Original Research Article

INTER-RELATIONSHIPS OF RESISTANCE TO PENETRATION, MOISTURE AND SOIL ORGANIC MATTER WITH IRRIGATED BEAN YIELD

Abstract

The common bean (*Phaseolus vulgaris* L) can be cultivated practically throughout the year in different regions of Brazil, provided there are no water and temperature limitations. This study was carried out in a Quartzarenic Neosol, in the municipality of Cassilândia, state of Mato Grosso do Sul (MS), Brazil, in the 2016/2017 agricultural year. This study aimed to establish the linear and spatial interrelations of the penetration resistance (PR), gravimetric moisture (GM), and organic matter content (OM) with bean grain yield (GY) in the 0.00-0.10 and 0.10-0.20 m soil layers, collected in a mesh of 117 georeferenced points [81 points of the base mesh (6 m spacing among points)] and 36 mesh points with higher density (2 m spacing among points). Data analysis was carried out by statistical and geostatistical techniques that enabled to note that the organic matter content correlates linearly and negatively with penetration resistance, indicating that soil management practices aiming to increase its profile improve its physical conditions and therefore the bean grain development and yield. The gravimetric moisture and soil organic matter content correlate spatially, directly, and linearly with bean grain yield, proving to be the best properties among those surveyed to estimate and increase its agricultural productivity.

Keywords: precision agriculture, geostatistics, soil physical property,irrigation.

INTRODUCTION

The common bean (*Phaseolus vulgaris* L) can be cultivated practically throughout the year in different regions of Brazil, provided there are no water and temperature limitations. Improvements in cultivation practices, coupled with the new cultivar development and the innovative technology adoption, allowed significant increases in grain yields from a national average of 500 kg ha^{-1} in 1970 to over 1000 kg ha^{-1} currently [1]. Considering the 2016/2017 harvest, it is estimated that the total area of beans will increase to 3078 hectares, 8.5% higher than in the previous harvest. The bean national production is expected to be 3285.3 tons, 30.7% higher than the last season [2].

Some soil physical factors are especially important when assessing crop response to a specific management strategy, including soil water content, aeration system, water storage, and mechanical impediments to root development. Thus, knowledge about the soil properties variation can help managers to refining and improving agricultural productivity [3].

On the other hand, management aiming at the maintenance and/or addition of organic matter in the soil is very important, since the benefits are mainly increased erosion resistance and water storage capacity, due to its performance on soil structure, by increasing the aggregates' stability as well as improving soil fertility [4].

In this context, a geostatistical method can be used as a tool to evaluate the spatial variability of soil and plant properties through a simple semivariogram and kriging process to estimate values at different locations. This approach is appropriate to analyze properties whose variability has a certain organization degree expressed by spatial dependence [5].

Since soil physical properties have an important influence on the development of commercial crops and their management, this study sought to establish the linear and spatial relationships of penetration resistance, gravimetric moisture, and organic matter content with bean grain yield in a Quartzarenic Neosol of the state east region of Mato Grosso do Sul (MS), Brazil.

MATERIAL AND METHODS

This study was carried out in the irrigated area of a central pivot, at the vicinity of the 356,381.383 m and 7,893,667.280 m [Universal Transverse Mercator (UTM)] geographic coordinates, from Flor Jardim Farm, municipality of Cassilândia, Mato Grosso do Sul (MS), Brazil (Fig. 1). The average annual rainfall is 1,500 mm and the average temperature is 24.2 °C (Fig. 2). The climatic type is Aw, according to Koeppen classification, characterized as humid tropical with rainy summer season and dry winter season.

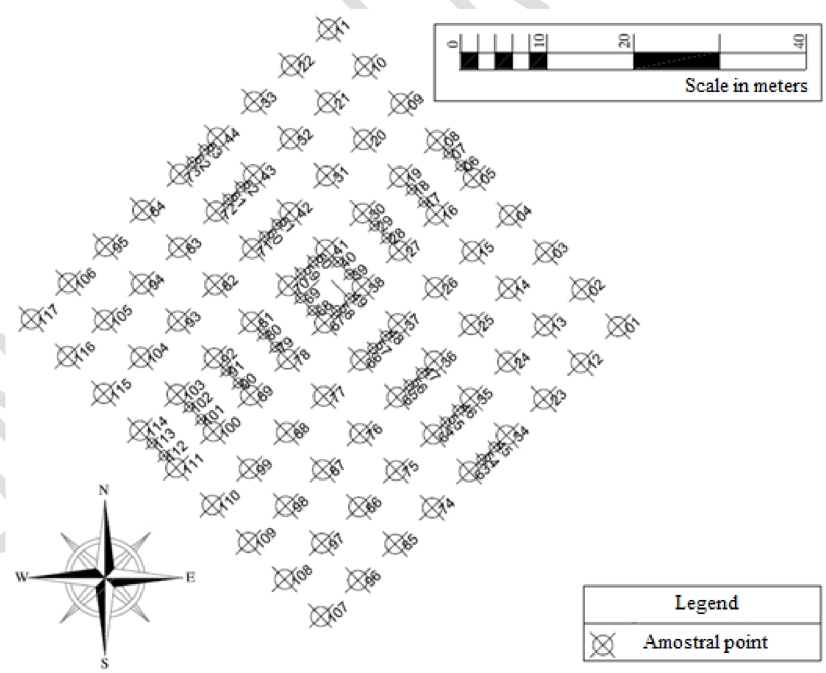

Figure 1. Sample mesh and detailing performed at Flor Jardim Farm, Cassilândia - Mato Grosso do Sul State

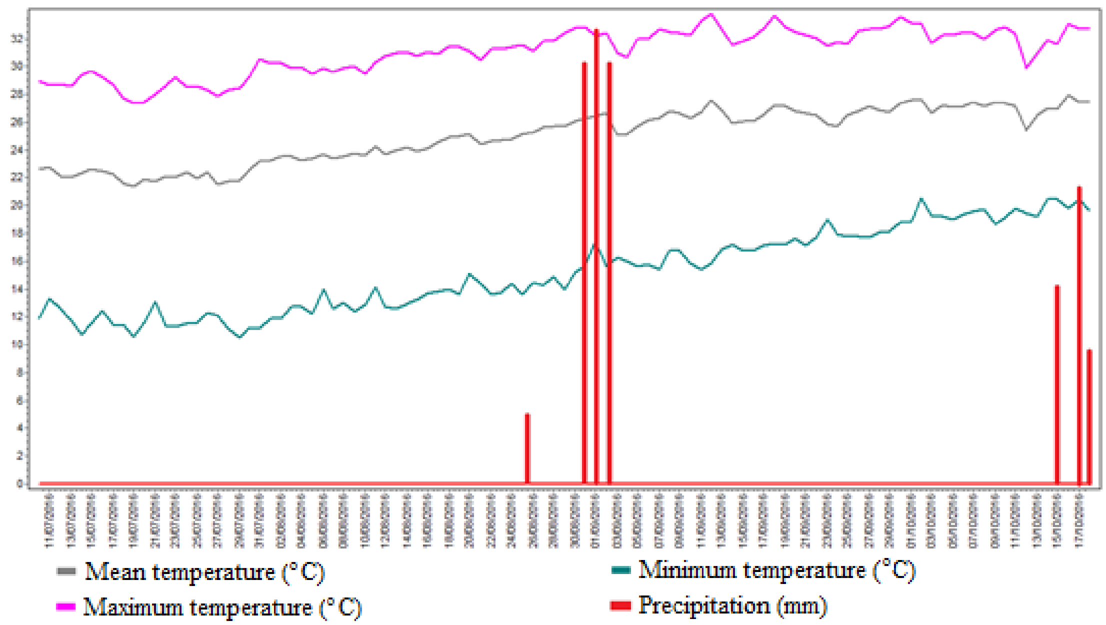

Figure 2. Climatic data of temperatures and precipitations in the experimental area during the bean culture at Flor Jardim Farm, Cassilândia (MS)

The soil in which the experimental meshes were installed was classified according to the Brazilian Soil Classification System. It is an Orthic Quartzarenic Neosol of very sandy texture. Table 1 shows the values of the physical and chemical analyzes.

Table 1. Physical and chemical analyzes of the Quartzarenic Neosol of the area under study

Layer	Composition			Chemical analysis										
m	sand	silt	clay	pH	P	K^{+}	Ca^{+2}	Mg^{+2}	$H^{+}+Al^{+3}$	Al^{+3}	SB	CTC	V%	m%
	……..g kg^{-1}			$CaCl_2$	mg dm^{-3}	..............................$mmol_c$ dm^{-3}							%	%
0 - 0.20	946	11	43	5.4	8	0.2	17	8	13	0	25	38.2	66	0
0.20 - 0.40	932	20	48	5.1	12	0.5	7	2	15	1	9.5	24.5	39	10

In the crop management area, with no-tillage system in irrigated area, only the weed desiccation prior to the common bean plant was applied, with an application of 2.0 kg ha^{-1} of glyphosate herbicide, and the area was prepared on 8 and 9 July 2016. On 10 July 2016, the Elite cultivar bean was sown at 0.45 m spacing among rows, with density of 246,914 plants per hectare. For this procedure, 11 seeds on average were used per meter of sowing. Harvesting was performed after 100 days sowing.

The *x* and *y* directions of the Cartesian coordinate system were defined, and the experimental mesh was staked close to the common bean maturation, that is, in the first ten days of October/2016, spaced 6.0 m apart. Each experimental mesh was consisted of nine transects of 48.0 m x 48.0 m. Therefore, the transects had 6.0 m spacing with 6.0 m x 6.0 m squared sample points, containing 81 points. However, points with smaller spacings than those mentioned were allocated inside the large mesh, with 2.0 m spacing among them (mesh with higher density). The total of sample points in this case was 36, and in the data network it was 117. This sampling type using higher density meshes within a larger mesh was also used in studies by [6] [7].

The soil and plant properties of the common bean were determined and individually collected around each sampling point, which usually consisted of collecting data from the plant positioned in the center and its surrounding areas. The stage of laboratory analysis was carried out from October to December 2016. The representative area of this collection was 3.20 m^2, with four plant rows (1.80 m x 1.80 m). All plants around the sample point were collected.

The bean grain yield (GY) obtained with the transformed values for the standardized conditions of 0.13 kg kg^{-1} moisture, represented in kg ha^{-1}, was evaluated.

The soil physical properties were the mechanical penetration resistance (PR1, PR2, PR3, PR4, RPM), gravimetric moisture (GM1 and GM2), and organic matter content (OM1 and OM2), in which, the number following the attribute refers to the depth as: (a) 1= 0.00 to 0.10-m depth; (b) 2=0.10 to 0.20-m depth; (c) 3=0.20 to 0.30-m depth; (d) 4=0.30 to 0.40-m depth; except MPR, which refers to the mean penetration resistance with 0.00 to 0.40-m depth. A Falker digital penetrometer, PenetroLOG-PLG 1020 model, was used to determine soil penetration resistance, typified to record readings every 5-mm depth and constant penetration velocity with the Mega Pascal (MPa) unit.

For determining GM1 and GM2 (kg kg^{-1}), deformed soil samples were collected with auger pitcher of 0.10-m diameter by 0.20 m height [8]. The OM content was obtained from the organic carbon by the wet-combustion method via colorimetric in accordance with the following expression [9]:

$$OM = C \times 1.724 \times 10 \qquad (1)$$

in which, OM is the organic matter content (g dm^{-3}) and C is the organic carbon content. The soil samples were analyzed in the Physics and Soil Fertility Laboratories of the Federal University of Mato Grosso do Sul, Chapadão do Sul Campus, MS.

For each studied property, the classic descriptive analysis was made using the SAS statistical program, in which the mean, median, minimum, and maximum values, standard deviation, variation coefficient, kurtosis, asymmetry were calculated; and the analysis of data frequency distribution was made. Thus, [10] test at 5% was used to test the normality hypothesis or properties lognormality. By this test, the Statistics tests the null hypothesis, considering the sample coming from a population with normal distribution.

To characterize the structure and the magnitude of the spatial dependence of the soil and plant properties of the bean crop, the semivariogram was adjusted and semivariance was estimated, estimating the theoretical model coefficients for the semivariogram called the nugget effect (C_0), threshold (C_0+C), and the range (A_0). After adjusting the semivariograms, the data were interpolated by kriging to allow the visualization of property spatial distribution patterns in the bean crop by maps. Standard error maps of kriging prediction were generated. These maps refer to the prediction standard deviation for any individual point [11]; they are obtained to provide information about the confidence of the interpolated values in the area under study [12]. Cross-validation is a tool to evaluate alternative models of simple and crossed semivariograms, which will perform kriging and cokriging, respectively. In its analysis, each point inside the spatial domain is removed individually, and its value is estimated as if it did not exist. In this way, a graph of estimated values versus observed values can be constructed for all points.

RESULTS AND DISCUSSION

Table 2 shows the descriptive analysis of the studied properties. In accordance with [13], a property variability can be classified considering the magnitude of its variation coefficient (VC). The variation coefficient classes were determined as low (VC<10%), medium (10%<VC<20%), high (20%<VC<30%), and very high (VC>30%). Therefore, bean grain yield (GY) presented a very high variation coefficient (31.3%). [14] and [5], when analyzing a dystroferric Red Latosol under no-tillage in regular meshes of 117 and 124 sampling points, found high variability for bean grain yield (21.1% and 22.2%, respectively). In this aspect, [7] found different values, mean variability (18.3%), when evaluating bean culture under the same conditions. Also, the PR1 and PR2 together with OM2 presented very high variability, 49.6%; 30.9%; and 42.3%, respectively. The same results with penetration resistance were found by [6], studying the correlation among bean grain yield and physical properties of an Oxisol in Mato Grosso do Sul, finding variations from 58.1% for RP1, and 51.3% for RP2. [4] found high variation (20.9%) for OM2, when studying the productivity interrelations of the ratoon crops of sugarcane with penetration resistance and the soil moisture and organic matter. The PR3, PR4, MPR, and OM1 properties presented high variability (24.0%; 29.7%; 21.0%; and 28.8%, respectively). [6] found a very high variation for PR3 (35.1%). [4] found a mean variation for OM1 (18.5%). The gravimetric moisture (GM1 and GM2) had mean variations (11.3% and 12.2%) equal to the mean variations found by [4], 12.2% and 11.1%, respectively.

The variability rates from mean to high and very high found for most soil properties and bean grain yield can be explained by the fact that the studied soil (Quartzarenic Neosol) is very sandy and poor in nutrients (Table 1), thus increasing the variation coefficient value of soil and bean culture properties.

Table 2. Initial descriptive statistics of bean grain yield and some physical properties of a Quartzarenic Neosol of Flor Jardim Farm (Cassilândia, MS)

Properties (a)	Mean	Mínimum	Máximum	Standard deviation	Variation (%)	Kurtosis	Asymmetry	Pr<w	FD (b)
GY	1,088.90	328.20	1,991.70	340.50	31.3	-0.193	0.197	0.6540	NO
PR1	0.39	0.00	0.91	0.20	49.6	-0.104	0.359	0.1120	NO
PR2	2.97	0.26	5.27	0.92	30.9	0.425	-0.066	0.6430	NO
PR3	5.52	1.40	9.10	1.32	24.0	0.358	-0.206	0.6880	NO
PR4	5.58	1.66	8.51	1.66	29.7	-0.624	-0.477	0.0020	IN
MPR	1.81	0.92	2.84	0.38	21.0	-0.505	0.004	0.4320	NO
GM1	0.06	0.03	0.08	0.01	12.2	2.977	0.267	0.0001	IN
GM2	0.07	0.05	0.11	0.01	11.3	3.506	1.061	0.0001	IN
OM1	4.90	1.90	8.70	1.40	28.8	-0.275	0.297	0.1680	NO
OM2	4.20	0.00	8.80	1.79	42.3	-0.047	0.176	0.6910	NO

(a)GY=grain yield, (kg ha^{-1}), (kg ha^{-1}); PR1=Mechanical penetration resistance of 0 to 0.10 m depth (MPa); PR2=Mechanical penetration resistance of 0.10 to 0.20 m depth, (MPa); PR3=Mechanical penetration resistance of 0.20 to 0.30 m depth, (MPa); PR4=Mechanical penetration resistance of 0.30 to 0.40 m depth, (MPa); MPR=Mean mechanical penetration resistance from 0 to 0.40 m depth, (MPa); GM1=Soil gravimetric moisture of 0.00 to 0.10 m depth, (kg kg^{-1}), GM2=Soil gravimetric moisture of 0.10 to 0.20 m depth (kg kg^{-1}); OM1=Soil organic matter content of 0 to 0.10 m depth (g dm^{-3}); OM2=Soil organic matter content of 0.10 to 0.20 m depth (g dm^{-3}); (b)FD=Frequency distribution: NO = normal type; IN = indeterminate type.

The studied properties showed some results as: (a) positive asymmetry coefficients for GY, PR1, MPR, GM1, GM2, OM1, and OM2, which were respectively 0.197; 0.359, 0.004; 0.267; 1.061; 0.297; and 0.176; (b) negative asymmetry coefficients for PR2, PR3, and PR4 which were -0.066; -0.206; and -0.477 respectively; (c) positive kurtosis coefficients for PR2, PR3, GM1, and GM2 which were 0.425; 0.358; 2.977; and 3.506, respectively. However, regardless of such coefficients, the GY, PR1, PR2, PR3, MPR, OM1, and OM2 properties were significant at 5% probability by the normality test of [10], since their respective probabilities were of 0.6540; 0.1120; 0.6430; 0.6880; 0.4320; 0.1680; and 0.6910. Similar results for GY and PR1 were verified by [4], in whose studies these properties were normal with respective probabilities of 0.180 and 0.664; in the present work, the GM1 and GM2 had frequency distributions of the indeterminate type, differing from the works of [4], [14], [6] and [15], who found frequency distributions of the normal and tending to normal types for GM.

In the study of the Pearson linear correlations of GY with soil physical properties (Fig. 3), the GY established positive and highly significant correlations at the 1% probability level with GM1 (r=0.255**), GM2 (r=0.281**), and OM1 (r=0.278**), in accordance with those of [16] and [4]. However, it is explained that the GY x GM1, GY x GM2, and GY x OM1 correlations were positive, leading to conclude that there was a benefit due to the increased water availability (sandy soil) and, therefore, a probable improvement in the nutrient absorption of the soil solution, and nutrient was released by the OM1 increase. The above-mentioned authors found that the PR2 x OM1 and PR3 x OM2 correlations showed negative and significant effects, indicating that the increase of soil OM reduces PR.

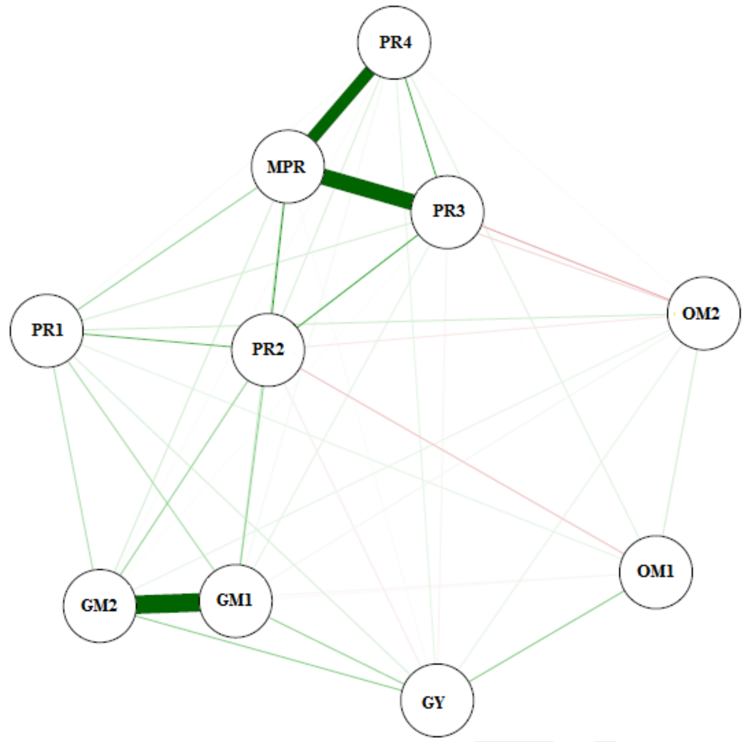

Figure 3. Correlation network of bean grain yield and some physical properties of a Quartzarenic Neosol of Flor Jardim Farm, Cassilândia - MS

In the context of the simple linear regressions (Fig. 4), exponential equations (GY x OM1, GY x GM2, and GY x PR1) and linear equation (GY x GM1) were modeled. It was observed a positive relationship among the regressions, indicating that an increase in PR1, OM1, GM1, and GM2 will affect positively on the GY (Fig, 4a, 4b, 4c), because increase in PR1 affects directly on soil microporosity and, therefore, on the improvement of water availability, allowing advance in the nutrient absorption of the soil solution. Thus, for the maximum soil compaction condition observed in the present study [PR1=0.91 MPa (Table 1)], the estimated GY basis on the equation $GY=945.25.e^{0.2252.PR1}$ (Fig. 4b) was 1160.24 kg ha^{-1}. Similarly, considering the maximum soil GM1 content of 0.08 kg kg^{-1}, the GY=12,252.GM1+378.92 equation (Fig. 4c) estimated a GY of 1359.08 kg ha^{-1}; for the soil GM2 equals 0.11 kg kg^{-1}, the equation $GY=434.61.e^{12.122}$ (Fig. 4d) estimated a GY of 1648.91

kg ha^{-1}. The GY x OM1 regression indicated that the variation of OM1 contents from 1.9 to 8.7 g dm^{-3} in the GY=720.65.e$^{0.0735.OM1}$ equation (Fig. 4a) will involve GY variation from 828.65 to 1365.95 kg ha^{-1}, whereas an estimated GY of 1063.91 kg ha^{-1} will occur for the OM1 mean content (5.3 g dm^{-3}). However, such equation is intended for yield estimates only for this data amplitude, approaching to [4] equations, who also found a positive linear relation among these variables. These equations have relevance for soil management and conservation, since OM is influencing its chemical, physical, and biological properties.

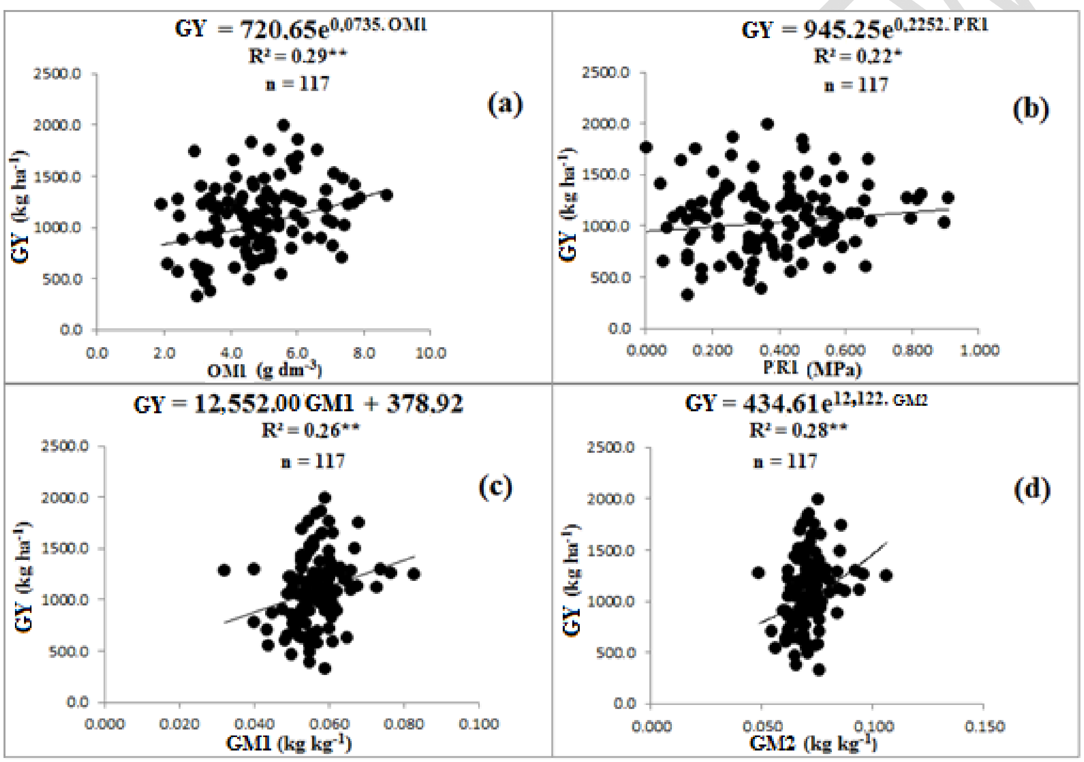

Figure 4. Regression equations of bean grain yield (GY) in relation to: (a) organic matter content (OM1); (b) penetration resistance (PR1); (c) gravimetric moisture (GM1); and (d) gravimetric moisture (GM2) of a Quartzarenic Neosol of Flor Jardim Farm, from Cassilândia - MS

In relation to the inverse behavior regressions, the linear increase in the OM2 contents substantially improved the soil physical condition because decreased its compaction when evaluated by PR2, and the reverse was perfectly true (Fig. 5). These observations are in accordance with those cited by [4]. Thus, in the present study, when OM2 ranged from 0.0 to 8.8 g dm^{-3}, PR1 ranged from 2.981 to 2.590 MPa (Fig. 5).

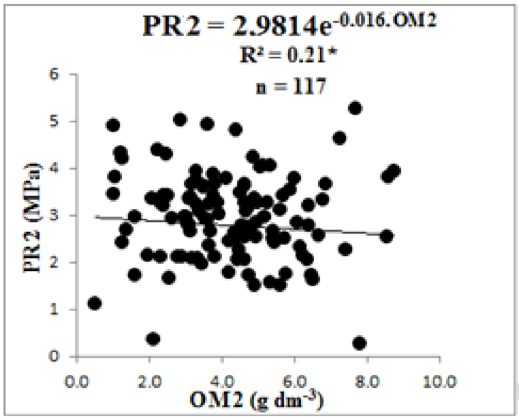

Figure 5. Regression equation of penetration resistance (PR2) due to the organic matter content (OM2) of a Quartzarenic Neosol of Flor Jardim Farm, Cassilândia - MS

The geostatistical analysis (Table 3) showed that there was spatial dependence for the semivariograms of the GY, PR4, and GM1 properties, adjusted to the spherical model, while PR2 and GM2 were adjusted to the exponential model, in accordance with [7], who say that spherical and exponential models present themselves as the most common theoretical of soil and plant properties. But the MPR and OM1 properties adjusted to the Gaussian model, as well as the cross-semivariograms of bean grain yield, depending on the gravimetric moisture (GM2) and organic matter (OM1). [4] also adjusted the yield of sugarcane to the gravimetric moisture by the Gaussian model, but [14], studying the bean productivity depending on the gravimetric moisture, adjusted by the spherical model. The remaining (PR1, PR3, and OM2) presented pure nugget effect.

The ranges values for the simple semivariograms found by soil and plant properties varied in ascending order of 9.9 m (PR2); 10.0 m (PR4); 11.0 m (OM1; 17.0 m (MPR); 51.0 m (GY); 60.0 m (GM1); and 70.0 m (GM2). Therefore, considering the way this research was carried out using the same properties, it is suggested that the ranges values to be used should not be less than 9.9 m, because they represent the distance within which the values of certain property are equal to each other (Table 3).

Table 3. Estimated parameters for the simple and crossed semivariogram of the variables

Properties [(a)]	Model [(b)]	C_o	C_o+C	A_o (m)	r^2	SSR [(c)]	SDE [(d)]		Cross - validation		
							%	Class	a	b	r
γ(h) simple - attribute of the plant											
GY	sph	$3.82x10^{4}$	$1.58x10^{5}$	51.0	0.866	$3.13x10^{9}$	75.8	High	91.06	0.917	0.651
γ(h) simple - attribute of soil											
PR1	epp	$3.66x10^{-2}$	$3.66x10^{-2}$	-	-	-	-	-	-	-	-
PR2	exp	0.121	0.863	9.9	0.217	$1.39x10^{-1}$	86.0	High	0.96	0.677	0.280
PR3	epp	1.765	1.765	-	-	-	-	-	-	-	-
PR4	sph	1.870	2.600	10.0	0.092	$1.70x10^{1}$	28.1	Medium	0.01	0.992	0.190
MPR	gau	$1.2x10^{-1}$	$1.5x10^{-1}$	17.0	0.356	$2.19x10^{-3}$	20.0	Weak	0.64	0.646	0.170
GM1	sph	$3.8x10^{-5}$	$7.6x10^{-5}$	60.0	0.940	$8.54x10^{-11}$	49.7	Medium	0.00	0.933	0.449
GM2	exp	$5.2x10^{-5}$	$9.7x10^{-5}$	70.0	0.947	$1.01x10^{-10}$	46.4	Medium	0.01	0.889	0.390
OM1	gau	1.100	2.000	11.0	0.582	$4.81x10^{-1}$	45.0	Medium	0.70	1.490	0.335
OM2	epp	3.130	3.130	-	-	-	-	-	-	-	-
γ(h) crossed [plant = f(soil)]											
GY=f(GM2)	gau	0.200	1.580	53.0	0.863	$3.86x10^{-1}$	87.2	High	258.87	0.895	0.422
GY=f(OM1)	gau	1.62x10[illegible]	2.88x10[illegible]	58.0	0.930	6.29x10[illegible]	94.4	High	285.47	0.739	0.387

(a)GY=grain yield, (kg ha^{-1}), PR1=Mechanical penetration resistance from 0 to 0.10-m depth (MPa); PR2=Mechanical penetration resistance from 0.10 to 0.20-m depth, (MPa); PR3=Mechanical penetration resistance from 0.20 to 0.30-m depth, (MPa); PR4=Mechanical penetration resistance of 0.30 to 0.40-m depth, (MPa); MPR=Mean mechanical penetration resistance from 0 to 0.40-m depth, (MPa); GM1= Soil gravimetric moisture of 0.00 to 0.10-m depth, (kg kg^{-1}); GM2=Soil gravimetric moisture from 0.10 to 0.20-m depth, (kg kg^{-1}); OM1=Soil organic matter content from 0 to 0.10-m depth, (g dm^{-3}); OM2=Soil organic matter content from 0.10 to 0.20-m depth, (g dm^{-3}). GY=f(GM)=bean grain yield due to gravimetric moisture; GY=f(OM1)=bean grain yield due to soil organic matter; (b)Sph=Spherical); Gau=Gaussian; (c)RSS=residual sum of squares; (d)SDE=spatial dependency evaluator.

As regards the performance of the simple semivariograms, the decreasing relation of them, analyzed by the magnitude of the spatial determination coefficient (r2), was the following: (a) GM2 (0.947); (b) GM1 (0.940); (c) GY (0.866); (d) OM1 (0.582); (e) MPR (0.356; (f) PR2 (0.217); and (g) PR4 (0.092). In relation to the spatial dependence evaluator (SDE), the relationship was: (a) PR2 (86.0%); (b) GY (75.8%); (c) GM1 (49.7%); (d) GM2

(46.4%); (e) OM1 (45.0%; (f) PR4 (28.1%); and (g) MPR (20.0%). Thus, high magnitudes of both spatial dependence coefficient (r2) and spatial dependence evaluator (SDE) were found for GY, GM1 and GM2. On the other hand, the GY presented strongly both the spatial determination coefficient (r2=0.866) and the spatial dependence evaluator (SDE=75.8%). Thus, these data were basically in the same value magnitudes as those of [17] and [14], which were, respectively, r2=0.869 and SDE=73.1%; and r2=0.766 and SDE=74.1%.

The cross-semivariogram between GY and GM2, with a Gaussian model, had 53.0-m range and strong SDE, showing that 87.2% spatial variability of GY was explained by the GM2 spatial variability (Table 3, Fig. 7a, 7b). Thus, it was observed that where the highest values of GM2 occurred (Fig. 6d), the highest values of GY were mapped (Fig. 6b), and the reverse was true, about the surveyed area, at the sites, in which GM2 varies from 0.060 to 0.073 kg kg^{-1}, the expected GY will be from 354.0 to 1430.0 Kg ha^{-1}, confirming the GM2 great influence on the bean grain yield in Quartzarenic Neosol (with 93.2% sand composition), mainly in a region where water deficits are common, as the eastern region of Mato Grosso do Sul State.

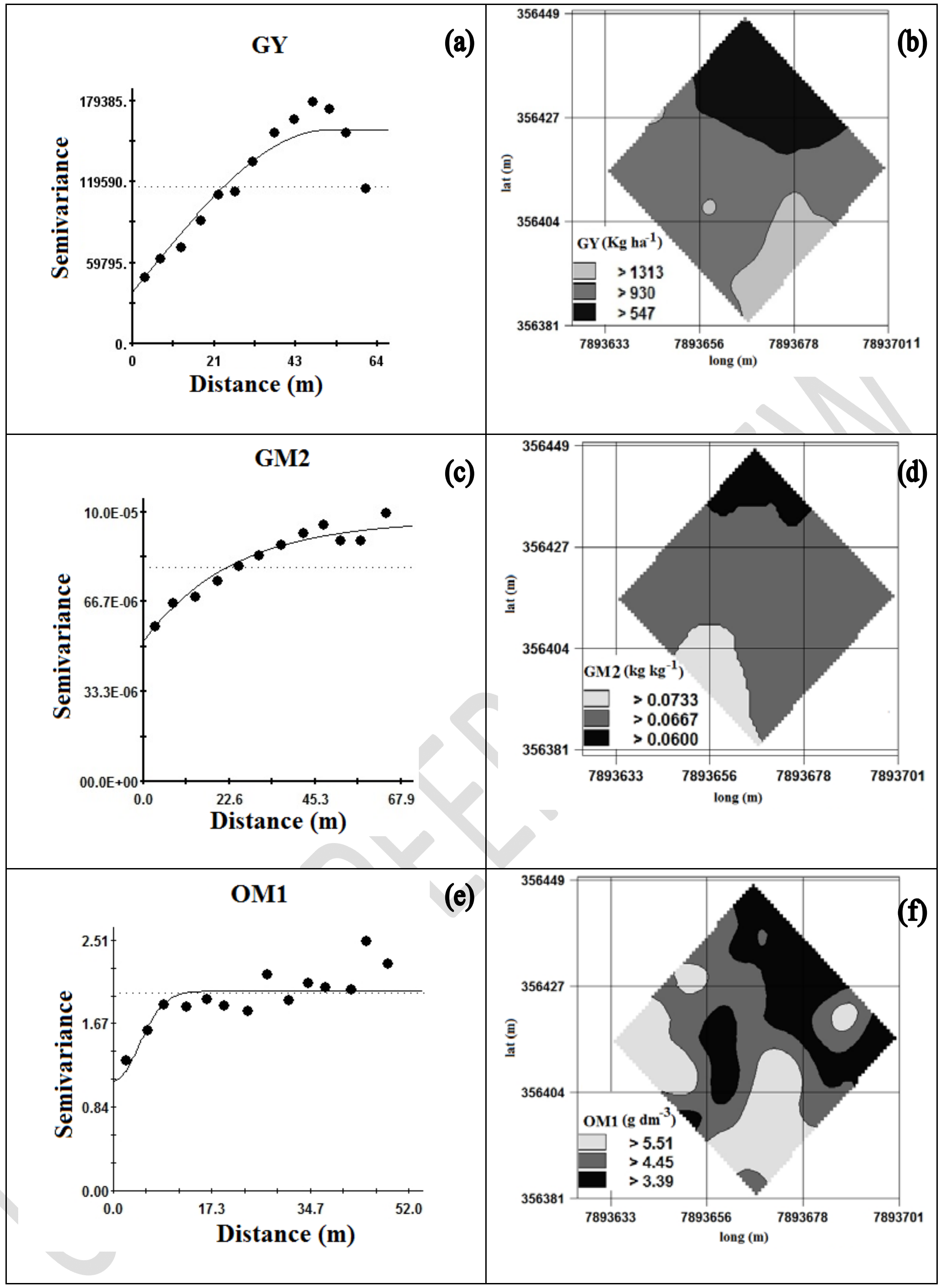

Figure 6. Simple semivariograms and kriging maps of bean grain yield properties (kg ha^{-1}), gravimetric moisture (kg kg^{-1}), and organic matter content (g dm^{-3}) of a Quartzarenic Neosol of Flor Jardim Farm, Cassilândia - MS

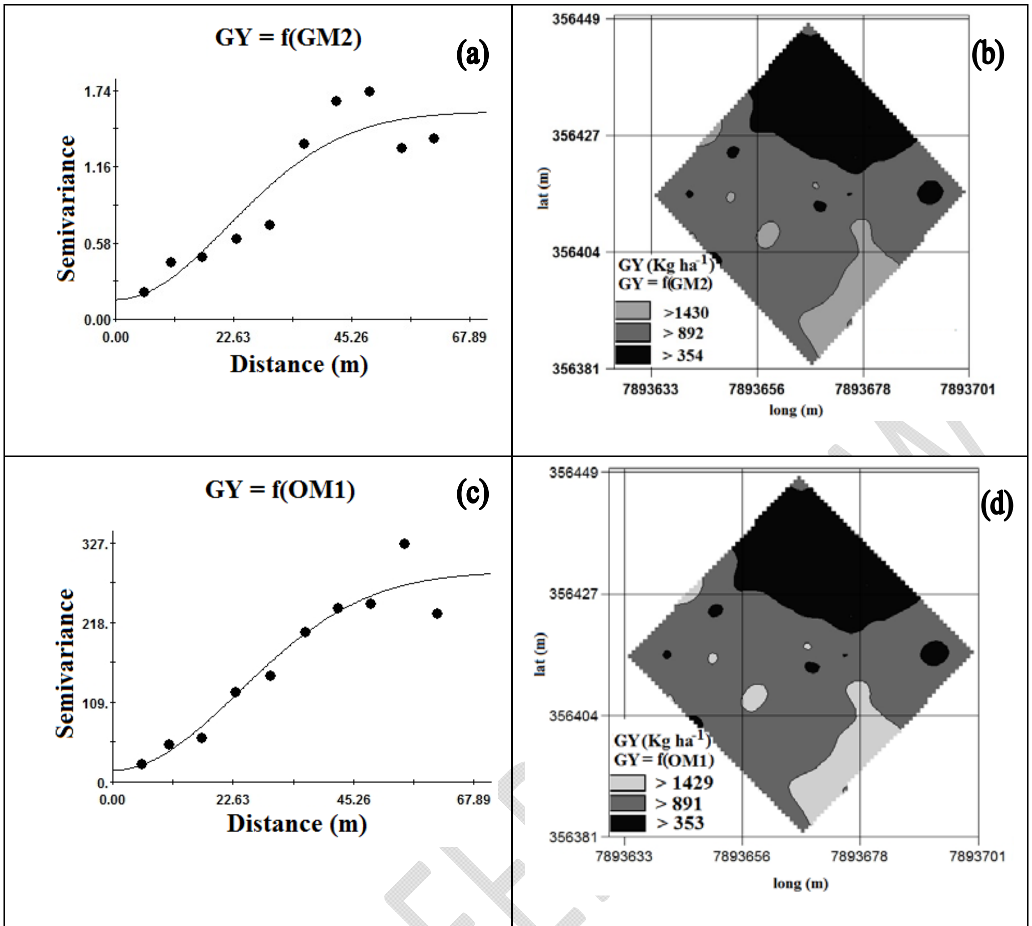

Figure 7. Crossed semivariograms and cokriging maps of bean grain yield (kg ha^{-1}) due to the gravimetric moisture (GM2) and organic matter content (OM1) of a Quartzarenic Neosol from Fazenda Flor Jardim, Cassilândia - MS

In addition, the cross-semivariogram with Gaussian model and the cokriging map of GY depending on the OM1 (Table 3, Fig. 7c, 7d) showed that the OM1 spatial variability explained 94.4% of the GY spatial variability (4.45-5.51 g dm^{-3}), so that, the sites in which the highest OM1 values occurred (4.45-5.51 g dm^{-3}) were precisely those in which GY had the highest values (891.0-1,429.0 Kg ha^{-1}), whereas the places where GY presented the lowest values (353.0-891.0 kg ha^{-1}), OM1 had the lowest values (3.39-4.45 g dm^{-3}). Thus, it was observed that GY has high spatial dependence from OM1, suggesting the importance of agricultural practices aiming at the elevation of nutrient content in soil, once their benefits to bean grain yield were clear both in the physical improvement (aggregation and water availability) and fertility [4].

When analyzing the map of yield spatial variability, it was possible to realize that the southern and southeastern regions of that area presented the crop highest yields. The yield lowest values were observed in the northern region and also in the northeast part of the area. The observation of a yield map (Fig. 3a), together with the observation of other map types, such as those of soil properties, can contribute to find reasons for the yield variability occurrence, especially in the case of low yields, which will enable the fault correction, allowing that these problems can be minimize in the next harvest. In this way, the farmer can take advantage of the historical information from the previous mapping area to make the necessary decisions for the crop good progress, identifying the regions with greater or lesser need for intervention, either in the soil or in the crop [18].

The classified Gravimetric Moisture showed that the southern and southeastern regions of the area showed the crop highest moisture content. The yield lowest values were observed in the northern region and in the northeast part of the area, characteristics equal to those of yield.

The classified organic matter showed that the south, east, and southeast of the area had the yield highest values. The yield lowest values were observed in the northern region and in the northeast part of the area, characteristics similar to those of yield.

Table 3 shows the cross-validation parameters for krigings of bean grain yield and soil properties. Their decreasing ratio, analyzed by the correlation coefficient magnitude (r), was calculated as follows: (a) GY (0.651); (b) GM1 (0.449); (c) GM2 (0.390); (d) OM1 (0.335); (e) PR2 (0.280); (f) PR4 (0.190; and (g)) MPR (0.170). Thus, the four best cross-validations were established for the GY, GM1, GM2, and OM1 properties, whose correlation coefficients ranged from 0.651 to 0.335. On the other hand, the correlation values for the cokriging were

0.422 for GY=f(GM2) and 0.387 for GY=f(OM1). The cross-validation make the measurement of the interpolated values confidence, in which it was possible to observe that the biggest errors for all the variables under study are in the area border; and it was observed that the smaller standard errors are in the places closest to the sampling points. In this way, it is observed that the maps were satisfactorily estimated (Fig. 6b, 6d, 6f, 7b. and 7d), because the errors were relatively low in relation to the variations presented by the studied properties (Table 2).

Nevertheless, considering the spatial and soil management, it was possible to verify that both the water content and the soil organic matter showed to be good indicators of bean grain yield.

CONCLUSION

The organic matter content correlates linearly and negatively with the penetration resistance, indicating that soil management that aims to increase its profile improves its physical conditions and, consequently, the development and the bean grain yield.

Gravimetric moisture and organic matter content of the soil correlate spatially, directly, and linearly with bean grain yield, showing that they are the best properties among the surveyed ones to estimate and increase its agricultural productivity.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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