revista engenharia agrícola
Journal of the Brazilian Association of Agricultural Engineering
ISSN: 1809-4430 (on-line)

PHYSICAL PROPERTIES OF SOILS AND SOYBEAN YIELDS AFTER PLANTING COVER CROPS

Doi:http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v35n2p280-292/2015

DIEGO DOS SANTOS[1], EDUARDO G. DE SOUZA[2], LÚCIA H. P. NÓBREGA[3], CLAUDIO L. BAZZI[4], FERNANDO N. DE QUEIROZ[5]

ABSTRACT: Cover crops are important for improving soil quality. However, soil properties usually have some spatial dependence. Thus, this study aimed to evaluate the effect of winter cover crops on physical properties of soil and soybean yields using thematic maps. Five winter treatments were used: black oats; intercropping 1 (forage turnips and black oats); intercropping 2 (forage turnips, black oats and common vetch); wheat; and control. Macroporosity, microporosity, total porosity, bulk density and water content of the soil from 0 - 0.1 m depths were evaluated after the winter cover crop management. Soybeans were sown over the entire area in the summer after the winter cover crop management, and the soybean yield was determined for each treatment. Maps for each treatment were created and compared to the control treatment using the relative deviation coefficient (RDC). The cover crops improved the total macroporosity of the soil in some regions of the study area. The black oats were more efficient at maintaining higher water content of the soil, and it can be used to decrease the bulk density.

KEYWORDS: soil porosity, bulk density, crop rotation.

ATRIBUTOS FÍSICOS DO SOLO E PRODUTIVIDADE DA SOJA SOB PLANTAS DE COBERTURA

RESUMO: As plantas de cobertura são importantes na melhoria da qualidade do solo, cujos atributos frequentemente apresentam dependência espacial. Assim, o objetivo deste trabalho foi avaliar o efeito de plantas de cobertura em manejo de inverno nos atributos físicos do solo e a produtividade da soja por meio de mapas temáticos. Os tratamentos foram cinco manejos de inverno: aveia-preta; consórcio 1 (nabo forrageiro e aveia-preta); consórcio 2 (nabo forrageiro, aveia-preta e ervilhaca comum); trigo e testemunha (pousio). Avaliaram-se a macroporosidade, a microporosidade, a porosidade total, a densidade e o teor de água do solo, na profundidade de 0 - 0,1 m após o manejo das coberturas de inverno. A soja foi semeada em toda a área no verão, após o manejo das coberturas de inverno e determinada sua produtividade para cada tratamento. Elaboraram-se mapas temáticos para os tratamentos, os quais foram comparados com a testemunha, utilizando-se do coeficiente de desvio relativo (CDR). As plantas de cobertura melhoraram a macroporosidade e a porosidade total do solo em algumas regiões dentro da área em estudo. A aveia-preta foi mais eficiente em manter mais elevado o teor de água do solo e demonstrou maior potencial para reduzir a densidade do solo.

PALAVRAS-CHAVE: porosidade do solo, densidade do solo, rotação de culturas.

[1] Engº Agrônomo, Prof. Assistente da Universidade Federal da Fronteira Sul - UFFS, Laranjeiras do Sul – PR, Fone: (42) 3635-0000, diegosagro@hotmail.com
[2] Engº Mecânico, Prof. Associado da Universidade Estadual do Oeste do Paraná - UNIOESTE, Pesquisador de Produtividade do CNPq, Programa de Pós-Graduação em Eng. Agrícola/UNIOESTE, Cascavel – PR, eduardo.souza@unioeste.br
[3] Engª Agrônoma, Prof. Associada Universidade Estadual do Oeste do Paraná - UNIOESTE, Pesquisadora de Produtividade do CNPq, Programa de Pós-Graduação em Eng. Agrícola/UNIOESTE, Cascavel – PR, eduardo.souza@unioeste.br
[4] Tecnólogo em Processamento de Dados, Prof. Adjunto da Universidade Tecnológica Federal do Paraná - UTFPR, Medianeira - PR, clbazzi@gmail.com
[5] Bacharel em Ciência da Computação, Prof. Mestre do Centro de Ensino Superior de Foz do Iguaçu - CESUFOZ, Foz do Iguaçu - PR, fernandonakayama@gmail.com
Recebido pelo Conselho Editorial em: 23-11-2011
Aprovado pelo Conselho Editorial em: 13-9-2014

INTRODUCTION

In a no-tillage system, the soil is not subjected to much machine traffic; however, without overturning, surface soil compaction may occur. Soil compaction occurs because of an increase in both bulk density and microporosity, which decrease the total porosity and, particularly, the macroporosity (ROSA FILHO et al., 2009). Thus, the determination of properties such as density and soil porosity is essential to the agricultural management of soil. These properties indicate whether the soil is suitable for plant development and root exploration, as well as whether there are compaction problems (RAMÍREZ-LÓPEZ et al., 2008; STRUDLEY et al., 2008).

HAMZA & ANDERSON (2005) suggested a combination of practices to reduce or delay the problem of soil compaction. Such practices include no-tillage systems, controlled traffic of agricultural combines, and crop rotation management, which involves plants with deep and strong roots that are able to penetrate compacted soils. The growth of plant species can also provide the soil with good coverage and organic matter, which improve the physical, chemical and biological conditions of the soil and contribute to weed control. The soil coverage using plant residues and the plant roots in the soil profile helps retain water, increase the porosity of the soil, and improve aeration. The cover also decreases the soil density due to the organic matter effect (CALEGARI, 2006; PENTEADO, 2007).

Physical properties of soils vary over short distances. According to SCHAFFRATH et al. (2008), this non-uniformity is most likely due to soil management systems, the chosen cultures and the intrinsic properties of the soil (particular factors and generational processes).

Once the spatial dependence is quantified, it can be used to classify and register a soil survey in an area. Then, the soil characteristics can be mapped for an area using interpolation methods. The mapping of both soil properties and yields requires data on the spatial variability of the area (GONÇALVES et al., 2001).

Thus, this study aimed to evaluate the performance of cover crops during winter management and their effect on the physical properties of soils and soybean yields based on a comparison of thematic maps.

MATERIAL AND METHODS

This study was conducted from June 2008 to April 2009 in an agricultural area of 2.03 ha, 153 m wide and 133 m long, located in the city of Cafelândia, western Paraná (24° 37' 05" S and 53° 19' 18" W), where the average elevation is 550 m. The area has subtropical and humid mesothermal weather, with an annual average rainfall of 1,850 mm and an average annual temperature of 20 °C. The soil was characterized as Distroferric Red Latosol (EMBRAPA, 2006), whose composition is 92, 363 and 545 g kg^{-1} of sand, silt and clay, respectively.

The experiment was designed to be completely random, with five treatments and six replications per treatment (30 plots) (Figure 1). Each plot was 5.1 m wide and 133 m long. The five winter managements were as follows: black oats (*Avena strigosa*), intercropping of forage turnips (*Raphanus sativus*) and black oats (intercropping 1); intercropping of forage turnips, black oats and common vetch (*Vicia sativa*) (intercropping 2); wheat (*Triticum aestivum*) and control (remained under fallow during the winter). During the summer, soybeans (*Glycine max*) were planted over the entire area.

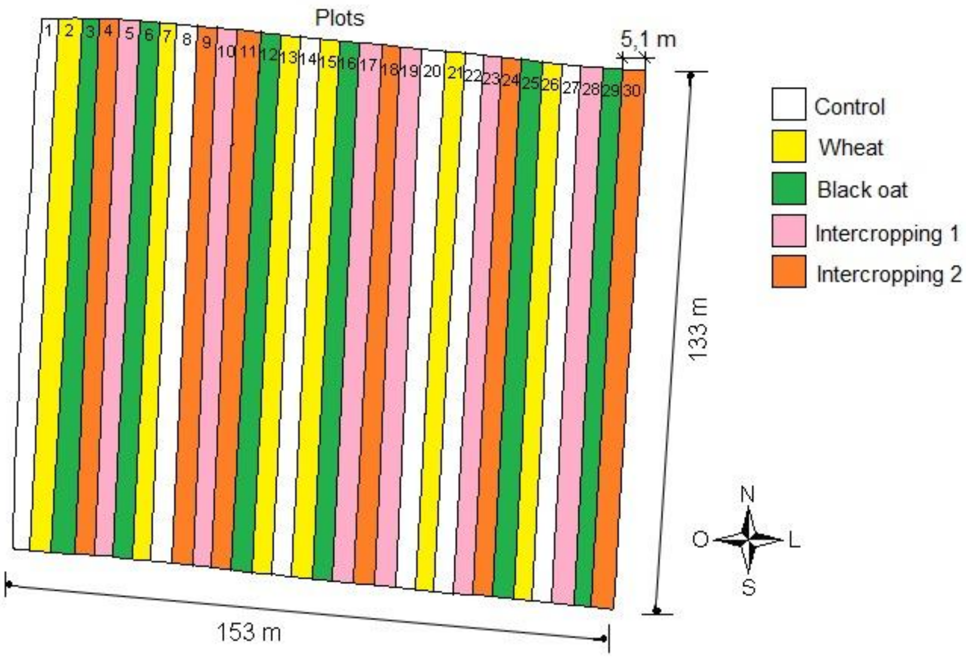


FIGURE 1. Sketch of the completely randomized experimental design.

According to the recommendations of Calegari (2006), the following amounts of seeds were used: 50 kg ha^{-1} (black oats treatment); 30 kg ha^{-1} of black oats and 10 kg ha^{-1} of forage turnips (intercropping 1 treatment); and 30 kg ha^{-1} of black oats, 8 kg ha^{-1} of forage turnips and 15 kg ha^{-1} of common vetch (intercropping 2 treatment). Wheat was sown with a 65 plants m^{-1} density, and 165 kg ha^{-1} of fertilizer was applied to the seeding rows using 8-20-20 NPK fertilizer as the soil analysis required. Fertilization was not used for the other treatments. The cover crops were managed at the full blossoming term (100 days after sowing) with a roller crimper, while the wheat was cropped with a harvester.

Using a no-tillage system in the summer, 50 days after the management of the cover crops and 15 days after the wheat harvest, a 16 plants m^{-1} density and 0.45 m length was used to sow the soybeans. 2-24-16 NPK fertilizer was applied to the sowed rows at 206 kg ha^{-1}, according to the soil analysis and crop requirements.

Evaluations were obtained after the management of the winter treatments (50 days after the management of the cover crops and 15 days after the wheat harvest). Two points were delimited in each plot (strip) with a GPS (DGPS Trimble Geo Explorer 3) for a total of 60 points. At each point, the macroporosity, microporosity, total porosity, bulk density and water content of the soil at 0 to 0.10 m depths were obtained, according to the EMBRAPA methodology(1997).

The soybean harvest was manual and occurred separately at ten sampling points for each strip (plot), which were delimited with stakes and guided by GPS. Each plot was divided to obtain five points in each strip (plot). To obtain spatial variability at short distances, points were included (using a tape measure) at 5 m distances from each one of these five points. At each of the 300 sampling points, soybean plants, which were in 1 m length of two sowing rows, were harvested. The seeds were packaged, labeled and weighed to determine the yield, with the water content adjusted to 13%.

The data were analyzed using descriptive and exploratory statistics and geostatistics. During the exploratory analysis of the data, the position measurements (mean and median) of the dispersion (standard deviation and coefficient of variation (CV)) and the form of the distribution (coefficients of skewness and kurtosis) were calculated.

The CV values were interpreted as follows: low (homoscedasticity) when CV ≤ 10%, medium when 10% < CV ≤ 20%, high when 20% < CV ≤ 30% and very high (heteroscedasticity) when CV > 30% (PIMENTEL GOMES & GARCIA, 2002). The hypothesis of data normality was tested by

Anderson-Darling and Kolmogorov-Smirnov tests, with 5% significance, using Minitab 14 software. Based on the geostatistics analysis of the soybean yields, semivariograms were produced to determine the spatial dependence of the data. Matheron´s estimator was used to estimate the experimental semivariance function. Theoretical models fixed to the semivariograms were spherical, exponential and Gaussian.

The experimental semivariograms were obtained by applying the adjustment methods of ordinary least squares (OLS) to estimate parameters, such as the nugget effect (C0), sill (C0 + C1) and range (a), by adopting the isotropic model (omnidirectional semivariogram) with a 50% cut-off of the maximum distance. ArcView 9.2 software was used during this analysis. Thematic maps were produced through interpolation by ordinary kriging, and the best model was selected by cross-validation using the method of BAZZI et al. (2009).

The spatial dependence, represented by the nugget effect coefficient (E% C0/(C0 + C) x 100), was considered robust when E% < 25%, moderate when 25 ≤ E% ≤ 75% and weak when E% > 75% (CAMBARDELLA et al., 1994).

To prepare thematic maps of variables that were evaluated in each treatment, only the sampled points in the plots where a winter treatment was implemented were considered. Then, the sampled values at these points for the entire area were interpolated, as this treatment had been used throughout. Thus, the same procedure was conducted for each treatment.

For the analysis of the physical properties of the soil and soybean yields, 12 and 60 sampling points were used in each treatment, respectively, because there were six plots for each treatment. Two points were sampled for the analysis of the physical properties of the soil, and ten points were sampled to evaluate the soybean yields. The structure of the spatial dependence of the physical properties of the soil was not analyzed by the preparation of an experimental semivariogram because the sampling grid did not provide a minimum of 30 pairs of points for the semivariance calculation, as recommended by WOLLENHAUPT et al. (1997). Thus, to prepare the thematic maps related to the physical properties of the soil, an inverse distance interpolation was used.

For the map comparison, the relative deviation coefficient (RDC, COELHO et al., 2009; [eq. (1)] adapted to RDC_{local} [eq. (2)] was used, where the former shows the average difference, in modulus, of the interpolated values of a thematic map compared to a reference map, while the latter shows the percentage difference at each point of the interpolated values for each thematic map. In this study, the treatments (black oats, intercropping 1, intercropping 2 and wheat) were compared to the reference control conditions (remained fallow during the winter).

$$RDC = \sum_{i=1}^{M} \left| \frac{\hat{Z}_{ij} - \hat{Z}_i^*}{\hat{Z}_i^*} \right| \frac{100}{M} \tag{1}$$

$$RDC_{local_i} = \frac{(\hat{Z}_{ij} - \hat{Z}_i^*)*100}{\hat{Z}_i^*} \tag{2}$$

where,

$\hat{Z}_i^*$ - estimated reference value at the location *i* on the reference map;

$\hat{Z}_{ij}$ - value at location i for treatment j (j = 1: black oats; j = 2: intercropping 1; j = 3: intercropping 2; j = 4: wheat) on the map to be compared, and

M - the total number of interpolated locations on the yield maps.

Furthermore, linear correlation was measured through the Pearson correlation coefficient (R) using the classification proposed by Konopatzki et al. (2012): very weak for $0 \le |r| < 0.2$; weak for $0.2 \le |r| < 0.4$; moderate for $0.4 \le |r| < 0.6$; strong for $0.6 \le |r| < 0.8$; and very strong correlation for

$0.8 \leq |r| \leq 1$.

RESULTS AND DISCUSSION

The normality of the soybean yields, all physical attributes of the soil, and symmetrical and mesokurtic distributions were measured after the management of the winter treatments (Table 1). Considered anomalies, the macroporosity presented a negative skewed distribution, while the density showed a platykurtic distribution in the wheat treatment.

The CV indicated homogeneity of the data (CV ≤ 10%) for microporosity, total porosity, density and water content. However, for the soybean yields, 20% <CV ≤ 30%, which is a high CV. The results differ from ROSA FILHO et al. (2009), who obtained an average variability in CV by studying the yields of no-tillage soybeans that had been planted after corn (in summer) and beans (in winter) in a Distroferric Red Latosol. The macroporosity, for which the CV is considered very high (CV > 30%), is in agreement with the results obtained by SCHAFFRATH et al. (2008), who studied Distroferric Red Latosols under no-till conditions after planting soybeans (in summer) and wheat (in winter).

The lowest value (1.18 kg dm^{-3}) and the highest value (1.48 kg dm^{-3}) for the bulk density were obtained for the intercropping 1 treatment. The average values for this soil attribute were 1.33 kg dm^{-3} (control treatment), 1.34 kg dm^{-3} (black oats and intercropping 1), 1.35 kg dm^{-3} (intercropping 2) and 1.37 kg dm^{-3} (wheat), where values were close to critical, according to REICHERT et al. (2009). The average macroporosity for all of the treatments was below 0.10 m^3 m^{-3}. The average ground water levels were 0.34 (control), 0.35 (intercroppings 1 and 2 and wheat) and 0.36 kg kg^{-1} (black oats).

The averages of the soybean yield after all of the treatments were lower than the average yield of 2,337 kg ha^{-1} in Paraná, according to CONAB (2010), most likely due to the drought that occurred in December 2008 and January 2009 (SIMEPAR, 2010). The droughts damaged the ideal development of the soybean crops in the region where the experiment was conducted.

TABLE 1. Descriptive statistics of macroporosity, microporosity, total porosity, density, water content of soil and soybean yields for winter treatments of black oats, intercropping 1, intercropping 2, wheat and control conditions.

Treatment	Minimum	Mean	Median	Maximum	S.D	CV (%)	Skewness	Kurtosis	Normal*
MACROPOROSITY (m^3m^{-3})									
Black oats	0.01	0.05	0.05	0.09	0.026	49	-0.22 (a)	0.28 (A)	yes
intercropping 1	0.02	0.07	0.07	0.12	0.029	43	-0.33 (a)	0.04 (A)	yes
intercropping 2	0.01	0.07	0.06	0.12	0.035	52	-0.36 (a)	-0.54 (A)	yes
Wheat	0.01	0.06	0.07	0.08	0.021	35	-1.58 (c)	2.12 (A)	yes
Control	0.01	0.07	0.07	0.12	0.035	48	-0.38 (a)	-1.05 (A)	yes
MICROPOROSITY (m^3m^{-3})									
Black oats	0.48	0.49	0.49	0.51	0.009	2	0.15 (a)	-0.43 (A)	yes
intercropping 1	0.45	0.49	0.49	0.54	0.024	5	0.53 (a)	0.88 (A)	yes
intercropping 2	0.46	0.49	0.49	0.50	0.011	2	-1.19 (a)	2.12 (A)	yes
Wheat	0.46	0.49	0.49	0.52	0.016	3	-0.51 (a)	0.57 (A)	yes
Control	0.47	0.49	0.49	0.52	0.016	3	0.79 (a)	-0.29 (A)	yes
TOTAL POROSITY (m^3m^{-3})									
Black oats	0.51	0.55	0.55	0.61	0.027	5	0.53 (a)	1.84 (A)	yes
Intercropping 1	0.50	0.56	0.56	0.62	0.029	5	-0.16 (a)	1.97 (A)	yes
Intercropping 2	0.50	0.55	0.55	0.60	0.032	6	-0.04 (a)	-0.58 (A)	yes
Wheat	0.50	0.55	0.56	0.59	0.028	5	-1.05 (a)	0.18 (A)	yes
Control	0.49	0.57	0.57	0.63	0.038	7	-0.52 (a)	0.70 (A)	yes
DENSITY ($kgdm^{-3}$)									
Black oats	1.26	1.34	1.34	1.40	0.039	3	-0.55 (a)	0.36 (A)	yes
Intercropping 1	1.18	1.34	1.36	1.48	0.080	6	-0.39 (a)	0.36 (A)	yes
Intercropping 2	1.27	1.35	1.34	1.41	0.037	3	-0.34 (a)	0.71 (A)	yes
Wheat	1.30	1.37	1.35	1.43	0.046	3	0.09 (a)	-1.67 (B)	yes
Control	1.23	1.33	1.34	1.42	0.059	4	-0.54 (a)	-0.34 (A)	yes
WATER CONTENT ($kgkg^{-1}$)									
Black oats	0.34	0.36	0.36	0.38	1.252	3	0.07 (a)	-0.58 (A)	yes
Intercropping 1	0.31	0.35	0.34	0.41	2.712	8	1.20 (a)	2.06 (A)	yes
Intercropping 2	0.33	0.35	0.35	0.36	0.734	2	-0.57 (a)	0.52 (A)	yes
Wheat	0.32	0.35	0.36	0.38	1.745	5	-0.84 (a)	-0.18 (A)	yes
Control	0.32	0.34	0.34	0.38	1.559	4	0.81 (a)	0.16 (A)	yes
YIELD ($kgha^{-1}$)									
Black oats	857	1666	1642	2903	420	25	0.50 (a)	0.31 (A)	yes
Intercropping 1	708	1472	1430	2333	368	25	0.22 (a)	-0.47 (A)	yes
Intercropping 2	941	1702	1710	2653	413	24	0.26 (a)	-0.43 (A)	yes
Wheat	1030	1872	1843	2971	539	29	0.20 (a)	-1.1 (A)	yes
Control	729	1793	1756	2952	455	25	0.26 (a)	-0.09 (A)	yes

* Anderson-Darling and Kolmogorov-Smirnov Normality test;
Skewness - symmetrical distribution (a) positive skewness (b) negative skewness (c);
Kurtosis – mesokurtic (A), platykurtic (B), leptokurtic (C);
S.D. - standard deviation;
CV - Coefficient of Variation.

Spatial dependence could be assessed for soybean yields (planted after all winter treatments), which was determined in a denser sampling grid (60 points in each treatment). The maximum distance of spatially correlated points (range; Table 2) was 14 m in the soybean yields (intercropping 1) and 123 m in the wheat. Note that the degree of spatial dependence of the soybean yields was classified as moderate (25 ≤ E% ≤ 75%) in most treatments (except for the black oats treatment). These results corroborate to those obtained by ROSA FILHO et al. (2009). The spatial distribution of the soybean yields (kg ha^{-1}) for the winter treatments can be observed in Figure 2.

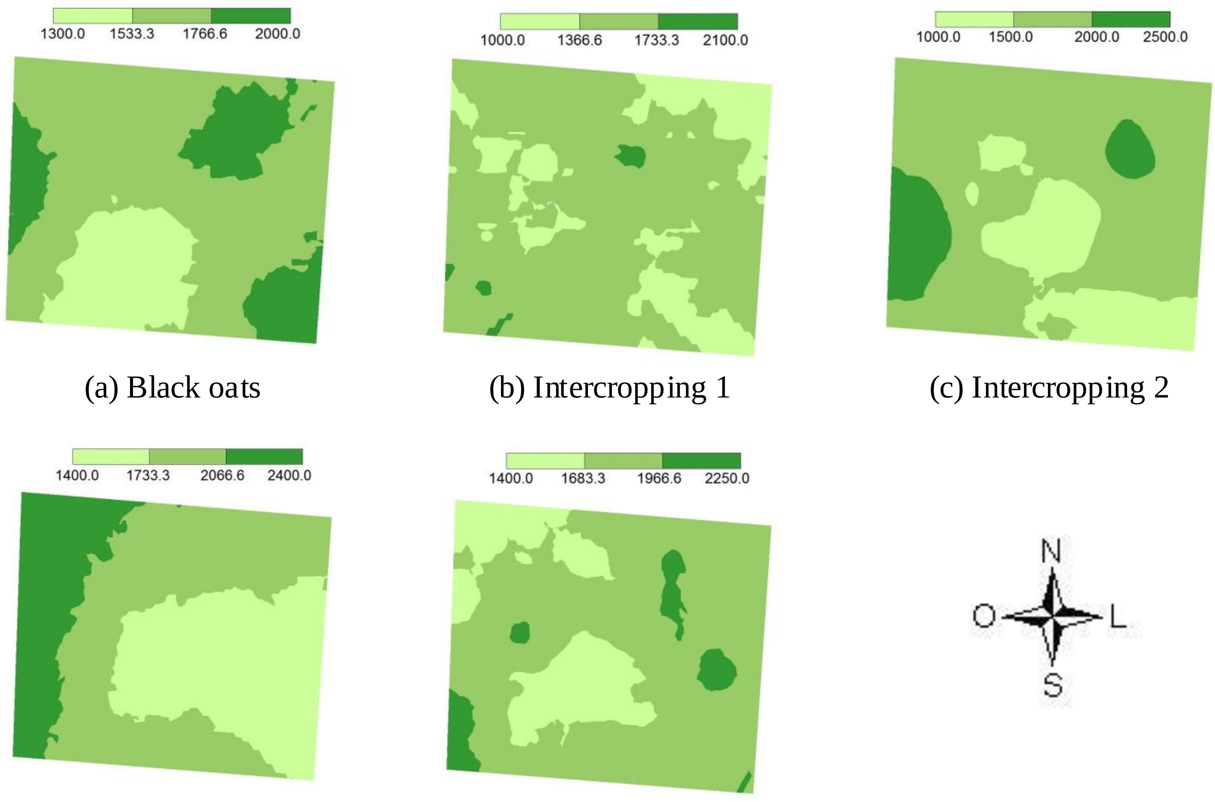
TABLE 2. Models and parameters estimated from experimental semivariograms of the soybean yields for the following treatments: black oats, intercropping 1, intercropping 2, wheat and control.

Treatment	Model	C_0 (nugget effect)	C_0+C_1 (sill)	a (range)	E%* $(C_0/(C_0+C_1))$x100	Spatial Dependence
YIELD						
Black oats	Spherical	147570	185342	76	80	weak
Intercropping 1	Exponential	65061	139100	14	47	moderate
Intercropping 2	Spherical	53453	177503	34	30	moderate
Wheat	Gaussian	219980	354450	123	62	moderate
Control	Exponential	130170	212068	56	61	moderate

*E% = coefficient of nugget effect.

Different spatial dependence characteristics were observed among the treatments. Therefore, different managements may have changed the spatial variability of the soil attributes, indicating that the spatial variability of a particular physical attribute depends not only on factors of soil formation but also on the management adopted, as emphasized by LIMA et al. (2009).

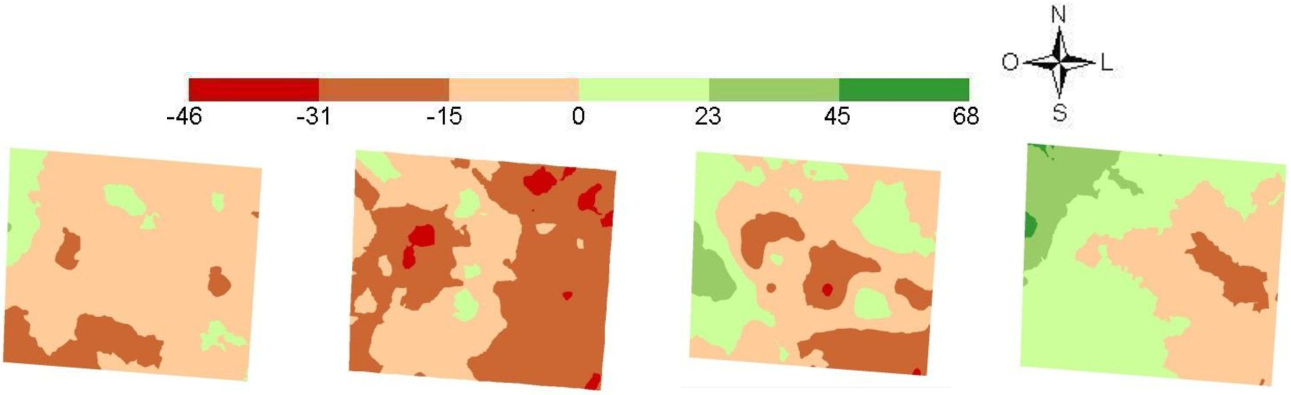
A map of percentages differences between each treatment and the control (RDC_{local}) was used for the comparison. Thus, it was possible to determine points where there was positive or negative change from the control values, as well as the percentage of the area in which there were negative or positive deviations or where no deviation (zero) occurred. The lowest values of soybean yields occurred in the treatments of black oats, intercropping 1 and intercropping 2, where nearly 89, 95, and 71% of the areas had lower yields compared to the control, respectively (Figure 3).



(a) Black oats (b) Intercropping 1 (c) Intercropping 2

(d) Wheat (e) Control

FIGURE 2. Spatial distribution of the soybean yields (kg ha^{-1}) for the winter treatments: black oats, intercropping 1, intercropping 2, wheat and control.



(a) Black oats (b) Intercropping 1 (c) Intercropping 2 (d) Wheat

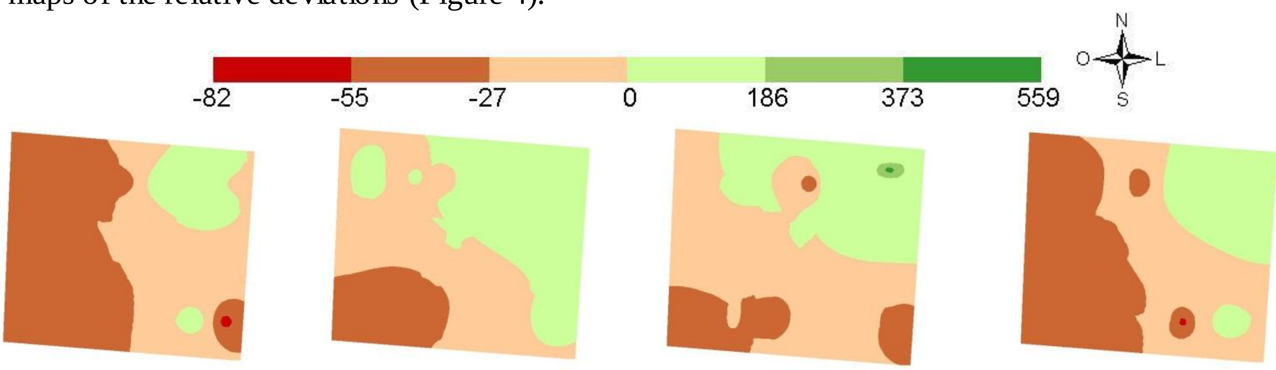
FIGURE 3. Thematic maps of RDC_{local} (percentage difference from the control) values for soybean yields for treatments of black oats, intercropping 1, intercropping 2 and wheat.

It should be noted that cover crops used in crop rotations did not adversely influence commercial crop yields, according to several researchers (KUBO et al., 2007; LOPES et al., 2007; NUNES et al., 2006). This contradictory result can be explained by the timing of the treatment management (black oats, intercropping 1 and intercropping 2), which resulted in germination and sprouting of the cover crops in areas they were planted as winter treatments; thus, these cover crops became weeds and competed with soybean plants in the initial term.

The development of the cover crops was rapid and non-uniform due to the weather conditions during the winter treatment set-up. Thus, although most plants were blooming, there were plants with seeds and physiologically mature plants when the treatments (black oats, intercropping 1 and intercropping 2) were managed.

There were larger areas with reduced soil macroporosity in the treated areas compared with the control. The lowest macroporosity values occurred in the wheat and black oat treatments, with almost 77 and 86% of the area with lower values of macroporosity, respectively. Such results disagreed with those obtained by some authors who observed an increase in the macroporosity when using cover crops (NICOLOSO et al. 2008).

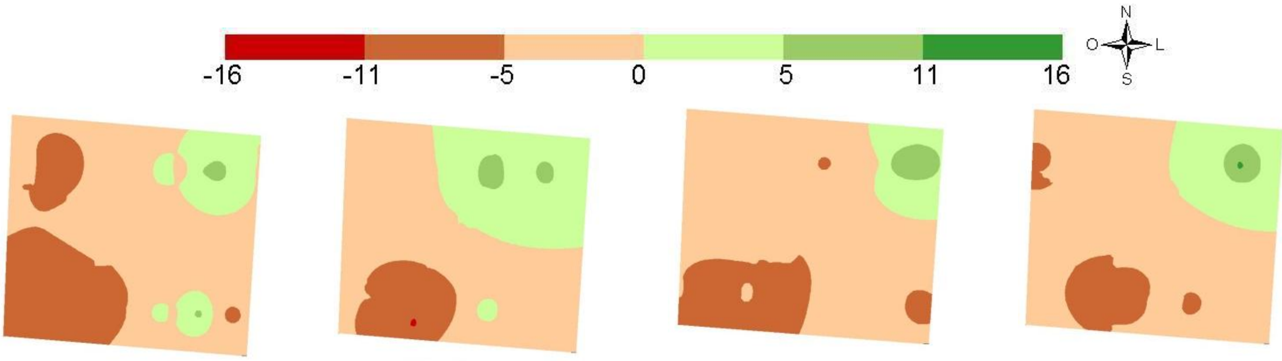
Attention should be given to the fact that these authors have worked with average values. Although most part of the area exhibited lower values of macroporosity when compared to the control, 42.4% (intercropping 1) and 32.7% (intercropping 2) of the areas had higher values of macroporosity when using cover crops, up to 186% higher, as can be observed in the thematic maps of the relative deviations (Figure 4).



(a) Black oats (b) Intercropping 1 (c) Intercropping 2 (d) Wheat

FIGURE 4. Thematic maps of RDC_{local} (percentage difference from the control) values for soil macroporosity for treatments of black oats, intercropping 1, intercropping 2 and wheat.

The regions in which the lowest and the highest values of total pores occurred are presented in Figure 5. The southwestern region is highlighted because it showed the lowest values of the total porosity when the four treatments were compared to the control. Although all treatments showed larger areas with negative deviations from the control (68, 80, 86, 88% of the areas for treatments of intercropping 1, wheat, black oats and intercropping 2, respectively), some areas in the northeastern region of the map showed the highest values of total pores when using winter coverage plants. These data correspond with the region where the highest values of macroporosity were found (Figure 4).

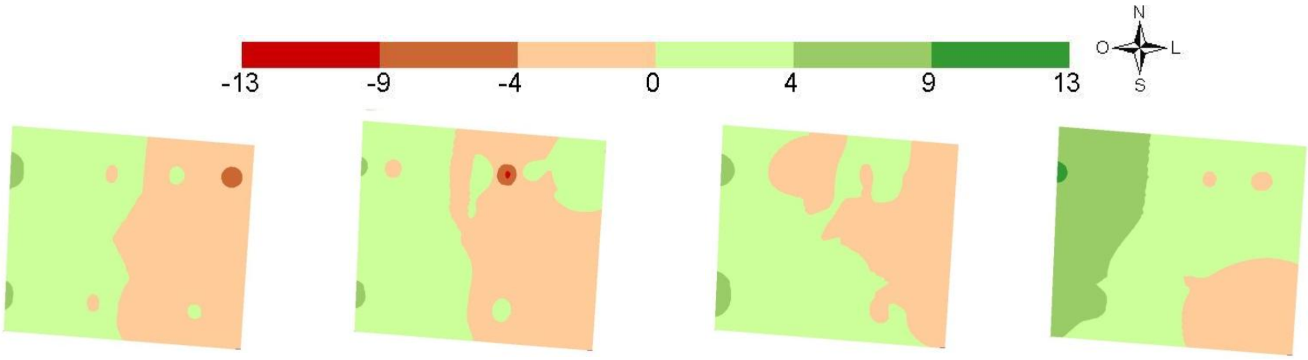


(a) Black oats (b) Intercropping 1 (c) Intercropping 2 (d) Wheat

FIGURE 5. Thematic maps of RDC_{local} (percentage difference from the control) values for the total porosity of the soil for treatments of black oats, intercropping 1, intercropping 2 and wheat.

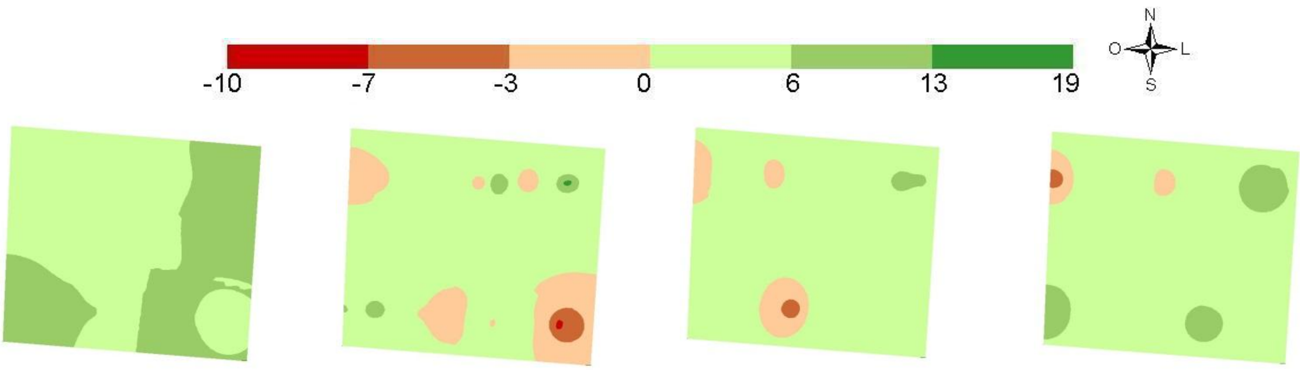
The bulk density associated with the soil macroporosity is an attribute related to soil compaction; 80.3% of the area treated with winter wheat exhibited higher bulk densities compared to the control (Figure 6d). However, when black oats were managed, there was a reduction in the density for half of the area (Figure 6a). The increase in the bulk density, over most of the area, was observed for intercropping 2; this is similar to the results found by NICOLOSO et al. (2008), who attributed the increase in the density of superficial layer of soil to lateral pressure exerted by forage turnip roots, due to their large tap-root diameters.

The soil water content increased from 82.1 (intercropping 1) to 100% (black oats) of the area when compared to the control. The increase in the water content was most likely due to cover crop waste that was used to protect and retain the soil moisture. The black oat treatment is highlighted because it had the highest water content response for 100% of the area, with an increase up to 13% (Figure 7a) when compared to the control, whose soil was very exposed at the period of collection (weed coverage only). Black oat plants helped maintain the water content of soil because straw slowly decomposes due to the high C/N ratio and high lignin contents, which increase with the development of culture (RIZZARDI & SILVA, 2006).



(a) Black oats (b) Intercropping 1 (c) Intercropping 2 (d) Wheat

FIGURE 6. Thematic maps of RDC_{local} (percentage difference from the control) values for the density of the soil for treatments of black oats, intercropping 1, intercropping 2 and wheat.



(a) Black oats (b) Intercropping 1 (c) Intercropping 2 (d) Wheat

FIGURE 7. Thematic maps of RDC_{local} (percentage difference from the control) values for the soil water content for treatments of black oats, intercropping 1, intercropping 2 and wheat.

Average tests can be used to compare treatments, typically with the experimental design that is chosen for the trial. Therefore, the data concerning the physical properties of the soil were obtained from the analysis of variance, but there was no significance using the F test in any of the analyses. Significant differences (classical statistics) in the physical properties of the soil using cover crops as treatments are found for longer experiments. Thus, the thematic maps and local coefficients of deviation (RDC_{local}) enabled us to determine the spatial distribution of the properties in the study area, as well as compare the results with the control in the first year.

There was no significant linear correlation between the soybean yields and the physical properties of the soil (Table 3). ROSA FILHO et al. (2009), working in a Distroferric Red Latosol, also found no correlation between density and soybean yields, unlike ANDREOTTI et al. (2010), who found significant linear correlations between soybean yields and macroporosity, microporosity and bulk density in a Distroferric Red Latosol.

It was observed a weak negative linear correlation between the bulk density and macroporosity. According to THIMOTEO et al. (2001), a porosity decrease may increase the bulk density, decrease the water infiltration and consequently make the soil susceptible to erosion.

TABLE 3. Pearson's correlation coefficients (r) between macroporosity (Macro), microporosity (Micro), total porosity (TP), bulk density (BD), water content of the soil (WCS) and soybean yields (Yield).

	WCS	BD	Macro	Micro	TP	Interpretation
BD	-0.420*					$0 \leq \lvert r\rvert < 0.2$ (very weak)
Macro	-0.030	-0.381*				$0.2 \leq \lvert r\rvert < 0.4$ (weak)
Micro	0.583*	-0.027	-0.185			$0.4 \leq \lvert r\rvert < 0.6$ (moderate)
TP	0.276*	-0.363*	0.851*	0.337*		$0.6 \leq \lvert r\rvert < 0.8$ (strong)
Yield	0.047	-0.012	0.015	-0.003	0.043	$0.8 \leq \lvert r\rvert \leq 1$ (very strong)

*T-test significant ($\alpha = 0.05$ level); N = 60.

There was a moderate, negative linear correlation between the density and the water content of the soil, consistent with KIEHL (1979) and ROSA FILHO et al. (2009), who explained that a decrease in the bulk density of the soil corresponds to a predominance of small particles with a large capacity for water retention. A strong correlation was also detected between the macroporosity and the total porosity, agreeing with the results obtained by SCHAFFRATH et al. (2008).

CONCLUSIONS

According to the winter treatment results, only the wheat treatment provided an increase in soybean yields compared with the control treatment for most of the area in the first year of management.

Different spatial dependence structures were observed among the treatments.

The cover crops improved the macroporosity and total porosity in some regions (northeast) of the studied area.

The use of black oats as cover plants was more efficient at retaining higher soil water contents; black oats have also shown the greatest potential to reduce the bulk density in a no-tillage system. In the studied area, the results suggest this crop rotation maybe benefit soybean yields.

REFERENCES

ANDREOTTI, M.; CARVALHO, M.P.; MONTANARI, R.; BASSO, F.C.; PARIZ, C.M.; AZENHA, M.V. VERCESE, F. Produtividade da soja correlacionada com a porosidade e a densidade de um Latossolo Vermelho do cerrado brasileiro. *Ciência Rural*, Santa Maria, v.40, n.3, p.520-526, 2010.

BAZZI, C.L.; SOUZA, E.G.; URIBE-OPAZO, M.A.; SANTOS, D. *Uso da validação cruzada na seleção de modelos de semivariogramas*. In: CONGRESSO BRASILEIRO DE ENGENHARIA AGRÍCOLA, 38., 2009, Petrolina/Juazeiro. *Anais*... Petrolina/Juazeiro: Associação Brasileira de Engenharia Agrícola, 2009. 1 CD-ROM.

CALEGARI, A. Plantas de cobertura. Cap. 5. In: CASÃO JUNIOR, R.; SIQUEIRA, R.; MEHTA, Y. R.; PASSINI, J.J. *Plantio direto com qualidade*. Londrina: IAPAR; Foz do Iguaçu: ITAIPU Binacional, 2006.

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 America Journal*, Madison, v.58, n.5, p. 1501-1511, 1994.

COELHO, E.C.; SOUZA, E.G.; URIBE-OPAZO, M.A.; PINHEIRO NETO, R. Influência da densidade amostral e do tipo de interpolador na elaboração de mapas temáticos. *Acta Scientiarum Agronomy*, Maringá, v.31, n.1, p. 165-174, 2009.

CONAB - COMPANHIA NACIONAL DE ABASTECIMENTO. *Soja em números* (safra 2008/2009). Disponível em: http://www.cnpso.embrapa.br/index.php?op_page=294&cod_pai=16. Acesso em: 4 jan. 2010.

EMBRAPA - EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA. *Manual de métodos de análise de solo*. 2. ed. Rio de Janeiro, 1997. 212p.

EMBRAPA - EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA. *Sistema brasileiro de classificação de solos*. 2. ed. Rio de Janeiro: CNPS, 2006. 306p.

GONÇALVES, A.C.A.; FOLEGATTI, M.V.; MATA, J.D.V. Análises exploratória e geoestatística da variabilidade de propriedades físicas de um argissolo vermelho. *Acta Scientiarum*, Maringá, v.23, n.5, p. 1149-1157, 2001.

HAMZA, M.A.; ANDERSON, W.K. Soil compaction in cropping systems: A review of the nature, causes and possible solutions. Soil and Tillage Research, Amsterdam, v.82, n.2, p.121-145, 2005.

KIEHL, E.J. *Manual de edafologia*: Relações solo-planta. Piracicaba: Agronômica Ceres, 1979. 264p.

KONOPATZKI, M R S ; SOUZA, E. G. ; NÓBREGA, L. H. P. ; URIBE-OPAZO, M. A. ; SUSZEK, G. Spatial variability of yield and other parameters associated with pear trees. Engenharia Agrícola, Jaboticabal, v. 32, n.2, p. 381-392, 2012.

KUBO, C.T.; MATA, J.D.V.; SILVA, M.A.G.; SENGIK, E.; MUNIZ, A.S.; NEIRO, E.S. Produtividade de soja em plantio direto em sucessão ao trigo, aveia branca, aveia preta com e sem adubação nitrogenada. *Acta Scientiarum Agronomy*, Maringá, v.29, n.2, p. 235-240, 2007.

LIMA, J.S.S.; SATTLER, M.A.; PASSOS, R.R.; OLIVEIRA II, P.C.; SOUZA, G.S. Variabilidade espacial de atributos físicos de um Argissolo vermelho amarelo sob pastagem e vegetação secundária em regeneração natural. *Engenharia Agrícola*, Jaboticabal, v.29, n.2, p.185-195, 2009.

LOPES, R.A.P.; PINHEIRO NETO, R.; BRACCINI, A.L.; SOUZA, E.G. Efeito de diferentes coberturas vegetais e sistemas de preparo do solo na produção da cultura da soja. *Acta Scientiarum. Agronomy*, Maringá, v. 29, n. 4, p. 507-515, 2007.

NICOLOSO, R.S.; AMADO, T.J.C.; SCHNEIDER, S.; LANZANOVA, M.E.; GIRARDELLO, V.C.; BRAGAGNOLO, J. Eficiência da escarificação mecânica e biológica na melhoria dos atributos físicos de um latossolo muito argiloso e no incremento do rendimento de soja. *Revista Brasileira de Ciências do Solo*, Viçosa, MG, v.32, n.4, p. 1723-1734, 2008.

NUNES, U.R.; ANDRADE JÚNIOR, V. C.; SILVA, E.B.; SANTOS, N.F.; COSTA, H.A.O.; FERREIRA, C.A. Produção de palhada de plantas de cobertura e rendimento do feijão em plantio direto. *Pesquisa Agropecuária Brasileira*, Brasília, v.41, n.6, p. 943-948, 2006.

PENTEADO, S.R. *Adubação verde e produção de biomassa:* melhoria e recuperação dos solos. Campinas: Fraga & Penteado: Livros Via Orgânica, 2007. 164p.

PIMENTEL-GOMES, F.P.; GARCIA, C.H. *Estatística aplicada a experimentos agronômicos e florestais*. Piracicaba: FEALQ, 2002. v.11, 305p.

RAMÍREZ-LÓPEZ, L.; REINA-SANCHEZ, A.; CAMACHO-TAMAYO, J.H. Variabilidad espacial de atributos físicos de un Typic Haplustox de los Llanos Orientales de Colômbia. *Engenharia Agrícola*, Jaboticabal, v.28, n.1, p. 55-63, 2008.

REICHERT, J.M.; SUZUKI, L.E.A.S.; REINERT, D.J.; HORN, R.; HÅKANSSON, I. Reference bulk density and critical degree-of-compactness for no-till crop production in subtropical highly weathered soils. *Soil and Tillage Research*, Amsterdam, v.102, n.2, p. 242-254, 2009.

RIZZARDI, M.A.; SILVA, L.F. Influência das coberturas vegetais antecessoras de aveia-preta e nabo forrageiro na época de controle de plantas daninhas em milho. *Planta Daninha*, Viçosa, MG v.24, n.4, p.669-675, 2006.

ROSA FILHO, G.; CARVALHO, M.P.; ANDREOTTI, M.; MONTANARI, R.; BINOTTI, F.F.S.; GIOIA, M.T. Variabilidade da produtividade da soja em função de atributos físicos de um latossolo vermelho distroférrico sob plantio direto. *Revista Brasileira de Ciência do Solo*, Viçosa, MG, v.33, n.2, p. 283-293, 2009.

SCHAFFRATH, V.R.; TORMENA, C.A.; GONÇALVES, A.C.A.; FIDALSKI, J. Variabilidade e correlação espacial de propriedades físicas de solo sob plantio direto e preparo convencional. *Revista Brasileira de Ciência do Solo*, Viçosa, MG, v.32, n.4, p. 1369-1377, 2008.

SIMEPAR. INSTITUTO TECNOLÓGICO SIMEPAR. *Dados meteorológicos*. Disponível em: <http://www.simepar.br/>. Acesso em: 20 jan. 2010.

STRUDLEY, M.W.; GREEN, T.R.; ASCOUGH, J.C.; Tillage effects on soil hydraulic properties in space and time: State of the science. *Soil and Tillage Research*, Amsterdam, v.99, n.1, p. 4-48, 2008.

THIMÓTEO, C.M.S.; BENINNI, E.R.Y.; MURATA, I.M.; TAVARES, J.F. Alterações da porosidade e da densidade de um Latossolo Vermelho Distrófico em dois sistemas de manejo de solo. *Acta Scientiarum. Agronomy*, Maringá, v.23, n. 1, p. 1299-1303, 2001.

WOLLENHAUPT, N.C.; MULLA, D.J.; CRAWFORD, G. Soil sampling and interpolation techniques for mapping special variability of soil properties. In: PIERCE, F.J., SADLER, E.J. (Ed.). *The state of site-specific management for agriculture*. Madison: ASA, CSSA, SSSA, 1997. p.19-53.