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Relationships Between Grain Dry Matter of Common Bean and Soil Physical Properties of an Oxisol Under Minimum Tillage at The Brazilian "Cerrado" Region

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Abstract: In the "Cerrado" area of Brazil, minimum tillage (MT) is the most generalized tillage system. Under the prevailing soil and climatic conditions of this region, MT clearly has demonstrated advantages in reducing soil erosion losses, has also shown advantages in increasing soil available water and, in general, ameliorates the soil physical condition. This work analysed the basic soil physical properties of an Oxisol and grain yield of the common bean (*Phaseolus vulgaris* L.) at the microplot scale with emphasis on its spatial variability. Field trials were conducted at the experimental field of the Engineering Faculty of Ilha Solteira (UNESP). The study soil was classified as an Oxisol (USDA) equivalent to "Latossolo Vermelho distroférrico" (Brazilian Soil Classification System). A nested sampling grid with a total of 117 points was used. The main grid was in a square design consisting of 81 sampling points located 5 meters apart and in addition 36 samples were taken at smaller distances. Gravimetric soil water content (WC), mechanical resistance (PR) and pH were measured at the 0-10 cm, 10-20 cm and 20-30 cm soil depths. Also, grain dry matter yield of 100 bean grains per sampling point was assessed. Correlation coefficients between the study soil properties were in general not significant, except for the pairs WC x PR at the 20-30 cm depth (r= - 0.204) and PR x pH at the 0-10 cm depth (r=0.223) which were significant at the 0.05 probability level. Semivariogram analysis showed a moderate to strong spatial dependence of most of the studied soil attributes; the exceptions were WC and PR at the 0-10 cm depth. Kriging maps showed a good parallelism between WC, PR and grain production.
Key words: Common bean, no-tillage, Oxisol, Brazilian "Cerrado", geostatistics.

INTRODUCTION

In Brazil, common beans (*Phaseolus vulgaris* L.) constitutes one of the most representative agricultural crops, not only because of the culture area, but also due tor the production value. This crop is a basic food component of the population of Brazil, given it is an important source of protein and iron. During the crop season 2006/2007, the national production of beans reached 3339 million tons, occupying an area of approximately 4087 million hectares, highlighting the regions of the south, southeast and northeast, which produced 1150, 839 and 801 thousand tons of grain, respectively, with a mean productivity of 0.81 t ha^{-1} (CONAB, 2008).

Minimum tillage, also designed as reduced tillage consists of minimum soil disturbance and maintenance of the vegetable residue, covering the highest possible proportion of the surface. This means a decrease in management activities should be considered. This main system already spread throughout the country, consists of chisel plows, normally equipped with cutting disks in the front part of each shaft for operations in which crop residues remain on the soil surface. This equipment includes a specific roller for clod breaking, which is used to diminish the size of clods and level the soil for sowing. Altogether, the equipment with its implements performs simultaneously more than one tillage each time it is used (Furlani, 2000). Moreover, when selecting a system for soil preparation one should consider criteria such as the response to an increase in farming productivity, especially, when simultaneously the aim is to decrease soil loss by erosion, to control weeds, to increase the retention capability and movement of water and to recover its physical, chemical and biological properties (Henklain, 1997).

Knowledge of the soil properties variability under different uses and management systems an important goal, which may help to achieve more adequate management practices (Bhatti et al., 1991). In accordance with Vieira (2004), the spatial variability of soils has always existed and should be considered each time a field sampling is performed, given it can alert the local people about a differentiated management which eventually could be necessary. Analysis of spatial variability should be performed in spite of sampling representativity, so that a greater detailed analysis of the specific study area will be possible.

Similarly, the objective of this work was to analyse the spatial behaviour of the physical properties of a Latossolo Vermelho distroférrico and its correlation with bean production.

MATERIALS AND METHODS

This work was carried out during the agricultural year 2005/2006, in Fazenda de Ensino, Pesquisa e Extensão of the Faculty of Engineering of Ilha Solteira – UNESP, situated in the county of Selvíria (MS), at latitude 22°23'S and longitude 51°27'W (Fig. 1), with mean annual precipitation of 1300 mm and mean temperature of 23.7°C. The soil studied is an Oxisol (USDA, 1996) equivalent to "Latossolo Vermelho distroférrico" (EMBRAPA, 2006).

Figure 1. Geographic situation of the study area.

The study area measures 0.16 ha (40 m x 40 m) and was divided into a sampling grid containing 117 sampling points (Fig. 2). The sampling grid presents 81 points with 5 m x 5 m spacing and 36 points with 1.67 x 1.67 m spacing.

The mass of 100 bean grains (MBG, g) was calculated; grain samples were obtained from common beans plants in the neighborhood of the sample points. The soil properties: soil mechanical penetration resistance (PR, MPa), gravimetric soil water content (θ, kg kg-1) and pH at three depths 0.0-0.1 m (PR1, θ1 and pH1), 0.1-0.2 m (PR2, θ2 and pH2) and 0.2-0.3 m (PR3, θ3 and pH3). Soil mechanical resistance (PR) was determined following the methodology proposed by Stolf (1991). Gravimetric soil water content (θ) was determined by Embrapa (1979) and pH in CaCl2 according to Raij et al. (2001).

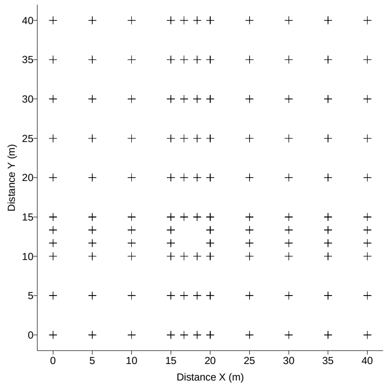

Figure 2. Sampling grid of the soil and plant properties.

The main statistical parameters (mean, minimum, maximum, standard deviation (SD), coefficient of variation (CV, %), asymmetry and kurtosis were determined using the program SAS (Schlotzhaver and Littel, 1997).

The analysis of spatial variability was performed using the semivariogram (Equation 1), based on the assumptions of the intrinsic hypothesis, using the program (GS+, 2004).

$$\gamma^*(h) = \frac{1}{2\,N(h)} \sum_{i=1}^{N(h)} [Z(x_i) - Z(x_i + h)]^2 \qquad (1)$$

where: γ*(h) is the estimated semivariance; N (h) represents the number of pairs measured Z (xi), Z (xi + h) separated by a vector (h). Hence, adjustment to a mathematical model representing the spatial variability of the soil properties is possible. The fitting parameters are: C0- nugget effect; C0 + C1 - sill and a - range. The nugget effect (C0) indicates the variability not detected in the sampling. The structural variance (C1) indicates up to what point the variability of the data increases until there is no resemblance between the variability of the samples; therefore (C0 + C1) is defined as the sill. The range (a) indicates up to what distance the samples have spatial dependence.

The fitting of the experimental semivariograms by theoretical models, was carried out in accordance with Robertson (1998). The spatial dependence ratio (RD) was determined as proposed by Cambardella et al. (1994):

$$RD = \frac{C_0}{C_0 + C_1} * 100 \qquad (2)$$

where: RD is the dependence ratio (%); C1 is the structural variance, and C0+C1 is the sill, where: RD ≤ 25% the spatial dependence is weak; 25 - 75% is the spatial dependence is medium and RD ≥ 75 % the spatial dependence between samples is strong variable.

RESULTS AND DISCUSSION

The results of the statistical analysis (Table 1) show that MBG, θ1, θ2, pH2 and pH3 present a normal frequency distribution for the data set, using the Shapiro and Wilk test to 1% probability. The rest of the properties present a distribution of undetermined frequency (PR1 and PR2) and also lognormal (PR3, θ3 and pH1). According to Isaaks and Srivastava (1989) more important than the normality of the data is the occurrence or not of the so-called proportional effect, whose mean is the variability and the data seem constant in the area studied. Nonetheless, since the data are obtained from nature, the fitting of a theoretical distribution is only approximated (Cressie, 1991).

In agreement with the classification of Pimentel-Gomes and Garcia (2002) the values of the coefficient of variation (CV, %) are low (< 10 %) for MBG, θ3, pH1, pH2 and pH3. The gravimetric soil water content at depths 0.1-0.2 m (θ2) and 0.2-0.3 m (θ3) present medium CV values (10-20%). The mechanical resistance values of the soil (PR1, PR2 and PR3) show elevated CV values (> 30 %) at all the depths studied. According to Vanni (1998), a coefficient of variation above 35% reveals that the series is heterogeneous and that the mean has little significance. If it is above 65%, the series is very heterogeneous and the mean has no significance. In this sense, we can state that the presence of elevated CV values, especially for PR1 and PR2, is a result of the variability of this property in this soil, due to the interaction of soil management with other soil properties, mainly those related with the structural stability of the soil.

The mean values of mechanical penetration resistance (PR) are considered average at the first study depth (PR1) and high at subsequent depths (PR2 and PR3), according to the classification proposed by Arshad et al. (1996).

The simple linear correlation (Table 2) shows that there is no correlation between the mass of the grains (MBG) and the properties of the soils analysed. However, among the soil properties significant correlations were verified between the pairs PR3 x θ3 (r=-0.204*) and PR1 x pH1 (r=-0.223*), significant at 5% probability and presenting an indirect correlation between cause and effect, that is, when the mechanical resistance increases, the gravimetric soil water content and the pH of the soil decrease.

Table 1. Statistical parameters.

Properties	Unit	Mean	Minimum	Maximum	SD	CV (%)	Skewness	Kurtosis	Normality*
MBG	g	23.3	19.8	25.7	1.03	4.4	-0.086	0.679	0.197 N
PR_1		1.09	0.54	2.98	0.63	58.1	1.063	0.145	0.0001 Un
PR_2	MPa	2.11	0.54	4.36	1.08	51.3	0.382	-0.916	0.0001 Un
PR_3		2.74	0.54	5.05	0.96	35.1	-0.317	0.126	0.022 Ln
θ_1		0.20	0.15	0.27	0.02	10.6	0.388	0.381	0.304 N
θ_2	kg kg^{-1}	0.22	0.15	0.30	0.02	10.1	0.119	0.829	0.216 N
θ_3		0.23	0.18	0.28	0.01	8.1	0.476	0.134	0.050 Ln
pH_1		4.7	4.3	5.4	0.20	4.4	0.476	0.134	0.050 Ln
pH_2	-	4.7	4.3	5.3	0.20	4.3	0.453	0.229	0.055 N
pH_3		4.8	4.2	5.4	0.24	5.1	0.196	-0.139	0.644 N

SD: standard deviation; *Normality of the data using the Shapiro and Wilk test at 1% probability: N- normal distribution, Ln-Lognormal distribution and Un undetermined distribution; MBG: mass of 100 bean grains (g); PR: soil mechanical penetration resistance (MPa); θ: gravimetrical soil water content (kg kg^{-1}).

Table 2. Coefficients of linear correlation.

	MBG	PR_1	PR_2	PR_3	θ_1	θ_2	θ_3	pH_1	pH_2	pH_3
MBG	1.000									
PR_1	-0.124	1.000								
PR_2	-0.117	0.607^*	1.000							
PR_3	-0.059	0.382^*	0.698^*	1.000						
θ_1	-0.091	0.064	-0.029	-0.016	1.000					
θ_2	0.062	0.143	0.044	0.027	0.375^*	1.000				
θ_3	0.044	0.157	-0.117	-0.204^*	0.260^*	0.189^{**}	1.000			
pH_1	-0.073	-0.223^{**}	-0.102	-0.052	0.210^{**}	0.125	0.067	1.000		
pH_2	-0.030	-0.077	-0.034	-0.044	0.271^*	0.191^{**}	0.076	0.781^*	1.000	
pH_3	-0.093	-0.167	-0.068	-0.085	0.309^*	0.142	0.016	0.692^*	0.773^*	1.000

* Significant at 1% probability; ** Significant at 5% probability; MBG: mass of 100 bean grains (g); PR: soil mechanical penetration resistance (MPa); θ: gravimetrical soil water content (kg kg^{-1}).

A geostatistical analysis (Table 3) demonstrated that MBG, PR1 and θ1 present a pure nugget effect, indicating that the sampling scheme was not sufficient to detect the spatial variability of these properties. The remaining properties were adjusted to the spherical model (PR2, pH1, pH2 and pH3) and to the exponential model (PR3, θ2 and θ3), confirming these models to be the most common for the properties of the soil and plants (Trangmar et al., 1985). Cavalcante et al. (2007) studying a Latossolo Vermelho found the same semivariogram models (spherical and exponential) for pH in CaCl2. Siqueira et al. (2008) studying the spatial variability of the volumetric water content of the soil described the spherical model as being more common for this property. Vieira et al. (2008) studying the spatial variability of the mechanical resistance of the soil describes the spherical model as corroborating the results obtained in this study.

Table 3. Geostatistical models and parameters.

	Model	C_0	C_1	a (m)	SDR
MBG	Pure nugget effect				
PR_1	Pure nugget effect				
PR_2	Spherical	0.114	1.132	7.7	9.14
PR_3	Exponential	0.329	0.720	14.7	31.36
θ_1	Pure nugget effect				
θ_2	Exponential	0.00004	0.00039	11.1	9.30
θ_3	Exponential	0.0001	0.00035	25.6	22.22
pH_1	Spherical	0.006	0.00419	16.5	58.88
pH_2	Spherical	0.0159	0.04386	13.8	26.60
pH_3	Spherical	0.309	0.06370	15.7	82.90

C_0: nugget effect; C_1: structural variance; a: range (m); SDR: spatial dependence ratio (%); MBG: mass of 100 bean grains (g); PR: soil mechanical penetration resistance (MPa); θ: gravimetrical soil water content (kg kg^{-1}).

The properties, that as with spatial dependence were modeled by means of the experimental semivariogram, present low nugget effect values (C0, Table 3). According to Siqueira et al. (2008) low nugget effect values indicate discontinuity between samples, that is, spatial variability is not detected during the sampling process.

The range values (a, Table 3) demonstrate that a pattern in the size of the microregions of spatial variability for the properties studied does not exist. The mechanical resistance of the soil (PR) presented range values (a) varying between 7.7 m (PR2) and 14.7 m (PR3). Gravimetric soil water content presented range values (a) between 11.1 m (θ2) and 25.6 m (θ2). The pH of the soil presented values varying between 13.8 (pH2) and 15.7 (pH3).

The degree of spatial dependence (SDR) according to the classification of Cambardella et al. (1994) is high for PR2, θ2, θ3 and pH2. The rest of the properties presented an average SDR (PR3, pH1 and pH3).

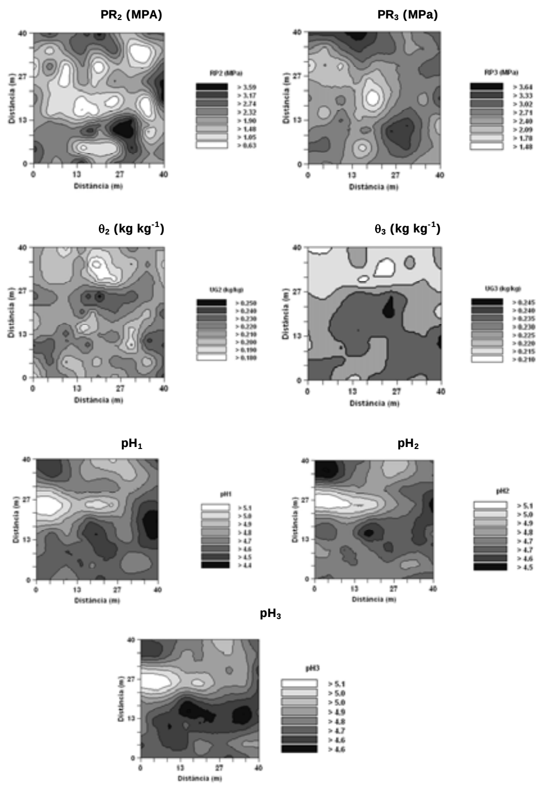

Figure 3. Kriging maps of the properties of a Latossolo Vermelho distroférrico.

The maps of spatial variability of the mechanical resistance of the soil (PR, MPa – Figure 3) demonstrate that a similar pattern occurs in the distribution of contour lines between PR2 and PR3. A gravimetric soil water content at depth 0.1-0.2 m (θ2) and at depth 0.2-0.3 m (θ3) describes that the lower half of the study area presented the highest soil water content values (kg kg-1). The maps of spatial variability of the soil pH at the different depths studied presented similar behaviour in the distribution of contour lines.

An indirect relation of cause and effect described for the simple linear correlation between PR3 x θ3 (Table 2), where the areas with the greatest mechanical resistance (PR3) presented the lowest gravimetric soil water content values (θ3), did not coincide with the spatial variability maps. The indirect relation of cause and effect between PR1 x pH1 cannot be confirmed by means of the maps of spatial variability once PR1 presented a pure nugget effect. Then, areas with the greatest soil mechanical resistance (PR2 and PR3) coincided with the areas whose soil pH was highest (pH1, pH2 and pH3).

CONCLUSIONS

All of the soil properties presented moderate to high spatial variability, with the exception of PR1 and θ1, minimum tillage being a system that triggered the heterogenization of the soil at the studied plot level.

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