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Full Length Research Paper

Spatial variability of physical attributes of a clayey latosol related to the grain yield of the crambe (*Crambe abyssinica* Hochst) culture

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The aim of this study was to determine, with the help of thematic maps obtained by kriging interpolation, the existence of relationship between spatial variability of soil density and soil resistance to penetration with crambe yield (*Crambe abyssinica*) under no-tillage system on clayey Latosol. The experiment was conducted in experimental area located in Cascavel-Paraná, Brazil. The experimental grid was established in 100 × 100 m area, totaling 100 points, in which samples of soil density and soil resistance to penetration were collected in order to relate them to the productivity of the crambe culture. The values results showed that the soil density and soil resistance to penetration, in all studied layers (0 to 0.1, 0.1 to 0.2 and 0.2 to 0.3 m), did not present significant values of compressed areas. After analysis of the thematic maps, one could note that there was no relation between the soil density and soil resistance to penetration with respect to yield of crambe culture. Among the attributes studied in this work, the soil resistance to penetration in the layer of 0 to 0.1 m was the one that showed greatest relation to productivity to crambe.

Key words: Energetic cultures, geostatistics, bulk density.

INTRODUCTION

Crambe (*Crambe abyssinica* Hochst) is an oilseed that belongs to the Brassicaceae family. It is native from the Mediterranean area and started to stand out with great potential for the production of oil destined for the production of biodiesel (Pilau et al., 2011). It is a culture with a cycle of approximately 90 days, tolerant to drought, low temperatures and frosts, except for the seedling and flowering stages, making it an option for crop rotation. However, the subsuperficial soil layer (0.2 to 0.4) conditions are primordial for the development of its aggressive and pivoting root system, what allows it to tolerate long periods of drought.

A good root development depends, among other factors, on physicohydric conditions of the soil. According to study carried out by Bonini et al. (2011) about physicohydric attributes of a latosol related to wheat productivity, one could observe a decrease in productivity, due to the alteration in the structure state of the soil which occurred with the increase of soil density and reduction in the volume of macropores, attributes which are considered important for the definition of soil resistance to penetration, water infiltration and gaseous changes in the soil. Soil compaction is a complex process that involves features of soil and plant response. Thus, further study on the physical characteristics of the soil in relation to the yield of crambe is essential for the development and spread of culture. According to

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Table 1. Chemical Attributes of the experimental area.

Acidity and liming diagnose								
pH water 1:1	Ca	Mg	Al	H+Al	CTC efet.	Saturation (%)		SMP index
	cmol$_c$ dm^{-3}					Al	Bases	
4.9	6.3	1.6	0.2	6.5	8.4	2.5	56.2	5.6
Macronutrient diagnose and NPK-S fertilization reference								
MO (%)	Clay (%)	Texture	S	P-Mehlich	P-resin	K	CTC pH7	K
m v^{-1}			mg dm^{-3}			cmol$_c$ dm^{-3}		mg dm^{-3}
4.7	60.5	3.0	-X-	13.2	-X-	0.3	14.7	133.0

Kitamura et al. (2007), identification of the spatial variability of the soil's physical attributes is a primal tool to understand the soil and decide which treatment should be used in the cultivated areas.

With the use of Geostatistics, it is possible to establish a semivariogram model that best describes the spatial variability of the data, making it possible to generate maps by means of kriging. Due to the large diversity of models and methods of semivariogram adjustments, the decision for one of them may be performed by cross-validation, because by using, it is possible to assure that the prediction based on the variographic model is not vitiated and that the quadratic error of the prediction is minimized (Cressie, 1991). After semivariogram model chosen, it provides the necessary parameters for the kriging method, in which weights are attributed, according to the spatial variability defined in the semivariogram (Oliver and Webster, 1990).

The aim of this study was to determine, with the help of thematic maps obtained by kriging interpolation, the existence of relationship between the spatial variability of soil density and soil resistance to penetration with crambe yield in a typic clay Latosol under no-tillage.

MATERIALS AND METHODS

The experiment was carried out from April, 2011 to September, 2011, in an area located in the city of Cascavel-Paraná, Brazil. The studied area is situated in the coordinate 24º 56' 24" S and 53º 30' 42" W, average height of 674 m, with average annual precipitation and temperature of 1.640 mm and 19ºC, respectively. Local climate is mesothermal temperate and super moist, Cfa (Köeppen). The studied area soil was classified as a typical distrophic red latosol, with clayey to very clayey texture (600 g kg^{-1} of clay; 320 g kg^{-1} of silt and 80 g kg^{-1} of sand), basalt substrate and gently rolling relief, according to Embrapa (2006). The chemical analysis of the soil was accomplished by the Chemical Soil Analysis Laboratory at the Soil Department of the Federal University of Santa Maria, as shown in Table 1.

The experimental area has been used in crop rotation under no-tillage for 10 years with crops of soybeans, corn and wheat. The sowing occurred at the end of the month of May and the cycle of the culture was extended until the beginning of September, completing about 110 days, in which the predominant weather was the winter. The crambe seed was used to grow FMS Bright, produced in the Brazilian state of Mato Grosso do Sul, because there are other experiments with the same seed. The spacings between lines were 0.21 m and the density was 30 seeds per meter of sowing line. For the installation of the experimental grid, a 100 × 100 m area was selected and marked at every 10 m with the help of a Garmim GPS model 60CSx, in two perpendicular directions, totaling 100 points. The collection of soil resistance to penetration (RSP), soil density (Ds) and yield crambe (Pd) was made at each georeferenced point. The RSP (MPa) was assessed with the help of a digital penetrometer model *penetroLOG PLG1020, by Falker - Solo Star,* coupled to an ATV, in order to obtain samples until 0.3 m of depth, with the average of five replications being used. Later, the cone index in the layers of 0 to 0.1 (RSP1), 0.1 to 0.2 (RSP2) and 0.2 to 0.3 m (RSP3) was calculated. The Ds (Mg m^{-3}) samples were collected by means of the volumetric ring method, in the layers of 0 to 0.1 (Ds1), 0.1 to 0.2 (Ds2) and 0.2 to 0.3 m (Ds3). As for the analysis of Pd (Mg ha^{-1}), an area of 4 m^2 was collected at each georeferenced point. The Pd was corrected for grain moisture of 13%.

Aiming to identify the behavior of the initial data, we used the software R (R Development Core Team, 2009) and Anderson Darling normality test. In the geostatistical analysis, pack GeoR was used (Ribeiro and Diggle, 2001), given that for the estimation of the spatial dependence structure, Matheron's estimator was used, Equation (1), in the cases in which the data presented normal distribution, because according to Faraco et al. (2008), Matheron's estimator is stable in normality cases and little resistant in atypical ones (outliers). In this case, the use of Cressie and Hawkins's estimator, Equation (2) is recommended. The semivariances were calculated by using a cut-off of 50% of the maximum distance (Clark, 1979).

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

$$\hat{\gamma}_c(h) = \frac{\left\{\frac{1}{N(h)} \sum_{i=1}^{N(h)} |Z(S_i) - Z(S_i + h)|^{\frac{1}{2}}\right\}^4}{0{,}914 + \frac{0{,}988}{N(h)}} \quad (2)$$

The methods used for the adjustment of the theoretical semivariogram were ordinary least-squares (OLS) and weighted least-squares (WLS), and the adjusted models were exponential (Exp) and spherical (Sph). The cross-validation was applied in order to assess which model best adapted to the experimental semivariogram. This technique allows one to compare the previewed values to the sampled ones (Isaaks and Srisvastava, 1989), given that the average error (EM) and the reduced average error (ER) must be closer to zero, the standard deviation of reduced average errors (S_{ER}) must be closer to 1 (one), the absolute error(EA) is a measure of the error magnitude in the unit of the regionalised variable (Mello, 2004). Equations (3) to (6) represent

Table 2. Descriptive analysis of soil resistance to penetration (MPa) and soil density (Mg m^{-3}) in the layers of 0 to 0.1 m (RSP1 and Ds1), 0.1 to 0.2 m (RSP2 and Ds2), 0.2 to 0.3 m (RSP3 and Ds3) and productivity of the Crambe culture (Mg ha^{-1}).

Attribute	Minute	1st Quartile	Median	Average	3rd Quartile	Max.	Standard deviation	CV (%)	*p*-value*
Soil resistance to penetration									
RSP1	0.545	1.039	1.236	1.218	1.398	1.981	0.291	23.89	0.9779
RSP2	1.466	1.876	2.123	2.211	2.468	4.023	0.452	20.45	0.0059
RSP3	1.129	1.551	1.766	1.843	2.048	3.060	0.405	22.00	0.0003
Density									
Ds1	0.926	1.029	1.084	1.076	1.121	1.222	0.062	5.848	0.1592
Ds2	0.900	1.044	1.080	1.080	1.115	1.197	0.056	5.211	0.5059
Ds3	0.862	0.985	1.027	1.034	1.076	1.220	0.065	6.300	0.0772
Productivity									
Pd	0.090	0.290	0.370	0.387	0.470	0.880	0.157	40.67	0.0004

*Anderson-Darling's normality test. The distribution which presents p-value higher than 0.05 is considered normal. Soil moisture (%) 0 to 0.1 m: 36.9; 0.1 to 0.2 m: 38.1; 0.2 to 0.3 m: 40.1. CV: Coefficient of variation.

this information.

$$EM = \frac{1}{n}\sum_{i=1}^{n}\left(Z(S_i) - \hat{Z}(S_{(i)})\right) \quad (3)$$

$$ER = \frac{1}{n}\sum_{i=1}^{n}\frac{Z(S_i) - \hat{Z}(S_{(i)})}{\sigma(\hat{Z}(S_{(i)}))} \quad (4)$$

$$S_{ER} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\frac{|Z(S_i) - \hat{Z}(S_{(i)})|}{\sigma(\hat{Z}(S_{(i)}))}} \quad (5)$$

$$EA = \sum_{i=1}^{n}\left|\hat{Z}(S_i) - Z(S_{(i)})\right| \quad (6)$$

A quantitative assessment was performed to verify the spatial variability by using the "nugget effect coefficient" (E_o), which is the percentage between the nugget effect and the baseline, in other words, $\Phi_1 (\Phi_{1} + \Phi_2)^{-1}$, given that the lower the coefficient, the higher is the spatial variability. According to Cambardella et al. (1994), models present strong spatial dependence with $E_o \leq 25\%$ and moderate spatial dependence with $25\% < E_o \leq 75\%$. After choosing the model, the ordinary kriging took place, in order to obtain the thematic maps of RSP and Ds in all three analysed depths (0 to 0.1, 0.1 to 0.2, 0.2 to 0.3 m) and the productivity map.

RESULTS AND DISCUSSION

The initial descriptive data of the soil's physical attributes (soil resistance to penetration and density) as well as productivity are shown in Table 2. As said by Pimentel Gomes and Garcia (2002), the variability of the physical attributes may be classified according to the values of its coefficients of variation (CV) as: low (CV ≤ 10%), average (10% ≤ CV ≤ 20%), high (20% ≤ CV ≤ 30%) and very high (CV ≥ 30%). By analysing the values of RSP1, RSP2 and RSP3 on Table 2, one can observe that all soil layers presented high variability (20% ≤ CV ≤ 30%), which mets the study by Faraco et al. (2008) who carried out a work on Dystrophic Red Latosol and found values for the coefficient of variation between high and average. Concerning Anderson Darling's test for RSP sets, only RSP1 presented normality, or *p-value* ≥ 0.05.

As for Ds1, Ds2 and Ds3, one could notice that in all layers there was normality and the CV values were below 10%, considered as having low variability, there was also homogeneity between the median values of Ds1 and Ds2, what demonstrates that the density between both layers did not obtain large variations, which was also observed by Cavallini et al. (2010). Pd data showed very high coefficient of variation, with CV ≥ 40%, with productive data ranging from 0.09 to 0.88 Mg ha^{-1} and average of 0.38 Mg ha^{-1}, which is a value inferior to that found by Pitol (2008), who highlights that under good soil and fertility conditions, such productivity may range from 1.0 to 1.5 Mg ha^{-1}. Due to the fact that the soil does not show the values of the physical attributes considered critical for this type of soil (Reichert et al., 2003), the likely explanation for the low yield may be related to the high acidity of the soil, with pH at 4.9 and introducing quantities of Al, 0.2 $cmol_c$ dm^{-3} (Table 1).

For the elaboration of the experimental semivariograms of RSP1, DS1, DS2 and DS3, Matheron's estimator was used, due to the fact that these data presented normal distribution. For the other monitored variables, the utilized estimator was Cressie e Hawkins'. Table 3 presents theoretical models adjusted and chosen through cross-validation and quantitative assessment of spatial variability. The smaller the value E_o, the higher the spatial dependency (Cambardella et al., 1994). All attributes on Table 3, except for Ds2, presented moderate spatial dependence ($25 \leq E_o \leq 75$).

The thematic maps obtained by ordinary kriging interpolation of the variables Ds1 and RSP1 in the layer

Table 3. Parameters of the semivariograms chosen by cross-validation*.

Attribute	Model	Method	Φ1	Φ2	a	Φ1+ Φ2	E_o (%)
RSP1	Exp.	OLS	0.04420	0.05360	128.81650	0.09780	45.19427
RSP2	Sph.	OLS	0.06430	0.17570	98.00004	0.24000	26.79167
RSP3	Sph.	WLS	0.09680	0.07060	97.99999	0.16740	57.82557
Ds1	Exp.	WLS	0.00280	0.00110	41.94024	0.00390	71.79487
Ds2	Sph.	WLS	0.00260	0.00050	64.00000	0.00310	83.87097
Ds3	Exp.	OLS	0.00280	0.00240	128.81650	0.00520	53.84615
Pd	Exp.	OLS	0.00010	0.02370	50.92848	0.02380	0.42017

*OLS: Ordinary least squares, WLS: weighted least squares Exp.: Exponential, Sph.: Spherical. Φ: nugget effect, Φ2: contribution, Φ1+ Φ2: baseline, a: range, E_o: coefficient of the nugget effect ($Φ1\ (Φ1+Φ2)^{-1}$).

of 0 to 0.1 m, RSP2 and Ds2 in the layer of 0.1 to 0.2 m, and Ds3 and RSP3 in the layer of 0.2 to 0.3 m are shown in Figure 1.

By observing the thematic maps for Ds1, Ds2 and Ds3 (Figure 1), one may notice that in the largest area of the maps, the values for Ds were inferior to 1.1 Mg m^{-3} in all three soil layers, given that the lowest values for Ds were found in the central and superior left areas of the maps. Concerning to thematic maps RSP1, RSP2 and RSP3, one can see that there was similarity in the behavior of all three maps, with concentration of higher and lower values for RSP, respectively, in the left and right areas of the maps, with values ranging from 1.0 to 3.0 Mpa. One can also notice that in RSP2, there was an increase in the RSP values when compared to RSP1 and RSP3, once that soil in the layer of 0.1 to 0.2 m is more susceptible to compression in direct drilling systems, mainly due to the intense traffic of agricultural machinery, which is in accordance with Secco et al. (2009) who in a study about physical attributes of the soil in compressed areas of latosols cultivated under direct drilling, verified that the highest values of RSP and Ds were found in the layer of 0.07 to 0.12 m.

Considering maps of Ds2 and RSP2, in which the RSP values were between 1.5 and 2.5 MPa, one can observe that there was no occurrence of indicative values of compressed areas for that depth, because, according to Reichert et al. (2003, 2008), for soils with clayey texture, only values of soil resistance to penetration above 2 Mpa, density above 1.25 Mg m^{-3} and macropore lower volume to 10% may be evidence of compressed layers. The thematic map for productivity is shown in Figure 2. By relating maps RSP1 and Ds1 with Pd (Figures 1 and 2), concerning soil depth of 0 to 0.1 m, one can notice that Ds1 and RSP1 did not present significant relation to Pd, in other words, areas with superior or inferior values of RSP1 or Ds1 did not correspond to superior or inferior values of Pd, however, one can observe a short relation between RSP1 and Pd in the inferior and superior left areas of the maps, where values of RSP close to 1.6 MPa corresponded to productivity values inferior to 0.2 Mg ha^{-1}. Even the culture studied in this work is a different one, it is still possible to take into account the fact that Johann et al. (2004), when studying the spatial variability of physical attributes of a clayey latosol related to soybean productivity, observed that among the studied attributes, soil resistance to penetration in the layer of 0 to 0.1 m depth was the variable that best related to productivity.

According to Carvalho et al. (2006), in a study on soil resistance to penetration and productivity of beans under direct drilling, there was no linear or spatial correlation between RSP and productivity of beans. Secco et al. (2005), when studying the productivity and physical properties of latosol, concluded that the compression level existent with RSP ≤ 2.6 MPa, Ug = 0.27 kg kg^{-1}, Ds ≤ 1.51 Mg m^{-3} and Macro volume ≥ 10 dm^3 dm^{-3}, in farming conditions, did not significantly compromise the grain yield of the soybean culture. In that sense, concerning the maps RSP2 and Ds2, referring to soil depth of 0.1 to 0.2m, one can verify that there is no evidence of compression for this layer of soil. One can also observe that RSP2 and Ds2, in the layer of 0.1 to 0.2 m, RSP3 and Ds3, in the layer of 0.2 to 0.3 m, do not present relation to Pd, however, it is possible to notice that there was occurrence of higher levels of productivity (0.6 to 0.8 Mg ha^{-1}), in areas where the values of map RSP2 did not exceed 3.5 MPa.

In a research carried out on Red Latosol subjected to conventional preparation, in the depth of 0.2 to 0.4 m, Freddi et al. (2006) also observed that the corn productivity did not show spatial correlation to soil resistance to penetration neither was it affected for values of RSP inferior to 2 MPa. Generally, the thematic maps of RSP and Ds in both studied depths did not present significant relation to that of Pd, what may be related is the fact that the soil does not show characteristics for compressed areas neither does it show significant variations to soil density, or even, the fact that this culture is not affected with the levels of RSP and Ds observed in the research. One must also take into account that other factors, such as the soil's chemical characteristics, which may be more related to spatial variability of the crambe productivity.

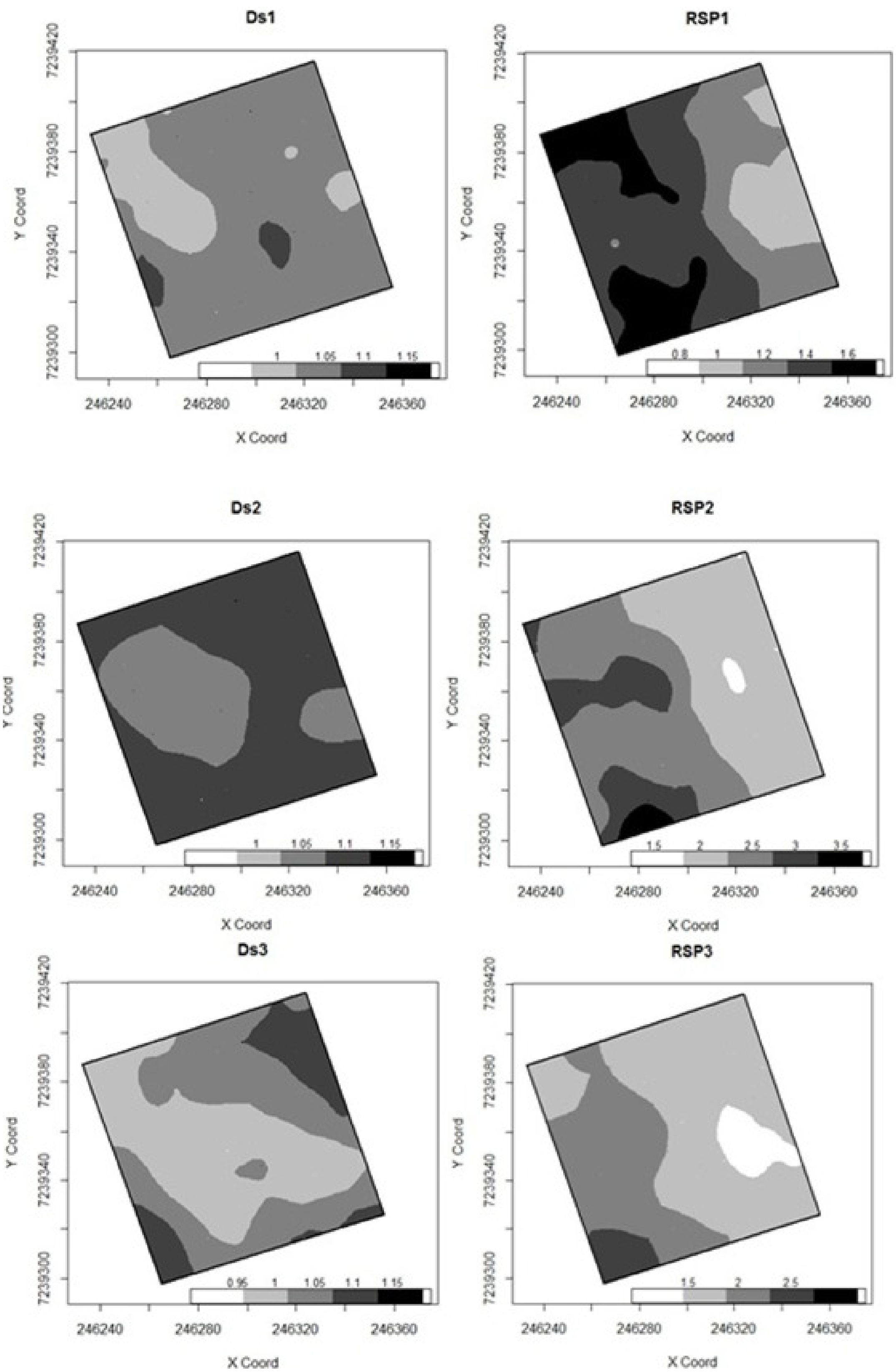

Figure 1. Thematic maps soil resistance to penetration (MPa) and bulk density (Mg m^{-3}) in the layers of 0 to 0.1 m (RSP1 and DS1), 0.1 to 0.2 m (RSP2 and DS2) and 0.2 to 0.3 m (RSP3 and DS3). Soil moisture (%) 0 to 0.1 m: 36.9; 0.1 to 0.2 m: 38.1; 0.2 to 0.3 m: 40.1. Y Coord: north and south (UTM), X Coord: east and west (UTM). Darker colors represent higher values and lower values bright colors.

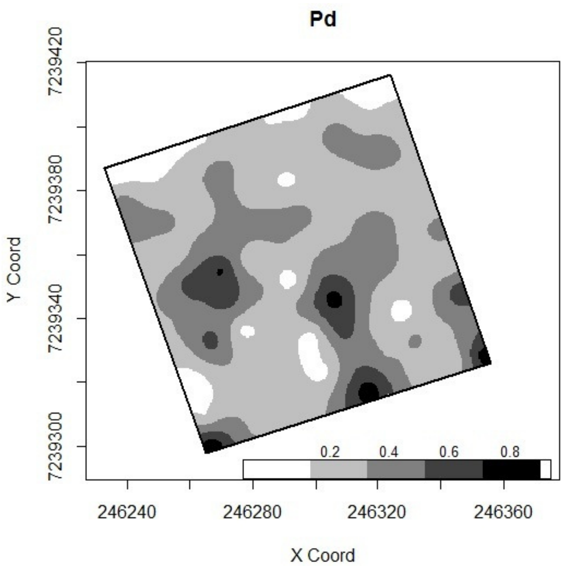

Figure 2. Thematic map for productivity of the crambe culture (Mg ha^{-1}). Y Coord: North and south (UTM), X Coord: east and west (UTM). Darker colors represent higher values and lower values bright colors.

Conclusions

1. The values for soil resistance to penetration, in both studied layers, did not present indicative values of compressed areas,
2. The thematic maps for attributes of soil density and resistance to penetration did not present relevant relation to the productivity of the Crambe culture,
3. Among the studied maps of attributes and depths, the one concerning soil resistance to penetration in the layer of 0 to 0.1 m showed the greatest relation to the productivity of the Crambe culture.

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