and consequently, the preservation of its structure.

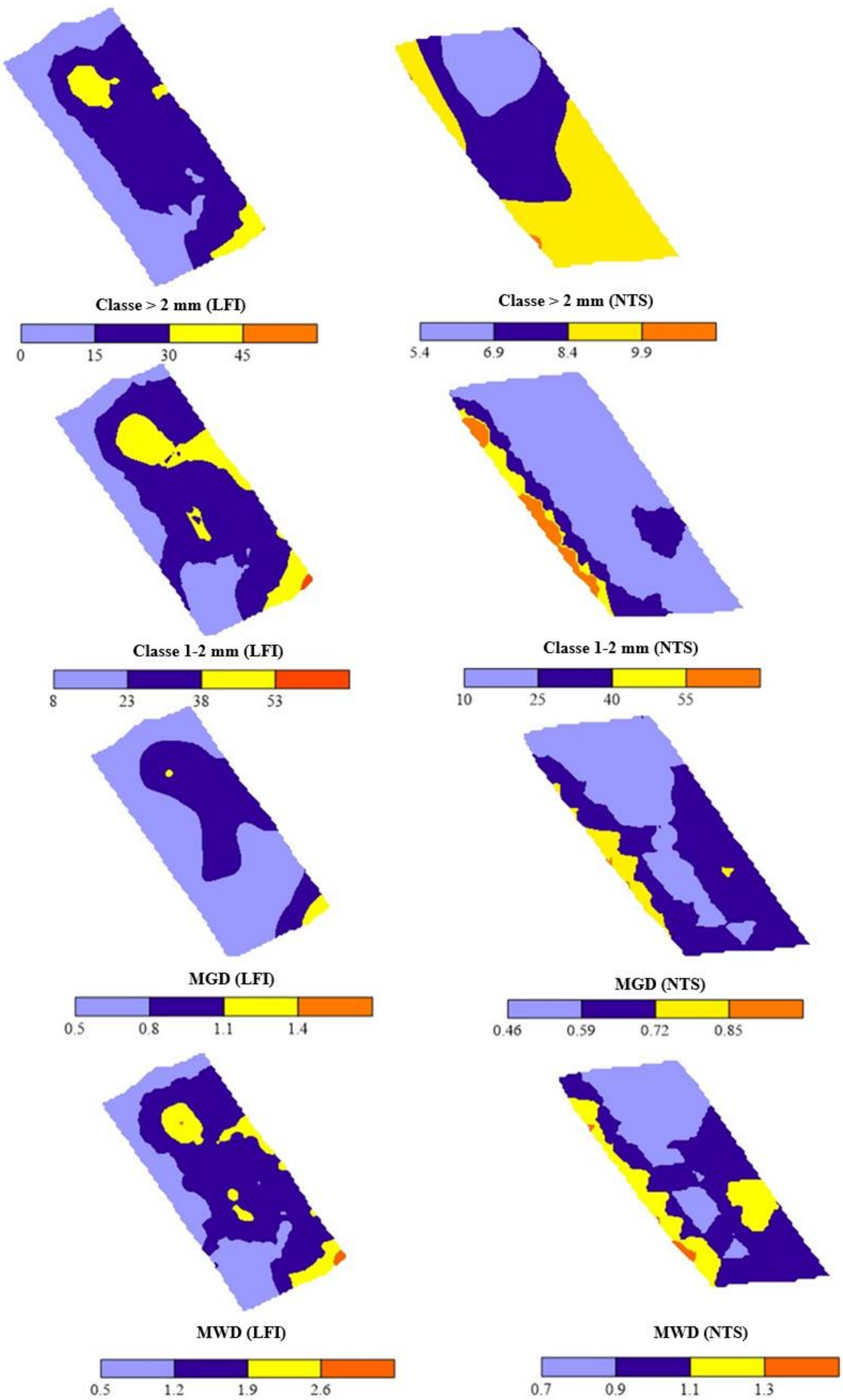

Figure 2. Ordinary kriging maps of the percentage of aggregates in the class> 2 mm (%), class 2–1 mm (%), Mean Geometric Diameter (MGD, mm), Mean Weight Diameter (MWD mm) for the Livestock Farming Integration (LFI) and No-Tillage (NTS).

Conclusion

All attributes presented strong to moderate spatial dependence. The soil managed with an livestock farming integration system showed higher aggregate stability when compared to the no-tillage system. The no-tillage system indicated less spatial variability than the livestock farming integration system, which shows a more homogeneous soil.

References

CAMBARDELLA, C. A; MOORMAN, T. B; NOVAK, J. M.; PARKIN, T. B.; KARLEN, D. L.; TURCO, R. F.; KONOPKA, A. E. Field-scale variability of soil properties in central Iowa soils. **Soil Science Society of American Jounal**, v.58, n.5, p.1501-1511, 1994. https://doi.org/10.2136/sssaj1994.03615995005800050033x

CASTRO-FILHO, C.; MUZILLI, O. E.; PODANOSCHI, A. L. Estabilidade dos agregados e sua relação com o teor de carbono orgânico em um Latossolo Roxo Distrófico, em função de sistemas de plantio, rotações de culturas e métodos de preparo das amostras**. Revista Brasileira de Ciência do Solo**, v.22, n.3, p.527-538, 1998. http://.doi.org/10.1590/S0100-06831998000300019

FIALGO. **Manejo do algodoeiro nas diferentes condições ecológicas do Estado de Goiá**s. Santa Helena de Goiás: FIALGO, 2005. (Relatório final Projeto FIALGO 016-2004)

GARCIA, D. O. **Produção de biomassa de plantas de cobertura e seu efeito sobre a estrutura do solo**. 2021. Monografia (Graduação) - Universidade Federal da Fronteira Sul, Cerro Largo, 2021.

GEPLAN. **Gerência de Planejamento e Desenvolvimento Econômico**. 2. ed. São Luís: Atlas do Maranhão, 2002.

GIONGO, V.; FREITAS, M. S. C.; FREITAS, R. C. A.; FREITAS, A. D. S.; TOURA, T. A.; LEITE, L. F. C. Matéria orgânica do solo em sistemas de produção integrados no nordeste brasileiro. *In*: **Solos sustentáveis para a agricultura no Nordeste**. Brasília: EMBRAPA, 2021. p.81-112.

ISAAKS, E. H.; SRIVASTAVA, R. M. **An introduction to applied geostatistics**. Nova Iorque: Oxford University Press, 1989. 561p.

KEMPER, W. D.; CHEPIL, W. S. Chapter 39 Size distribution of aggregates. *In*: BLACK, C.A., EVANS, D.D., WHITE, J. L. (Eds). **Methods of soil analysis**. American Society of Agronomy, 1965. p.499-510. http://doi.org/10.2134/agronmonogr9.1.c39

LIMA, V. M. P.; OLIVEIRA, G. C.; SERAFIM, M. E.; CURI, N. E.; EVANGELISTA, A. R. Intervalo hídrico ótimo como indicador de melhoria da qualidade estrutural de Latossolo degradado. **Revista Brasileira de Ciência do Solo**, v.36, n.1, p.71-78, 2012. http://doi.org/10.1590/S0100-06832012000100008

LIMA, M. G.; KHAN, A. S.; LIMA, P. V. P. S. Análise da Sustentabilidade Ambiental do Programa de Aquisição de Alimentos no Território dos Cocais/PI. **Revista Ibero-Americana de Ciências Ambientais**, v.10, n.1, p.167-179, 2019. https://doi.org/10.6008/CBPC2179-6858.2019.001.0014

LOPES, A K. L.; AGUIAR, F. I. S.; OLIVEIRA, I. R.; DANTAS, J. S. Variabilidade espacial de atributos químicos de um argissolo amarelo distrocoeso em diferentes densidades de amostragem. **Revista Científica Rural**, v.22, n.2, p.29-41, 2020. https://doi.org/doi.org/10.30945/rcr-v22i2.3229

LOSS, A.; PEREIRA, M. G.; GIÁCOMO, S. G.; PERIN, A. E.; ANJOS, L. H. C. Agregação, carbono e nitrogênio em agregados do solo sob plantio direto com integração lavoura-pecuária. **Pesquisa Agropecuária Brasileira**, v.46, n.10, p.1269-1276, 2011. http://doi.org/10.1590/S0100-06832012000100008

MARTINS, M. V. E.; SILVA, M. L. N. Physical-structural properties of soil in an area under degradation process near the margins of the Balsas-MA river. **Research, Society and Development**, v.11, n.1, p.e39711125106, 2022. http://doi.org/10.33448/rsd-v11i1.25106

MOREIRA, M. C. **Sistema de Plantio Direto de Hortaliças (SPDH) na produção orgânica:** uma construção em conjunto com agricultores assentados e universidade. 2022. Monografia (Graduação) - Universidade Federal do Rio Grande do Sul, Porto Alegre, 2022.

NUNES, F. C.; NOLASCO DE CARVALHO, C. C.; VILAS BOAS, G. S.; SILVA, E. F.; MAFRA, Á. L. M. L.; ANDRADE, J. J.; VITAL, S. R. O. Solos vermelhos e amarelos coesos de tabuleiros costeiros: gênese, evolução e influência da neotectônica. **Caminhos de Geografia,** v.20, n.72, p.294–314, 2019. https://doi.org/10.14393/RCG207241145

OLIVEIRA, I. R.; DANTAS, J. S.; RIBEIRO, L. S.; AZEVEDO, J. R.; SOUTO, L. S.; SILVA, F. A.; FREITAS, D. F.; AMORIM, S. C. Spatial variability in stability of aggregates and organic matter of an oxisol. **Journal of Agricultural Science**, v.10, n.8, p.328-333, 2018. https://doi.org/10.5539/jas.v10n8p328

RESENDE, A. V.; GIEHL, J.; SIMÃO, E. P.; ABREU, S. C.; FERREIRA, A. C. B.; BORIN, A. L. D. C.; MARRIEL, I. E.; MELO, I. G.; MARQUES, L. S.; GONTIJO NETO, M. M. **Créditos de nutrientes e matéria orgânica no solo pela inserção do capim-braquiária em sistemas de culturas anuais**. Embrapa, 2021. (Folhetos)

RESENDE, J. M. A.; MARQUES JUNIOR, J.; MARTINS FILHO, M. V.; DANTAS, J. S.; SIQUEIRA, D. S.; TEIXEIRA, D. B. Variabilidade espacial de atributos de solos coesos do leste maranhense**. Revista Brasileira de Ciência do Solo**, v.38, n.1, p.1077-1090, 2014. http://doi.org/10.1590/S0100-06832014000400004

ROSSI, C. Q.; PEREIRA, M.G.; MOURA, O. V. T.; ALMEIDA, A. P. C. Vias de formação, estabilidade e características químicas de agregados em solos sob sistemas de manejo agroecológico. **Pesquisa Agropecuária Brasileira**, v.51, v.9, p.1677-1685, 2016. https://doi.org/10.1590/S0100-204X2016000700068

SAUER, K.; STOODLEY, P.; GOERES, D. M.; HALL-STOODLEY, L.; BURMØLLE, M.; STEWART, P. S.; BJARNSHOLT, T. The biofilm life cycle: Expanding the conceptual model of biofilm formation. Nature **Reviews Microbiology**, v.20, n.10, p.608-620, 2022. http://doi.org/s41579-022-00767-0

SCHALLER, F. W.; STOCKINGER, K. R. A comparison of five methods for expressing aggregation data. **Soll Science Society of America Proceedings**, v.17, n.1, p.310-313, 1953. https://doi.org/10.2136/sssaj1953.03615995001700040002x

SILVA, I. F.; MIELNICZUK, J. Sistemas de cultivo e características do solo afetando a estabilidade dos agregados. **Revista Brasileira de Ciência do Solo**, v.22, n.2, p.311-317, 1998. http://doi.org/10.1590/S0100-06831998000200017

SILVA, L. F. D.; CUNHA, J. M.; CAMPOS, M. C. C.; LIMA, A. F. L.; PANTOJA, J. C. M.; SOARES, M. D. R.; MANTOVANELLI, B. C. Variabilidade espacial de agregados e estoque de carbono em solos antropogênicos sob floresta nativa. **Nativa**, v.5, n.1, p.540-547, 2017. https://doi.org/10.5935/2318-7670.v05nespa12

SILVA, M. O.; SANTOS, M. P.; SOUSA, A. C. P.; SILVA, R. L. V.; MOURA, I. A. A.; SILVA, R. S.; COSTA, K. D. S. Qualidade do solo: indicadores biológicos para um manejo sustentável. **Brazilian Journal of Development**, v.7, n.1, p.6853–6875, 2021. http://doi.org/10.34117/bjdv7n1-463

SOARES, A. **Geoestatística para ciências da terra e do ambiente**. 2.ed. Lisboa: IST Press, 2006. 214p.

SOARES, M. D. R.; CAMPOS, M. C. C.; CUNHA, J. M.; MANTOVANELLI, B. C.; OLIVEIRA, I. A.; BRITO FILHO, E. G.; LEITE, A. F. L. Variabilidade espacial da estabilidade dos agregados e matéria orgânica do solo em terra preta arqueológica sob pastagem. **Gaia Scientia**, v.12, n.2, p.125-133, 2018. https://doi.org/10.22478/ufpb.1981-1268.2018v12n2.34416

SOUZA, E. R.; SANTOS, M. G.; LIMA, J. R. S.; SOUZA, E. S.; LINS, C. M. T. Relação solo-planta-atmosfera. *In*: **Solos:** estudos, potencialidades e uso. Recife: Instituto Agronômico de Pernambuco, 2021. p.92-115.

TRANGMAR, B. B.; YOST, R. S.; WADE, M. K.; UEHARA, G. Applications of geostatistics to spatial studies of soil properties. **Advances in Agronomy**, v.38, n.1, p.45-94, 1985. https://doi.org/10.1016/S0065-2113(08)60673-2

WARRICK, A. W.; NIELSEN, D. R. Spatial variability of soil physical properties in the field. In: HILLEL, D. (Ed.). **Applications of soil physics**. New York: Academic, 1980. p.319-344. https://doi.org/10.1016/B978-0-12-348580-9.50018-3

YODER, R. E. A Direct method of aggregate analysis of soils and a study of the physical nature of erosion losses. **Agronomy Journal**, v.28, n.1, p.337-351, 1936. http://doi.org/10.2134/agronj1936.00021962002800050001x