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Spatial variability of soil physical properties as a result of different tillage systems

Variabilidade espacial das propriedades físicas do solo em função do preparo de solo

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ABSTRACT
Geostatistical tools allow soil physical properties to be monitored in order to describe the pattern of spatial variability and indicates the places with higher variation. Therefore, the purpose of this study is to assess the spatial variability of physical properties of soils under direct seeding and conventional tillage, using a native forest soil profile as reference. The areas where the samples were collected belong to the Federal University of Viçosa in the municipality of Viçosa in the state of Minas Gerais (Brazil). The studied soil physical properties were density, hydraulic conductivity, total porosity and moisture. The GS+ was used in order to do spatial distribution analysis and semivariograms. The spatial dependence index was fixed by the parameters based on the relative size of the nugget effect and sill. It was considered as strong spatial dependence when ≤ 25%, moderate spatial dependence between 26% and 74% and weak spatial dependence ≥ 75%. The range achieved in this study was higher than the distances between the sample points, proving the spatial continuity of the studied parameters. The forest area presented the lowest value of moisture and the highest value of hydraulic conductivity. Direct seeding area presented the highest density value and the lowest hydraulic conductivity when compared to the other two areas. Conventional tillage area had the highest total porosity in comparison to the other areas due to greater soil inversion. The spatial dependence indexes were classified as moderate for the variables soil density, total porosity and saturated hydraulic conductivity.

Keywords: Kriging, soil moisture, cultivation systems, geostatistics.

RESUMO
As ferramentas geoestatísticas permitem monitorar as propriedades físicas do solo, descrevendo o padrão de variabilidade espacial e indicando os locais com maior variação, permitindo aplicar manejos especificos. Portanto, o objetivo deste estudo é avaliar a variabilidade espacial das propriedades físicas dos solos sob plantio direto e preparo convencional, utilizando como referência o perfil do solo da floresta nativa. As áreas onde as amostras foram coletadas pertencem à Universidade Federal de Viçosa, no município de Viçosa, no estado de Minas Gerais (Brasil). As propriedades físicas do solo estudadas foram densidade, condutividade hidráulica, porosidade total e umidade. O GS + foi utilizado para análise de distribuição espacial e dos semivariogramas. O índice de dependência espacial foi fixado pelos parâmetros com base no tamanho relativo do efeito pepita e patamar. Foi considerada forte dependência espacial quando ≤ 25%, dependência espacial moderada entre 26% e 74% e dependência espacial fraca ≥ 75%. O alcance alcançado neste estudo foi superior às distâncias entre os pontos amostrais, comprovando a continuidade espacial dos parâmetros estudados. A área florestal apresentou o menor valor de umidade e o maior valor de condutividade hidráulica. A área de plantio direto apresentou o maior valor de densidade e a menor condutividade hidráulica quando comparada às outras duas áreas. A área convencional apresentou a maior porosidade total em comparação com as demais áreas, justificado pela inversão do solo. Os índices de dependência espacial foram classificados como moderados para as variáveis densidade do solo, porosidade total e condutividade hidráulica saturada.

Palavras-chave: Krigagem, umidade do solo, sistemas de cultivo, geoestatística.

1 INTRODUCTION

With the growing demand for food around the planet, managements that facilitate crop development are being used, one of these activities is soil tillage, which facilitates root development and increases soil porosity. Therefore, choosing the best soil preparation is essential to enable the best development of crops to be implemented (Lima et al, 2013). However, the impact of soil tillage on soil physical properties not taken into account for their choice, determining the best tillage can reduce soil degradation, and allow the choice of appropriate tillage for each crop.

Conventional soil tillage (TC) consists of tillage, which breaks up soil structure and overturns the soil surface, increasing organic material degradation, pore volume and soil density (Bertol et al., 2000; Lisboa et al., 2012)

In no-tillage system (DSS), soil inversion occurs only in its furrow dimensions. Compared to TC, the cover of organic waste decomposes at a slower rate, a greater accumulation of this residue promotes an increase in the total soil organic carbon content (Sales et al., 2016), in addition to preserving structure and moisture from soil.

The study of the physical properties of the soil becomes feasible to identify with confidence the best preparation, being possible to characterize the soil profile physically. The properties of saturated hydraulic conductivity (Ksat), soil density (SD) and soil porosity allow to evaluate the impacts caused by different tillage systems (Carneiro et al., 2009; Gonçalves et al., 2017), allied to for these variables, geostatistics can be used to describe the pattern of spatial variability of soil physical properties and to identify the limitations of each preparation in terms of actual depth of action. This tool allows the interpolation of data by the kriging and co-kriging method, generating spatial isolines and allows to monitor the variability and spatial distribution of the evaluated attributes (Nagahama et al., 2016).

Thus, the objective of this study is to evaluate the spatial variability of soil physical properties according to the soil preparation system adopted using geostatistical tools.

2 MATERIALS & METHODS

2.1 AREA CHARACTERIZATION

The experiment was conducted in an experimental area which belongs to the Federal University of Viçosa in the municipality of Viçosa in the state of Minas Gerais (Brazil), located at 20°46’06” south latitude and 42°52’09” west longitude, having 650 metres of mean altitude.

The region's climate is characterized as temperate, humid subtropical, mean temperature of 20.6 °C with variations of 6.5 °C, annual mean precipitation of 1,229 mm, classified as Cwa according to Köppen-Geiger. The site where the study was conducted has its soil classified as red-yellow argisol presenting clay texture (EMBRAPA, 2006).

2.2 SOIL PHYSICAL PROPERTIES

The sample plots were 0.6 meters deep and 3 meters wide. In each plot, the sampling was done in 15 distinct points, totaling 45 samples per repetition, 3 repetitions were made for each area.

For the properties K_{sat} and SD, undisturbed soil samples were collected in three depths: 0 to 20; 20 to 40 and 40 to 60 cm. Soil density was calculated by the volumetric ring method (EMBRAPA, 1997), K_{sat} was calculated using the constant-head method according to Klute (1965).

In order to evaluate the other properties, disturbed samples were collected with a dutch auger and undisturbed samples with Uhland auger, using Kopecky's rings which are made of stainless steel and have sharp edges with dimensions of 5 cm of height and 5 cm in diameter (Donagema et al., 2011).

The undisturbed samples were used to assess K_{sat}, total porosity and soil density.

2.3 GEOSTATISTICAL ANALYSIS

A two-dimensional coordinate grid was arranged to locate the points, in which x-axis corresponds to a distance up to 3.0 metres and y-axis corresponds to a depth up to 0.6 metres. The spatial distribution and semivariogram analysis was done by the GS+ software, version 5.1 (Robertson, 1998).

To model the spatial patterns via semivariance calculation, equation 1 was applied, considering the geographical position of the individuals which were georeferenced at the field sample plots and the subsequent calculation of the distances (h) and numerical differences of the variable (Z) in the grid points.

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

Equation 1: Variable Z(xi) semivariance = (**h**), **h** = euclidean distance; and N(**h**) **=** number of the measured pair of points Z(xi) and Z(xi + **h**), separated by a distance **h**.

The spatial dependence index (SDI) was classified according to Bhunia et al. (2018), defined by the parameters based on the relative size of the nugget effect and the sill, equation 2. Three levels of spatial dependence will be considered: strong ≤ 25%, moderate between 25% and 75% and weak when SDI ≥ 75%.

$$SDI=\frac{y(h)pepita}{y(h)total}*100 \quad (2)$$

Equation 2: Spatial dependence index, y(h) nugget - nugget effect semivariance and y(h) total - total semivariance or sill.

The parameters selected to choose the best model were two: the range (Ao) and the spatial dependence index (SDI). In order to use geostatistical tools, it is necessary that variograms and sills present established models, thus, allowing to accept the intrinsic hypothesis (Isaaks & Srivastava, 1989). Therefore, after the accomplishment of the semivariograms analysis, spatial variability maps were made for density, total porosity, hydraulic conductivity and moisture.

3 RESULTS AND DISCUSSION

3.1 GEOSTATISTICAL PARAMETERS

The results regarding the semivariogram theoretical adjustment parameters for moisture, K_{sat}, total porosity and SD are displayed in table 1. The model with the best-fitting results was the exponential one, except for the soil density of the forest area, and the moisture of the directing seeding area, in both cases, the model that presented the best-fitting was the Gaussian model.

Table 1. Geostatistical model's parameters selected for the variables soil moisture, hydraulic conductivity, soil density and total porosity.

Area	variable	Model	Co+C	Ao (m)	SDI (%)
Forest	Moisture	Exponential	0.00083	37.41	87.0
	Conductivity	Exponential	0.44880	15.01	50.1
	Density	Exponential	0.02256	15.02	50.0
	Total Porosity	Exponential	0.00280	07.58	71.1
Conventional Tillage	Moisture	Exponential	0.00039	56.16	80.1
	Conductivity	Exponential	0.01775	15.02	50.1
	Density	Exponential	0.00113	15.02	51.0
	Total Porosity	Exponential	0.00168	109.25	53.0
Direct Seeding	Moisture	Gaussian	0.00033	60.24	76.0
	Conductivity	Exponential	0.00531	15.00	50.1
	Density	Exponential	0.00505	01.67	53.0
	Total Porosity	Exponential	0.00147	123.32	50.0

Co+C – Sill; Ao – Range(meters); SDE – Spatial Dependence Index.

The relation between nugget effect and sill, (Co+C), results in the spatial dependence index (SDI) that presented an average of 57% for the variables, being considered moderate. Similar results were found in the research done by Silva et al. (2017) that studied the spatial variability of soil penetration resistance (SPR).

Soil moisture presented a strong SDI, due to the high variability of the water in the soil profile, the water level varies in the axis X and Y due to formation factors or caused by weather conditions or human actions, such as shading, soil depth, roots, solar incidence, among others (Silva & Cabeda, 2006).

The variables that highlighted strong spatial dependence suffer more influence of intrinsic soil properties, that is, soil formation factors, whereas moderate spatial dependence is of soil homogenization. The reached range was higher than the distance between the points, proving data spatial continuity, explaining the variation in this study.

The managed areas presented greater range, which is a property favoured by soil preparation. On the other hand, the forest area presented the lowest range for total porosity, corresponding to high variability.

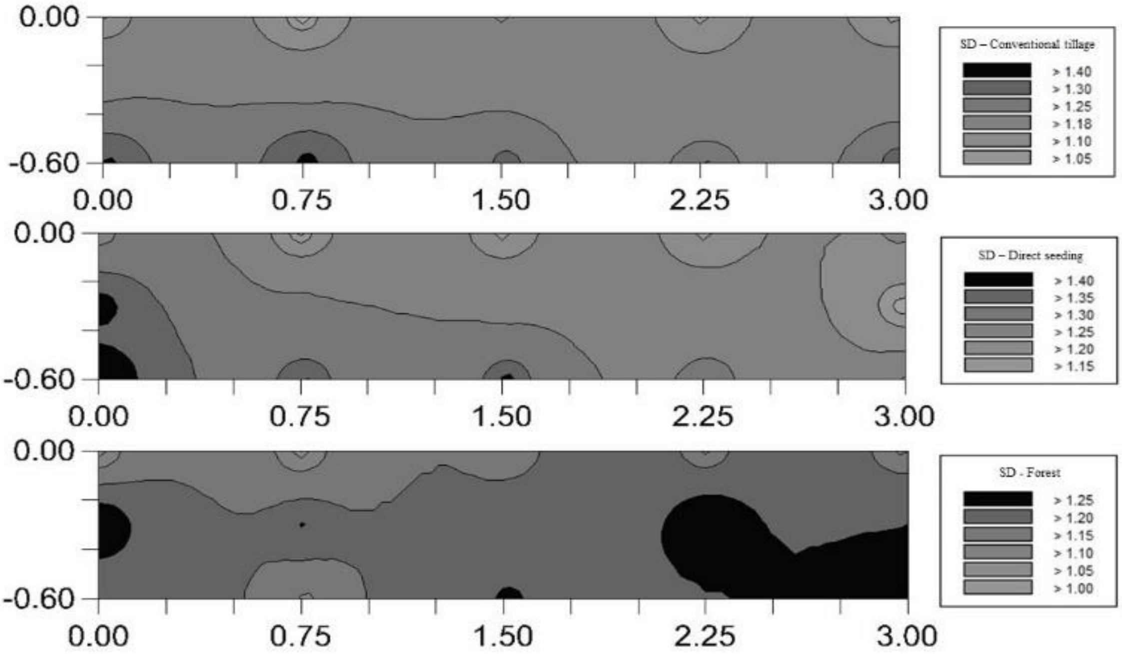
De Carvalho et al. (2002) in a research about variability of soil preparation, found a similar range, this is due to the homogenization of the physical characteristics of the soil, thus, allowing the optimization for independent management, providing better soil conditions, helping forest restoration or maximizing the production and reducing costs.

3.2 DENSITY

For the density map (Figure 1), one can observe variability in three distinct areas. The forest area showed high variability and lower density than the others, due to biological actions, such as the presence of ants, termites, and other insects that are abundant in tropical forests due to heavy rainfall and high decomposition of organic matter, reducing the density. In the superficial soil, it is possible to observe a great variation of the forest area, this density is caused by the presence of roots and stones that cause this greater agglomeration of the soil particles (Huang et al., 2015).

The conventional tillage presented similar density to the no tillage, but the deeper layers presented higher density, due to the depth reached by the mechanical implements that reach until 0.4 m of depth. There is also a homogeneity in relation to the other preparations, due to the use of the implements (USOWICZ e LIPIEC, 2017).

Image 1. Spatial distribution of density above soil profile till 0.6 meters depth in the three distinguished areas: direct planting, conventional tillage and forest.

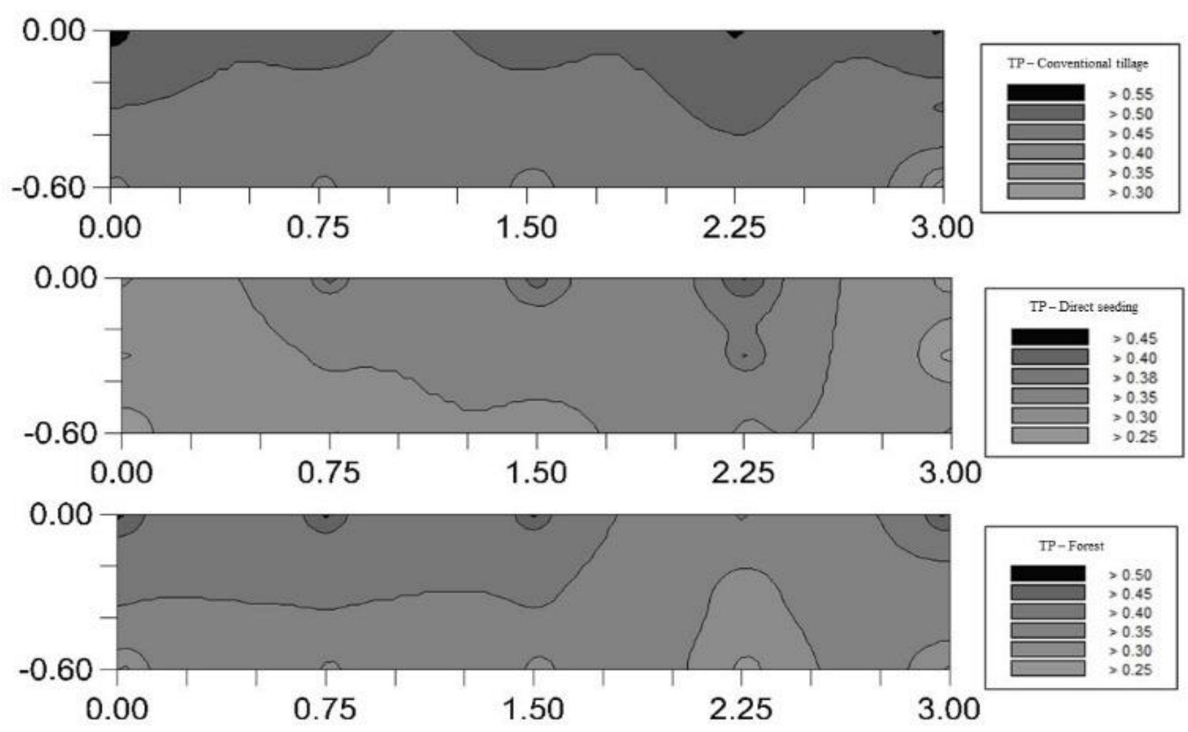


In the place where the no-tillage system was applied, there is a great spatial variability, where there is greater heterogeneity in the soil surface, due to the revolving only in the planting area, not being the whole area revolved, which is a reason for the cost. of direct preparation is smaller than conventional (López et al., 2019). Similar results were obtained by Sales et al. (2016) in their studies on no-till and conventional tillage.

3.3 TOTAL POROSITY

Regarding porosity (Figure 2), the conventional tillage system presented higher total porosity compared to the no-tillage system and forest area, provided by a higher soil inversion, increasing macroporosity. Similar results were achieved by Silva et al. (2005) who evaluated the long-term effects of conventional tillage, reduced tillage and no-tillage on the physical attributes of a red latosol. The forest presents great variation of the porosity in the soil profile, in the initial layers, due to the soil bioporos, formed mainly by the mesofauna of the soil and dead roots, the presence of organic matter favors the greater porosity by not closing the soil and consequently greater infiltration (Souza et al., 2019). PT is of great importance for crop development and soil preparation efficiency, it allows soil water percolation, respiration and gas translocation in the soil. soil, in addition to root growth.

Image 2. Spatial distribution of total porosity – TP (m^{-3}) of three different areas: direct seeding, conventional tillage and forest area.

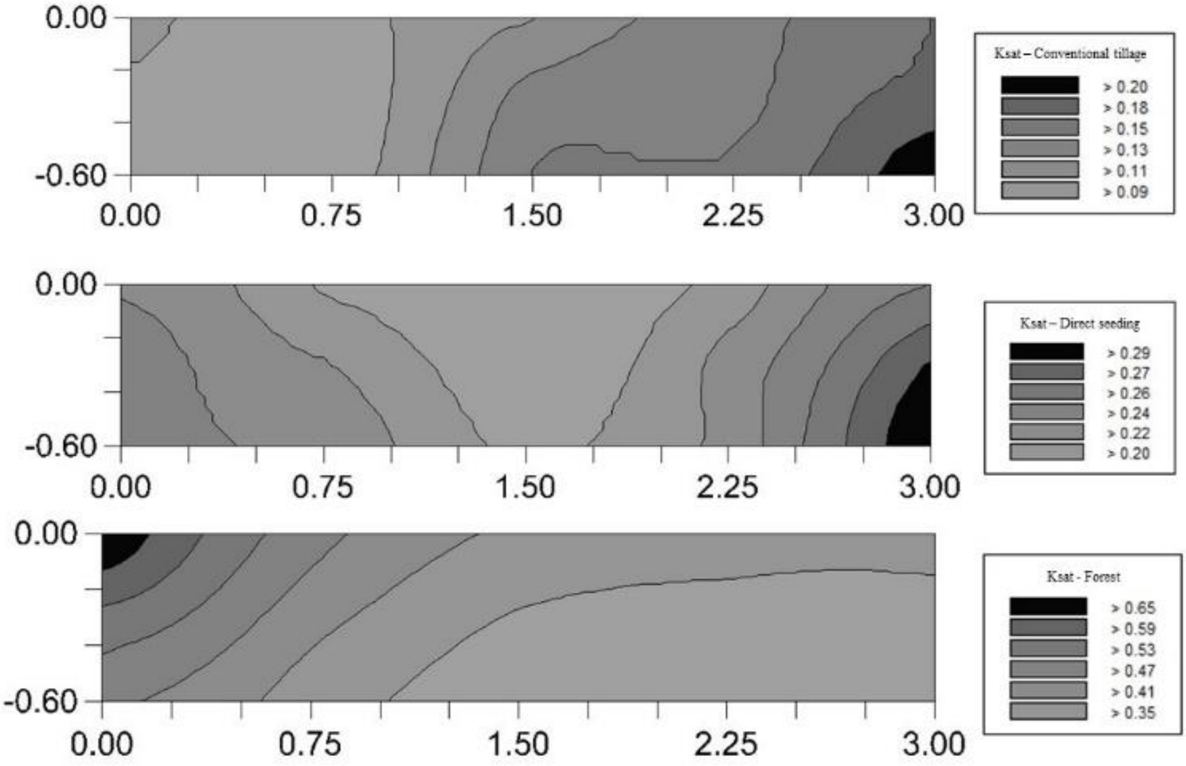


In the area of no-tillage, the lowest total porosity is caused by the lack of soil inversion, which results in the reduction of macroporosity. It is noted that there is a profile change, where there was porosity preparation and alteration, showing the variability of the soil. Soil tillage, Valadão et al. (2015) found similar values, however in the present study there was higher porosity due to soil constitution.

3.4 HYDRAULIC CONDUCTIVITY

According to the image 3, the soil in conventional tillage system was the one with the lowest Ksat, which can be attributed to a higher density in relation to forest, the deep compaction caused by the machine wheels is a determining factor, where the weight of the machine and implement cause a reverse effect on the soil subsurface (Jabro et al., 2016). The inversion of leiva in extreme humidity can lead to major problems, low humidity can lead to the formation of large soil aggregates, while high humidity causes greater soil compaction in depth (Naghdi et al., 2016). For the direct tillage, due to the continuous use of this system and the non inversion of the soil layer there is a smaller Ksat than the forest, the system presents high variability along the soil profile, where it is possible to observe the different levels of Ksat, showing Although the preparation is carried out in a specific location, its effects extend in a proximate region, thus the low Ksat still limits the productivity of crops grown in these areas (Seki et al., 2015), which may cause superficial flooding. in case of heavy rain (Li et al., 2019).

Image 3. Spatial distribution of hydraulic conductivity in three different areas: direct seeding, conventional tillage and forest area.



In the forest area, it presented high spatial variability and higher Ksat in the superficial layers compared to the other treatments, which can be attributed to the soil organic matter, intensive soil mesofauna activity, considerable root volume and other factors that improve the structure. soil, allowing greater conductivity of water (Silva & Kato, 1997), thus allowing a development of tropical forests (Moraes et al. 1996).

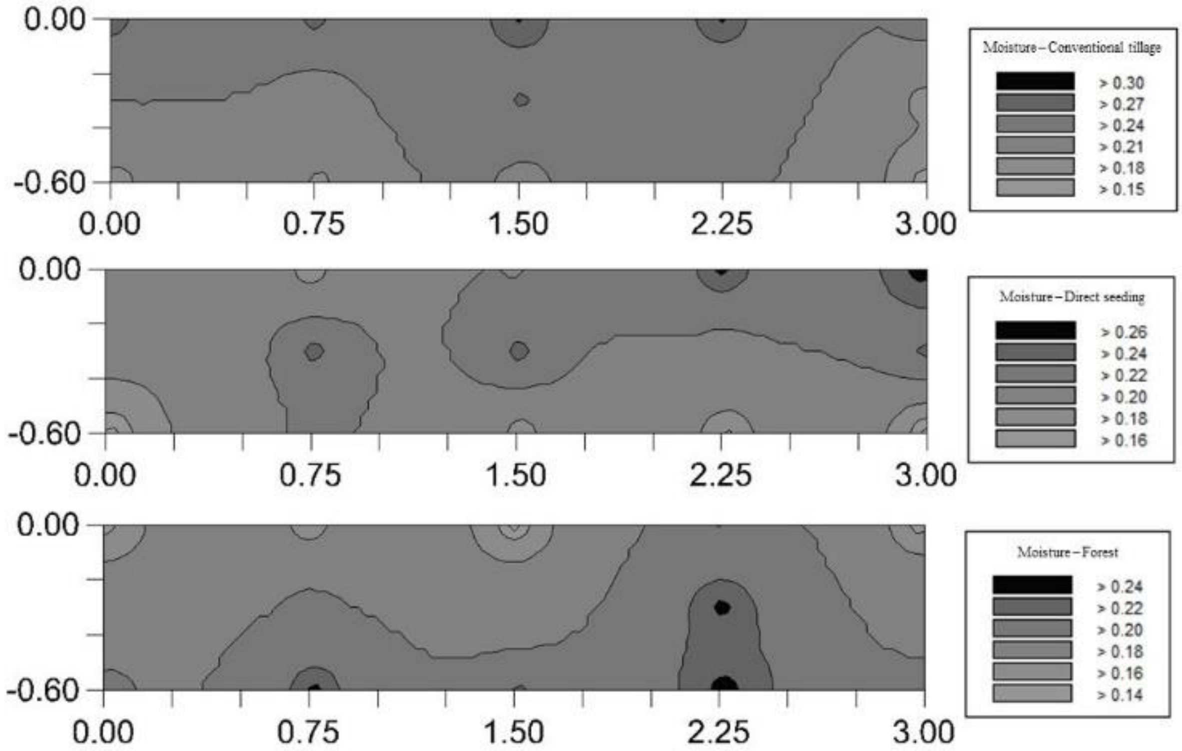
3.5 MOISTURE

Image 4 shows the spatial variability of soil moisture content in the three treatments studied: forest, direct seeding system and conventional tillage system. The no-tillage area presented the highest soil moisture content among the three treatments.

In no-tillage systems, dead organic material on the soil surface contributes to reducing evaporation, increasing organic matter which, in tropical soils with high weathering levels, means a means of rejuvenation, providing negative charge points (Lima et al., 2013), besides that, plant coverage mitigate the impact caused by intensive machinery traffic.

There was greater variation of the soil moisture content in the conventional tillage area. The lack of dead organic material and higher solar exposure, due to soil inversion, intensified water loss in some locations. This lack of dead organic material also exposes the soil to degradation and erosion, occuring with the same intensity that occurs in soils that are totally exposed (Almeida et al., 2016).

Image 4. Spatial distribution of soil moisture content in three different areas: direct seeding, conventional tillage and forest area.



The forest area presented lower soil moisture content. The water interception through tree tops and stem, as well as higher index of leaf area, may have contributed to these lower values of soil moisture content (Silva et al, 2016). The forest area presented lower variability of the values of soil moisture content. The lower spatial variability is associated to the lower soil moisture content value.

4 CONCLUSION

The spatial dependence indexes were classified as moderate for three variables: soil density, total porosity and saturated hydraulic conductivity. For soil moisture content, spatial dependence was classified as strong. The range was higher than the lower distance between the sample spots.

The forest area was considered the driest one, followed by direct planting area and then conventional tillage area. The area where the direct planting system was applied had the lowest quality related to soil physical condition, having the lowest values regarding saturated hydraulic conductivity of the saturated soil, and the highest values of soil density when compared to the soil under forest or conventional tillage. The soil under conventional tillage system presented the highest total porosity.

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DECLARATION OF CONFLICT OF INTEREST

No potential conflict of interest was reported by the authors.

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