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Full Length Research Paper

Crambe (*Crambe abyssinica* Hochst) yield as affected by soil physical properties: Linear and spatial correlations

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The growing concern about alternative energy sources enhances the interest for optimizing soil physical conditions to improve biomass production for biofuel. Studies involving linear correlation or geostatistics have been conducted to explain the dependence among soil physical properties and crops yield, however, limited studies have been carried out on oil crops. A field study was carried out on an Oxisol in Brazil to investigate the influence of soil physical properties on crambe (*Crambe abyssinica* Hochst) yield and linear and spatial behavior of crambe yield as correlated to soil physical properties. Undisturbed soil samples were collected from soil depths, 0 to 0.1, 0.1 to 0.2 and 0.2 to 0.3 m using core samplers to determine bulk density and gravimetric moisture content. Soil resistance to penetration was verified in a depth of 0 to 0.3 m and crambe yield was determined in plots of 4 m². The linear relation among the variables in 30 random spots was analyzed and then sampling was carried in 30 geo-referenced spots, in a regular grid in order to verify spatial correlation among the variables using the cross-semivariogram. The variables showed low linear correlation. Crambe yield was spatially correlated with soil resistance to penetration in the 0.1 to 0.2 m depth. Correlation between soil physical properties and crambe yield was verified by spatial and linear analyses.

Key words: Geostatistics, soil physical properties, crambe yield, cross-semivariogram.

INTRODUCTION

Crambe (*Crambe abyssinica* Hochst) has been used as an alternative for biofuel production, instead of sugar, soybean or maize, because this crop does not demand high soil fertility and is resistant to drought and frost. Some researchers, like Jasper et al. (2010) showed that crambe culture has high sustainability in the agricultural system. Although crambe culture is used in Brazil for biofuel production, it is perfectly adaptable to crop rotation systems, thereby becoming an important option as an intercalary crop in winter and summer due to the potential for industrial production of biofuel and high oil content (Toebe et al., 2010).

According to Abu and Malgwi (2011), the association between the variability of soil physical properties is one of the important steps for making decisions about soil management, therefore Mzuku et al. (2005) reported that crop yield is influenced by soil characteristics, then, variations in soil properties imply variations in yield patterns.

Correlation between soil physical properties and crop yield, especially for soybean and corn, has been demonstrated (Lima et al., 2009; Cavallini et al., 2010; Schaffrath et al., 2008; Santos et al., 2006), but few articles focused on linear or spatial correlation between

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soil physical properties with crambe yield. According to Pringle and Lark (2007), there is a linear relationship between soil strength and crop yield, and this correlation depends on spatial location.

Previous studies shows that only linear analysis of the behavior between soil properties may not be enough to explain crops yield, since it does not take into account the spatial distribution of data (Martins et al., 2009). Studies involving spatial variability are becoming more common and are used to solve central questions in a lot of areas such as agronomy (Druck et al., 2004).

The objectives of this study were to verify the existence of linear and spatial correlation between bulk density, gravimetric moisture, soil resistance to penetration and crambe yield, and to show spatial distribution maps concerning these properties.

MATERIALS AND METHODS

The experiment was carried out at the Experimental Farm of Faculdade Assis Gurgacz, in Cascavel, State of Paraná, Brazil in an area of 50 × 60 m. The area is located on 24°62'S latitude and 72°39'W longitude, and 760 m altitude. The soil is classified as an Oxisol, with clayey texture (600 g kg^{-1} clay; 320 g kg^{-1} silt, and 80g kg^{-1} sand), basalt substrate and low ondulating relief (Embrapa, 2006). The climate of the region is mild mesothermal and super humid; climactic type *Cfa* according to the Köeppen-Geiger climate classification system.

Undisturbed soil samples were collected from soil depths, 0 to 0.1, 0.1 to 0.2 and 0.2 to 0.3 m from each sampling spot using core samplers of known volume for the laboratory determination of bulk density – ρ_b (Mg m^{-3}) and gravimetric moisture content – θ_g (%). Samples were saturated in water baths for 48 h and oven-dried at 105°C for 48 h (Embrapa, 1997). Soil resistance to penetration – Srp (MPa) was determined using a Falker PenetroLOG penetrometer, SoloStar model, to a depth of 0.3 m. Five replications were used in each sampling spots. The cone index was calculated for the layers, 0 to 0.1, 0.1 to 0.2 and 0.2 to 0.3 m. Crambe yield (Cy) was measured by harvesting plants in an area 4 m², and moisture was corrected to 13%. Yield values were later transformed to Mg ha^{-1}.

The study was carried out in two phases. In the first one, the variables were studied using 30 spots randomly spread along the experimental area, and the existence of a correlation between the variables by linear regression was tested with the R software. In phase two, 30 spots were geo-referenced in a regular grid, where the same data variables (θ_g, ρ_b, Srp and Cy) were collected in order to verify the existence of a spatial dependence between the samples. The 30 random spots were also used in the geo-statistical analysis to improve the mapping. The GeoR pack of the R software was used to generate the cross-semivariogram as follows:

$$\gamma_{1,2}(h)=\frac{1}{2N(h)}\sum_{i=1}^{N(h)}\{[Z_1(x+h)-Z_1(x)][Z_2(x+h)-Z_2(x)]\}$$

In the equation, N(h) is the number of observations separated by a distance h and $\gamma_{1,2}$ is the cross-semi-variance among Z_1, Z_2 variables.

In order to know how samples of the variables were spatial dependent, we calculated the degree of spatial dependence (DSD), according to Cambardella et al. (1994):

$$DSD=\frac{C}{C_0+C}\times 100$$

where, DSD is the degree of spatial dependence, C is the sill and C_0 is the nugget. If DSD < 25%, there is a weak spatial dependence among samples, if 25% ≤ DSD ≤ 75%, the spatial dependence is moderate and if DSD > 75% there is a strong spatial dependence. Finally, surface maps were built for the variables that showed a spatial dependence among samples by using the R software.

RESULTS AND DISCUSSION

The descriptive statistic of data showed that the variability was low to gravimetric moisture and bulk density. Table 1 shows the results of descriptive statistics of random data. The results for the analysis of linear correlation showed that soil bulk density and gravimetric moisture were linearly correlated in the first layer (r = -0.27) and in the second layer (r = -0.63). The low correlation among variables in the first layer may be attributed to the fact that this is the place where constant mobilization happens by the planter furrow openers, which induce alterations on the structural state of this layer. Although in the 0.1 to 0.2 m layer, a large correlation occurred because in this layer, imposed deformations are concentrated by the tyres of agricultural machinery and implements, thereby inducing a negative alteration in the soil structural state. Secco et al. (2009) found similar results. The other variables in all the three depths and Cy were not correlated among each other.

All the variables showed spatial dependence among samples (Table 2). Only Srp_1 and Srp_3 showed strong spatial dependence; θ_{g1}, ρ_{b2} and Srp_2 were moderately spatially dependent. Bulk density in the first and third layer were weakly spatially dependent like the study of Dongli et al. (2010) in China. In the soil depth 0 to 0.1 m, all variables that presented a structure of spatial dependence have a dependence that follows the spherical model, ranging from 11.6 to 30 m. Cy and ρ_b showed a structure of spatial dependence with a 30 m range. Martins et al. (2009) also verified a 30 m range for bulk density.

Using the cross-semivariogram, ρ_{b1} and Srp_1 were spatially correlated in a range of 35 m, and θ_{g1} and Srp_1 until 40 m range. These results are confirmed by those of Souza et al. (2006). As we can see from the negative cross-semivariance, gravimetric moisture and soil resistance to penetration are inversely correlated, and soil resistance to penetration is directly correlated with bulk density in the first soil layer (0 to 0.1 m) (Figure 1).

Figure 2 shows the surface maps for the variables that brought a structure of spatial dependence between the samples in depths 0 to 0.1m. Variables θ_{g1} and Srp_1 were spatially correlated. In the spots where density was low in the depth 0 to 0.1m, Srp was also low. ρ_{b1} and Srp_1 were spatially correlated in a range of 55 m, and θ_{g1} and Srp_1

Table 1. Descriptive statistic from random data.

Variable	Minimum	Mean	Maximun	St. Dev.	C.V (%)
θ_{g1}	25.11	37.46	40.93	2.74	7.32
θ_{g2}	34.04	38.66	43.56	2.35	6.08
θ_{g3}	37.87	42.65	57.44	3.37	7.91
ρ_{b1}	0.81	1.07	1.22	0.07	6.99
ρ_{b2}	0.92	1.07	1.17	0.05	5.04
ρ_{b3}	0.78	1.01	1.1	0.06	6.27
Srp_1	0.97	1.38	1.99	0.22	15.52
Srp_2	1.66	2.13	2.6	0.24	11.23
Srp_3	1.28	1.71	2.19	0.23	13.55
Cy	0.22	0.42	0.57	0.09	22.68

θ_{g1}, Gravimetric moisture content in 0 to 0.1 m layer; θ_{g2}, gravimetric moisture content in 0.1 to 0.2 m layer; θ_{g3}, gravimetric moisture content in 0.2 to 0.3 m layer; ρ_{b1}, bulk density in 0 to 0.1 m layer; ρ_{b2}, bulk density in 0.1 to 0.2 m layer; ρ_{b3}, bulk density in 0.2 to 0.3 m layer; Srp_1, cone index in 0 to 0.1 m layer; Srp_2, cone index in 0.1 to 0.2 m layer; Srp_3, cone index in 0.2 to 0.3 m layer; Cy, Crambe yield.

Table 2. Spatial analyses from regular grid.

Variable	Model	*a*	C_0	C	DSD (%)	Spatial class
θ_{g1}	Spherical	11.6000	18.4500	45.0460	70.9431	M
θ_{g2}	Gaussian	26.6000	47.6200	0.0001	0.00021	W
θ_{g3}	Exponential	21.1500	51.9900	0.0001	0.00019	W
ρ_{b1}	Spherical	30.0000	0.0035	0.0001	2.77778	W
ρ_{b2}	Spherical	30.0000	0.0047	0.0030	38.961	M
ρ_{b3}	Spherical	30.0000	0.0066	0.0001	1.49254	W
Srp_1	Spherical	30.0000	0.0299	0.1200	80.0534	S
Srp_2	Gaussian	30.0100	0.0666	0.1300	66.1241	M
Srp_3	Exponential	30.0000	0.0270	0.1565	85.2861	S
Cy	Exponential	30.0010	0.0324	0.0039	10.7438	W

a, Range; C_0, nugget; C, sill; DSD, degree of spatial dependence; S = strong spatial dependence; M = moderate spatial dependence; W = weak spatial dependence; θ_{g1}, gravimetric moisture content in 0 to 0.1 m layer; θ_{g2}, gravimetric moisture content in 0.1 to 0.2 m layer; θ_{g3}, gravimetric moisture content in 0.2 to 0.3 m layer; ρ_{b1}, bulk density in 0 to 0.1 m layer; ρ_{b2}, bulk density in 0.1 to 0.2 m layer; ρ_{b3}, bulk density in 0.2 to 0.3 m layer; Srp_1, cone index in 0 to 0.1 m layer; Srp_2, cone index in 0.1 to 0.2 m layer; Srp_3, cone index in 0.2 to 0.3 m layer; Cy, Crambe yield.

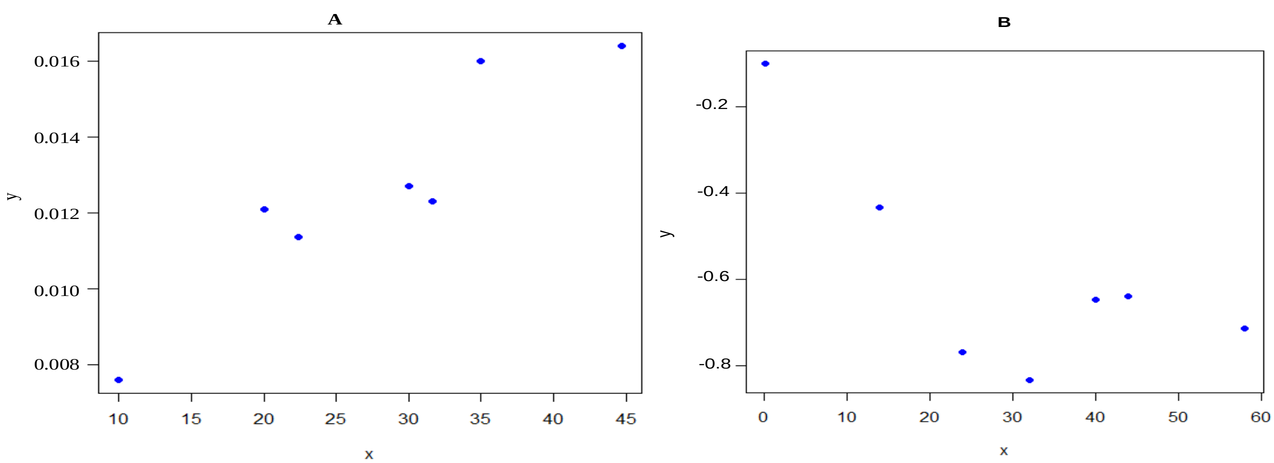

Figure 1. Cross-semivariograms of ρb1 and Srp1 (A) and θg1 and Srp1 (B).And the sizes of the figures A and B are different.

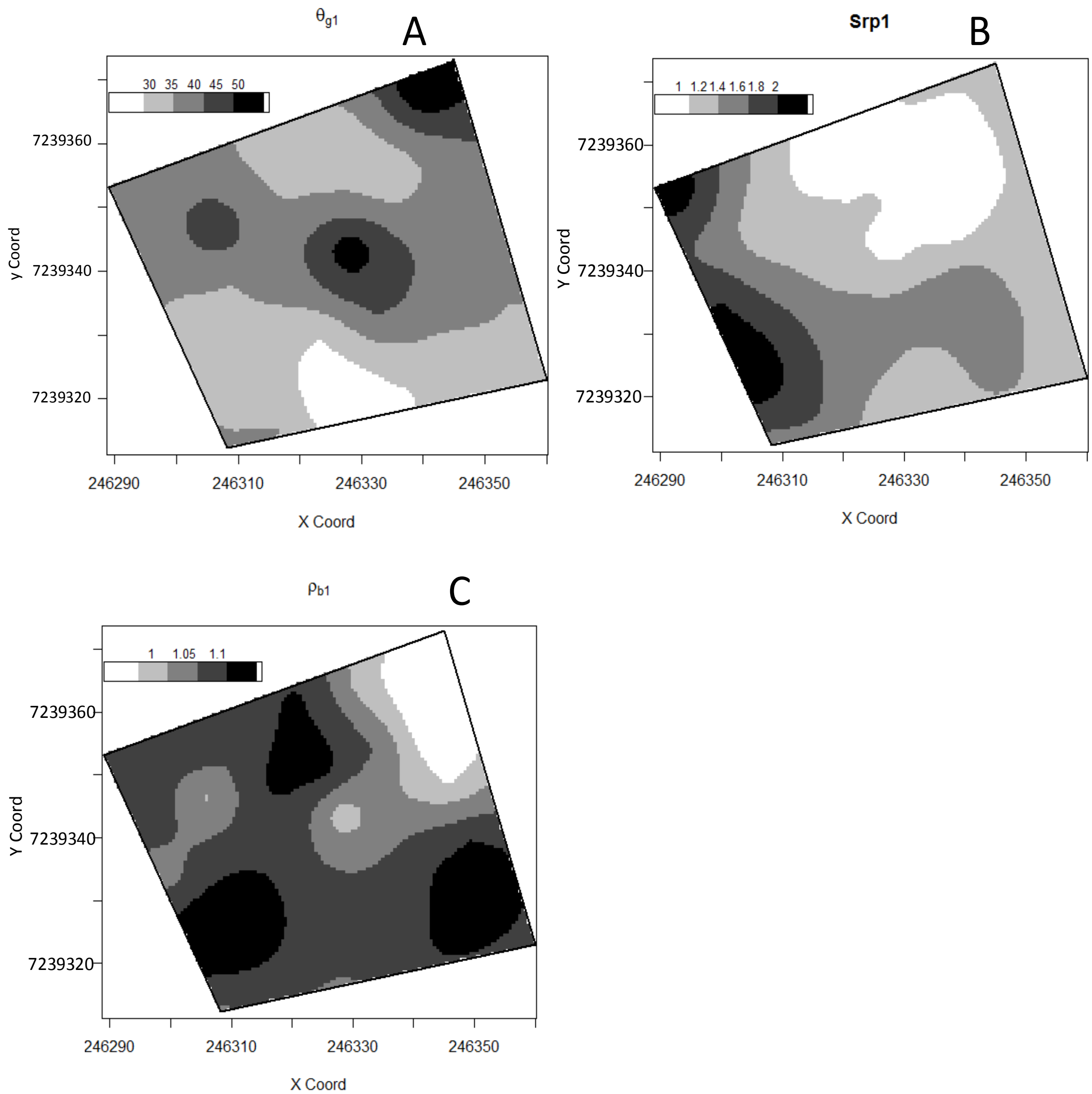

Figure 2. Surface maps of θg1: gravimetric moisture content in 0 to 0.1 m layer (A), Srp1: Cone index in 0 to 0.1 m layer (B), ρb1: bulk density in 0 to 0.1 m layer (C).

in a range of 55 m. As shown earlier, variables such as the gravimetric moisture and soil resistance to penetration were inversely correlated and soil resistance to penetration was also inversely correlated with crambe yield in the second layer (0 to 0.2 m).

Figure 3 shows the surface maps of variables θ_{g2}, Srp_2 and Cy. From Figure 3, Srp_2 was spatially influenced by θ_{g2} and grain yield may be estimated using the gravimetric moisture. Furthermore, Cy is spatially correlated with Srp_2. In a few places, although Srp is high, Cy was also high. A possible explanation is the fact that Srp values in this area do not limit root growth. Therefore, evidence about a small soil compaction is important. This will increase the number of soil micro pores, resulting in elevated water retention in the soil and water availability to the plants.

Conclusion

Correlation between soil physical properties and crambe yield was verified by spatial and linear analyses. In depth 0 to 0.1 m, soil resistance to penetration was spatially influenced by bulk density in a direct manner and by

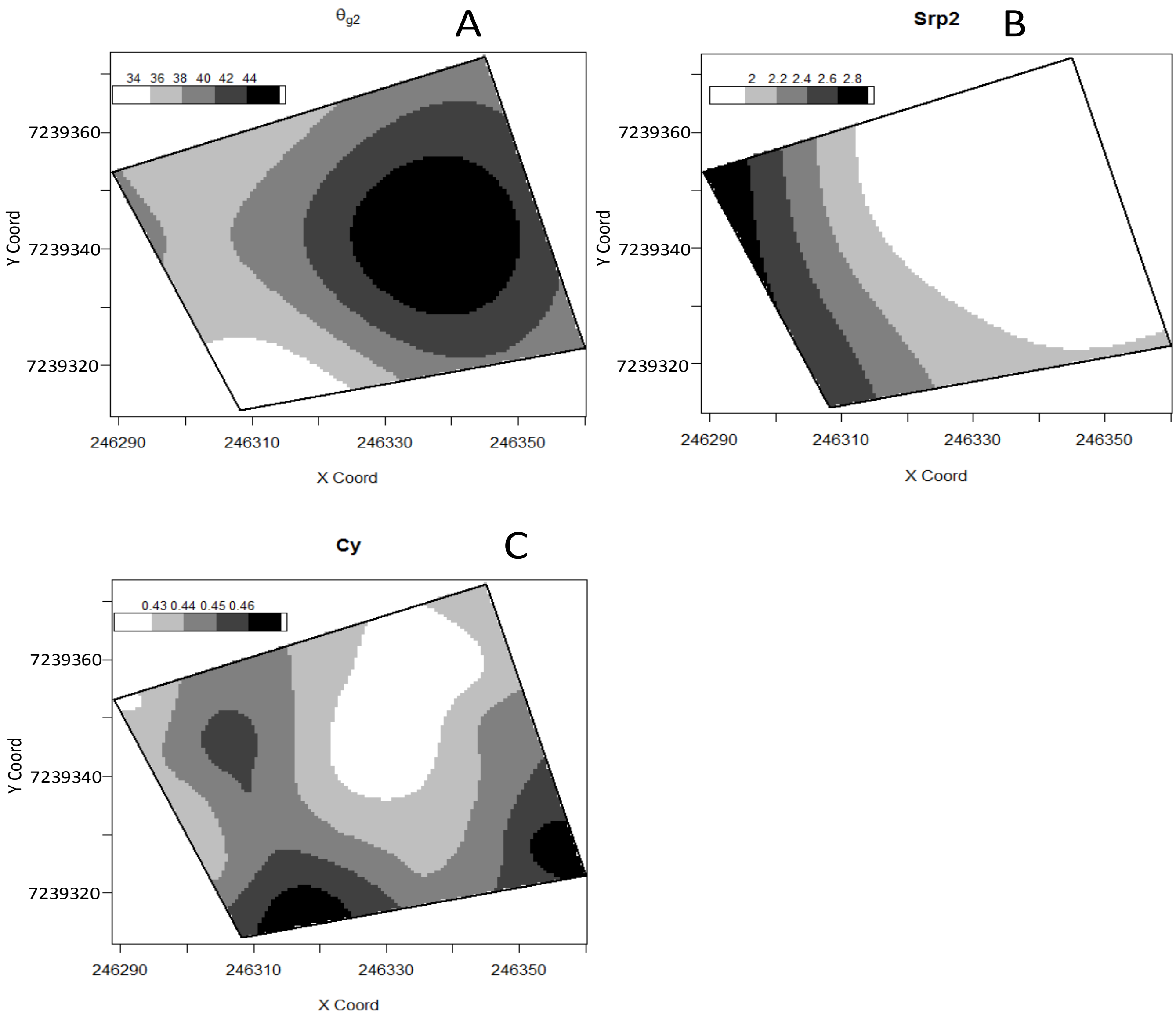

Figure 3. Surface maps of θg2: Gravimetric moisture content in 0.1 to 0.2 m layer (A), Srp2: cone index in 0.1 to 0.2 m layer (B), Cy: Crambe yield (C).

gravimetric moisture in an inverse manner. Crambe yield may be spatially explained by soil resistance to penetration in depth 0.1 to 0.2 m.

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