Revista Brasileira de Ciências Agrárias
ISSN: 1981-1160
agrarias.prppg@ufrpe.br
Universidade Federal Rural de
Pernambuco
Brasil

de Souza Lima, Elizeu; Montanari, Rafael; Lovera, Lenon Henrique; Ferrari, Samuel; dos Santos da Silva, Tatiana; Hernandes Andrade, Queiroz
Spatial correlation of productive component for peach palm crop and some physical attributes of Eutrochrept soil
Revista Brasileira de Ciências Agrárias, vol. 11, núm. 3, 2016, pp. 163-170
Universidade Federal Rural de Pernambuco
Pernambuco, Brasil

Agrária - Revista Brasileira de Ciências Agrárias
ISSN (on line) 1981-0997
v.11, n.3, p.163-170, 2016
Recife, PE, UFRPE. www.agraria.ufrpe.br
DOI:10.5039/agraria.v11i3a5381
Protocolo 5381 - 02/02/2016 • Aprovado em 24/08/2016

Spatial correlation of productive component for peach palm crop and some physical attributes of Eutrochrept soil

Elizeu de Souza Lima[1], Rafael Montanari[2], Lenon Henrique Lovera[2], Samuel Ferrari[3], Tatiana dos Santos da Silva[2], Hernandes Andrade Queiroz[2]

[1] Universidade Estadual de Campinas, Faculdade de Engenharia Agrícola, Avenida Cândido Rondon, 501 - Cidade Universitária Zeferino Vaz, Barão Geraldo, CEP 13083-875, Campinas-SP, Brasil. E-mail: elizeu.florestal@gmail.com
[2] Universidade Estadual Paulista "Júlio de Mesquita Filho", Faculdade de Engenharia de Ilha Solteira, Departamento de Fitossanidade, Engenharia Rural e Solos (DEFERS), Rua Monção, 226, Centro, CEP 15385-000, Ilha Solteira-SP, Brasil. E-mail: montanari@agr.feis.unesp.br; lenon_lovera@hotmail.com; tatianaengambiental@gmail.com; langoisa@gmail.com
[3] Universidade Estadual Paulista "Júlio de Mesquita Filho", Campus Experimental de Registro, Rua Nelson Brihi Badur, 430, Centro, CEP 11900-000, Registro-SP, Brasil. E-mail: ferrari@registro.unesp.br

ABSTRACT

Currently, Brazil sells around 300 million dollars per year of peach palms (*Bactris gasipaes*), wherein this country is responsible for being the largest worldwide producer, exporter and consumer. In crop year of 2014, productive components of *peach palms* were analyzed according to soil physical properties in Registro, SP, Brazil. The objectives were to evaluate the variability of the soil attributes and define a linear and spatial correlation between the crop productive components and the soil physical properties. Geostatistical grid was installed to collect data from soil and plant, with 54 sampling points in a total area of approximately 10,000 m^2. With regard to linear point of view, stem diameter and palm height was explained by direct and exponential potential model, which was highly significant due to mechanical resistance to penetration.

Key words: *Bactris gasipaes*, geoestatistical methods, management, variability

Correlação espacial dos componentes produtivos para cultura da pupunha e alguns atributos físicos de um Cambissolo

RESUMO

Atualmente o Brasil vende cerca de 300 milhões de dólares por ano de pupunha, sendo que este país é responsável por ser o maior produtor mundial, exportador e consumidor. No ano-safra de 2014, os componentes produtivos de *Bactris gasipaes* foram analisados de acordo com as propriedades físicas do solo em Registro, SP, Brasil. Com este trabalho, objetivou-se avaliar a variabilidade dos atributos de solo e estabelecer uma correlação linear e espacial entre os componentes produtivos da colheita e as propriedades físicas do solo. Malha geoestatística foi instalada para coletar dados de solo e na planta, com 54 pontos de amostragem, em uma área total de aproximadamente 10.000 m^2. Quanto ao ponto de vista linear, diâmetro do caule e altura de palma foi explicada pelo modelo potencial direto e exponencial, o que foi altamente significativa, devido à resistência mecânica à penetração.

Palavras-chave: *Bactris gasipaes*, métodos geoestatísticos, manejo, variabilidade

Introduction

Currenntly, Brazil sells around 300 million dollars per year of peach palms, this country is responsible for being the largest worldwide producer, exporter and consumer. In this context, Southeast Brazil has the largest cultivated and harvested palm area (around 40 %). Additionally, São Paulo State stands out as one of the largest Brazilian producers of peach palm with 8,580 ha planted and 3,120 ha harvested areas, and production of 9,220 Mg, mainly in Ribeira Valley region, which includes the cities of Registro, Iguape, Sete Barras, Jacupiranga, Cajati e Juquiá (IBGE, 2009).

Peach palm (*Bactris gasipaes* Kunth) farming for palm heart production has attracted interest since the 70s, as a new option for replacing *Euterpe* spp., which is traditionally exploited by extractivism. Given the agronomic, ecological, industrial and commercial qualities, peach palm stands out for having strong social and environmental impact, presenting itself as an alternative for small farmers (Trintinalio et al., 2005).

Since it is a perennial crop, palm is a quite demanding crop for soil attributes. In addition, it demands high water amount, so irrigation use becomes essential when are grown in areas with water shortage. However, the crop does not support poorly drained soils or problems with anoxia (Falcão et al., 1998).

Soil physical structure is an important factor involved in peach palm formation and establishment. Changes evidenced in physical attributes affect water, air, nutrient and root movements throughout soil profile (Cavallini et al., 2010). Therefore, soil management becomes an essential tool to be used in search for sustainable activities (Casalinho & Martins, 2004).

Thus, studying variability of soil physical properties is important to establish precision agriculture, in which specific local management is performed (Montanari et al., 2010). At this stage, semivariogram use allows great land drawings with intention to adopt variability in spatial scales. One way to solve these problems would be to use geostatistical methods to evaluate spatial variability of soil physical capacity (Cavallini et al., 2010).

With an indicator of soil physical quality that could represent possible causes of low yield of cultivations in Registro, São Paulo State, Brazil, the objective of this study was: a) analyze variability of these attributes; b) define a linear and spatial correlation between productive components of peach palm and soil physical properties.

Materials and Methods

Experiment was conducted at the Education, Research and Extension Farm of the College of Engineering in Registro city (SP), Brazil. The coordinates are 24º 32' 08" South and 47º 51' 55" West, with average annual rainfall of 1,500 mm, and annual temperature of 21.1 °C. The climate is classified according to Köppen-Geiger as *Af* type, characterized by tropical without dry season.

Soil characterization is defined as plain and river terraces of Iguape River basin, described as flat lands on low stream and / or tectonic depression of the river region of modern sediments in clayey alluvial soils of Eutrochrept eutrophic type areas upstream and hydromorphic soils on lowland (Embrapa, 2013).

Soil preparation was accomplished by the following activities: subsoiling on January 9, 2012; harrowing on January 19, 2012; and soil correction on January 20, 2012 with 1.5 t ha^{-1}, and then applied a dozer disc harrowing.

Seedlings were planted on January 24, 2012, at the Experimental Campus of UNESP-SP, and, plant and soil collection were performed on April 25, 2014. Time-of-planting fertilization was performed with 150 g NPK (4-14-08) per plant and maintenance made in accordance with soil analysis. Afterwards, in the first year after planting, topdressing fertilization was performed with 60 kg ha^{-1} N; 30 kg ha^{-1} P_2O_5 and 40 kg ha^{-1} K_2O + 1250 kg ha^{-1} FTE (Fritted Trace Elements) banana (Ca 7 %, S 5.7 %, B 1 %, Cu 1 %, Mn 1 %, Mo 0.1 % and Zn 18 %), which were applied on plant surrounding. Subsequently, in the second year, an amount of 100 kg ha^{-1} N, 50 P_2O_5 and 60 K_2O + 100 kg ha^{-1} FTE banana and 1000 kg ha^{-1} limestone was applied.

Plant spacing used for experiment installation was 2 × 1 m (rows × plant). Experimental area containing 54 points was georeferenced using a Garmin GPS to represent the entire sampling area of approximately one ha, and one sample the soil was collected at 0.10 m of plants the planting line. For plant attribute measurement, we used a 2 m graduated scale to determine height. Diameter was measured at 50 cm height from the ground with using a digital caliper. Finally, number of leaves and tillers were counted manually. The soil penetration resistance was determined by the method of Stolf, (1991):

$$PR = \left\{ 5.581 + 6 + 891 \times \left[\frac{N}{(P - A) \times 10} \right] \right\} \times 0.0981 \qquad (1)$$

where: PR is the soil penetration resistance (MPa); N is the number of hammer impacts performed to obtain penetrometer reading; A and N are, respectively, the readings before and after impact (cm).

The gravimetric moisture (GM) was determined at the time of soil collection, we used an auger to collect soil samples and afterwards to dertermine volumetric moisture (VM) according to the following equation:

$$VM = GM \times BD \qquad (2)$$

where: VM is volumetric moisture (m^3 m^{-3}); GM, gravimetric moisture (kg kg^{-1}); and BD, bulk density (Mg m^{-3}). For bulk density (BD) determination, we used the volumetric ring method and granulometric analysis (sand, silt and clay) throughout trench depth (Embrapa, 1997).

Plant attributes were stem diameter (Diam) in cm; plant height (Hei) in m; number of leaves and tillers (Till). And soil properties were penetration resistence (PR) in MPa; gravimetric moisture (GM) in kg kg^{-1}; volumetric moisture (GM) in m^3 m^{-3}; bulk density (BD) in Mg m^{-3}; real density (RP) in Mg m^{-3}; total porosity (TP) in m^3 m^{-3}; sand, silt and clay in g kg^{-1}; collected at 0.00-0.10 and 0.10-0.20 m depths. Being identified the following attributes at each depth: a) 0.00-0.10 m: PR1, GM1, VM1, BD1, RD1, TP1, Sand1, Silt1 and Clay1; b) 0.10-0.20 m: PR2, GM2, VM2, BD2, RD2, TP2, Sand2, Silt2 and Clay2.

For each studied attribute, it was performed a classical descriptive analysis using SAS statistical software (Schlotzhaver & Littell, 1997), in which average, median, minimum and maximum values, standard deviation, coefficient of variation, kurtosis, skewness and distribution frequency were calculated. Later, there was an identification of outliers, replacing them by average value of the surrounding mesh. To test normality hypothesis, or lognormalidade, was used Shapiro & Wilk at 5 % probability. A correlation matrix was set aiming to perform simple linear correlations for two by two of all studied attributes, as well as present regression analysis for pairs of great interest. On this purpose, we selected those with higher linear correlation, and therefore presented a cross semivariogram with consequent co-kriging. Subsequently, we examined the spatial dependence by calculating the simple semivariogram separately for each attribute. However, for those who showed spatial interdependence, we also calculated cross semivariograms based on assumptions of intrinsic hypothesis stationarity, using the *Gamma Design Software* (GS^+, 2004). Settings of simple and cross semivariograms, according to their models, were made primarily by the initial selection of: a) the smallest residual square sum (RSS); b) the highest coefficient of determination (r^2), and c) the highest spatial dependence evaluator (SDE). Therefore, final decision of model that represents the adjustment was performed by cross-validation, as well as to define neighborhood size, which provided better mesh kriging and/or co-kriging, performed by block kriging. For each attribute, it was related a nugget effect (C_o), range (Ao) and sill (C_o + C). Thus, spatial analisys dependence evaluator (SDE) was obtained according to the following expression (GS^+, 2004):

$$SDE = \left[\frac{C}{(C + C_o)} \right] \times 100 \quad (3)$$

where: SDE is the spatial dependence evaluator; C, is the structural variance; C + Co, sill. After, the spatial dependence evaluator (SDE) was classified as follows: SDE < 20 % = very low spatial dependence (VLD); b) 20 % < SDE< 40 % = low dependence (LOD); c) 40 % < SDE < 60 % = average dependence (AVD); d) 60 % < SDE < 80 % = high dependence (HID), and e) 80 % < SDE < 100 % = very high dependence (VHD), as proposed by Dalchiavon & Carvalho (2012). It is inferred that cross-validation is a tool to evaluate alternative models of simple and cross semivariograms, for kriging and co-kriging. During analysis, each point within spatial domain is individually removed, and its value estimated as if it did not exist. Thus, a graph of observed *versus* estimated values can be drawn for all points. Wherefore, correlation coefficient (r) between these values reflects efficiency adjustment, given by sum of squared deviation technique, representing the linear regression equation. A perfect fit would have a regression coefficient of 1 and the line of best fit would coincide with a perfect model, i.e., with a linear coefficient of zero and angle of 1 (GS^+, 2004). Thus, to obtain an optimal number of neighboring points, kriging and co-kriging maps were designed through interpolation of dependence and interdependence analysis among spatial properties. Finally, were established geostatistical components for simple semivariogram, cross semivariogram, cross-validation, kriging and cokriging.

Results and Discussion

According to Pimentel-Gomes & Garcia (2002), variability of attributes can be classified according to coefficient of variation (CV), in which classes were determined as low (CV ≤ 10 %), average (10 % < CV ≤ 20 %), high (20 % < CV ≤ 30 %) and very high (CV > 30 %). In Table 1, number of leaves (NL) had an average variability, with coefficient of variation of 19.7 %. As for stem diameter, plant height and tiller showed very high variability with coeficients of 33.8 %, 36.2 % e 41.5 %, respectively.

The PR, GM and VM showed an average variability at all soil depths, with coefficients of variation between 11.5-18.2 %; however, clay and silt, showed average varibility (10.6 and 13.2 %), only at 0.10-0.20 cm depth. For the other soil attributes (BD1, BD2, RD1, RD2, TP1, TP2, SAND1, SAND2, CLAY1 and SILT1), the variability was low (Table 1). When a statistical variable has normal frequency distribution, the most appropriate measure of central tendency to represent it, is average. In contrast, were used median or geometric average, in case of lognormal type (Rosa Filho et al., 2009). Therefore, central tendency measure to represent the attributes Diam, TILL Hei, Perf, GM1, GM2, VM1, VM2, BD1, BD2, TP1, TP2, SAND1, SAND2, CLAY1, CLAY2, SILT1 e SILT2 should be average.

Since they showed a frequency distribution of normal type, with positive skewness coefficients between 0.0018 and 0.854, as well as negative ones from -0.961 to -0.0001. In addition, it was also obtained positive kurtosis coefficients between 0.044 and 2.052, as well as negative ones between -0.513 e -0.052. However, these coefficients were all significant at 5 % probability by Shapiro and Wilk normality test, once such probability varied between 0.0001 and 0.7308 (Table 1).

For peach palm crop components, average value for number of leaves was 5.6; as for diameter was 6.3 cm. Height average was 1.16 m, while number of tillers was 6.7. Bovi et al. (2007), studying the use of sewage sludge in peach palm yield in Entisols, found a significant regression equation with r^2 of 0.97 that larger diameters increased crop yield.

Low values of bulk density were found for both layers (BD1=1.261 kg dm^{-3}, BD2=1.254 kg dm^{-3}) and penetration resistance (PR1=1.095 MPa, RP2=2.007 MPa) testified that, in which soil did not appear compact throughout experiment. Therefore, this fact has become a favorable factor for maximum crop development, because the soil is not compacted in depth assessed, which favored both root and shoot growth.

Once topsoil loses water more intensively by evapotranspiration, it is already expected increasing values of GM at deeper layer what is consistent with studies of Freddi et al. (2005), Santos et al. (2005), Carvalho et al. (2006) and

Table 1. Descriptive analysis of productive components for peach palm crop and some physical attributes in Eutrochrept soils of Registro-SP, Brazil

Attributes[1]	Descriptive statistical									
	Average	Median	Value		Standard deviation	Coefficients			Probability test [2]	
			Minimum	Maximum		Variation (%)	Kurtosis	Skewness	Pr<w	FD
Plant attributes										
NL	5.611	6	3	8	1.106	19.7	0.044	-0.118	0,0081	UN
Diam (cm)	6.342	6.5	2.1	13	2.632	41.5	-0.478	0.315	0.2076	NO
HEI (m)	1.169	1.140	0.5	2.180	0.395	33.8	-0.105	0.497	0.2804	NO
TILL	6.703	7	2	12	2.431	36.2	-0.494	0.220	0.1654	NO
Soil physical attributes										
PR1 (MPa)	1.095	1.094	0.801	1.562	0.177	16.2	0.433	0.854	0.0096	UN
PR2 (MPa)	2.007	2.027	1.460	3.071	0.364	18.2	2.052	1.138	0.0001	UN
GM1 (kg kg^{-1})	0.206	0.200	0.142	0.271	0.028	13.8	-0.368	0.103	0.5692	NO
GM2 (kg kg^{-1})	0.222	0.222	0.154	0.279	0.026	11.5	0.134	-0.260	0.6342	NO
VM1 (m^3 m^{-3})	0.260	0.259	0.167	0.334	0.039	15.2	-0.290	-0.022	0.2668	NO
VM2 (m^3 m^{-3})	0.279	0.277	0.165	0.353	0.039	14.0	0.038	-0.118	0.1892	NO
BD1 (Mg m^{-3})	1.261	1.270	1.115	1.402	0.065	5.1	-0.291	-0.075	0.7308	NO
BD2 (Mg m^{-3})	1.254	1.262	1.055	1.400	0.083	6.6	-0.067	-0.493	0.2113	NO
RD1 (Mg m^{-3})	2.481	2.488	2.410	2.532	0.025	1.0	1.104	-0.961	0.0001	UN
RD2 (Mg m^{-3})	2.494	2.500	2.410	2.532	0.027	1.1	0.691	-0.575	0.0001	UN
TP1 (m^3 m^{-3})	0.490	0.487	0.432	0.548	0.028	5.8	-0.513	-0.0001	0.4427	NO
TP2 (m^3 m^{-3})	0.496	0.494	0.441	0.575	0.034	6.8	-0.357	0.384	0.1532	NO
SAND1 (g kg^{-1})	630.3	630.5	566	701	22.480	3.6	1.862	0.076	0,1867	NO
SAND2 (g kg^{-1})	604.7	604.0	529	691	31.273	5.2	0.778	-0.042	0,6093	NO
CLAY1 (g kg^{-1})	216.1	214.5	170	280	19.451	9.0	1.334	0.344	0,4645	NO
CLAY2 (g kg^{-1})	241.2	239.5	173	317	31.821	13.2	-0.052	0.018	0,4249	NO
SILT1 (g kg^{-1})	152.0	152.0	114	180	12.186	8.0	0.681	-0.469	0.5267	NO
SILT2 (g kg^{-1})	154.1	155.0	102	197	16.372	10.6	1.871	-0.121	0.0789	NO

[1]NL, Diam, HEI, TILL, are respectively the number of leaves, diameter, height and tiller; PR, GM, VM, BD, RD, TP, SAND, CLAY and SILT, 1 and 2, are respectively the penetration resistance, gravimetric moisture, volumetric moisture, bulk density, real density, total porosity, sand, clay and silt, at depths of 0-0.10 and 0.10-0.20 m; [2]FD: frequency distribution; NO and UN stand for, respectively, normal and undetermined.

Martins et al. (2009). GM magnitude (0.206 and 0.222 kg kg^{-1}) testified that PR data were obtained in an optimum soil moisture since it was at maximum friability (Table 1).

Total porosity affects water, air, nutrient, and root movements throughout soil profile. Thus, average porosity observed in this study, which was 0.49 m^3 m^{-3} for both depths, were close to those found by Souza et al. (2004), who studied peach palm cultivation in Oxisols (Table 1). For Kiehl (1979), these values of total porosity are close to an ideal agricultural soil, which advocates 0.50 m^3 m^{-3} as being suitable for increasing farming yield.

Regarding particle-size fractions, the following average values were observed for sand (630 and 604 g kg^{-1}); silt (152 and 154 g kg^{-1}) and clay (216 and 241 g kg^{-1}) at two studied depths. In addition, for real density averages we found 2.48 kg dm^{-3}. Souza et al. (2004), also studying soil texture and particle size in Oxisols, obtained different values for sand and clay, which were 80 g kg^{-1} and 760 g kg^{-1}, respectively. Thus, only confirms to the silt which was 160 g kg^{-1}. As for the real particle the averages were closer to the present study, being of 2.59 kg dm^{-3}.

Correlations between plant and soil attributes (Table 2) showed significance for the pairs NL × Clay (r = -0.281*); Diam × GM1 (-0.332*); Diam × GM2 (-0.275*); Diam × Sand1 (0.294*); Diam × Clay1 (-0.419**); Diam × Silt1 (0.324*); Hei × GM1 (-0.433**); Hei × GM2 (-0.331*); Hei × Sand2 (0.321*); Hei × Clay1 (-0.430**) and Hei × Clai2 (-0.333*) and ranged respectively inverse and direct.

Table 2. Simple linear correlation matrix between productive components of peach palm crop and soil physical attributes in Eutrochrept soils of Registro-SP, Brazil

Attributes [a]	Coefficient of correlation (b)																				
	NL	Diam	Hei	Till	PR1	PR2	GM1	GM2	VM1	VM2	BD1	BD2	RD1	RD2	TP1	TP2	SAND1	SAND2	CLAY1	CLAY2	SILT1
Diam	0.697**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hei	0.667**	0.927**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Till	0.188	0.115	0.120	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PR1	0.251	0.314*	0.320*	-0.098	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PR2	0.101	0.051	0.018	-0.020	0.558**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GM1	-0.133	-0.332*	-0.433**	0.212	-0.353	-0.118	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GM2	-0.083	-0.275*	-0.331*	0.174	-0.404**	-0.143	0.844**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
VM1	-0.135	-0.316	-0.436	0.162	-0.384**	-0.149	0.939**	0.187**	-	-	-	-	-	-	-	-	-	-	-	-	-
VM2	-0.061	-0.222	-0.281	0.218	-0.317 *	-0.118	0.765**	0.891**	0.783**	-	-	-	-	-	-	-	-	-	-	-	-
BD1	-0.057	-0.061	-0.143	-0.088	-0.225	-0.171	0.143	0.192	0.471**	0.299*	-	-	-	-	-	-	-	-	-	-	-
BD2	-0.022	0.001	-0.040	0.111	0.010	0.001	0.202	0.156	0.295*	0.577**	0.337*	-	-	-	-	-	-	-	-	-	-
RD1	-0.104	-0.057	0.036	-0.112	-0.076	-0.298	-0.348**	-0.180	-0.323*	-0.131	-0.014	0.008	-	-	-	-	-	-	-	-	-
RD2	-0.037	-0.065	-0.087	-0.099	-0.188	0.092	0.048	0.137	0.075	0.198	0.103	0.188	-0.078	-	-	-	-	-	-	-	-
TP1	0.001	-0.015	0.082	0.049	0.178	0.112	-0.177	-0.178	-0.486**	0.289*	-0.955**	-0.350**	0.204	-0.168	-	-	-	-	-	-	-
TP2	0.014	-0.006	0.037	-0.158	-0.024	0.006	-0.220	-0.158	-0.316*	-0.571**	-0.344*	-0.978**	0.003	-0.022	0.346*	-	-	-	-	-	-
SAND1	0.058	0.112	0.196	-0.013	-0.009	-0.119	-0.390**	-0.259	-0.331*	-0.180	0.057	0.080	0.151	0.030	-0.030	-0.077	-	-	-	-	-
SAND2	0.138	0.294*	0.321*	-0.066	0.107	-0.043	-0.599**	-0.640**	-0.564**	-0.584**	-0.098	-0.147	0.019	-0.126	0.099	0.137	0.509**	-	-	-	-
CLAY1	-0.281*	-0.419**	-0.430**	0.061	-0.141	0.128	0.521**	0.429**	0.434**	0.355**	-0.083	0.046	-0.112	0.026	0.071	-0.054	-0.717**	-0.660**	-	-	-
CLAY2	-0.128	-0.249	-0.333*	0.064	-0.251	-0.051	0.568**	0.598**	0.547**	0.549**	0.134	0.168	-0.108	0.099	0.160	-0.161	-0.447**	-0.867**	0.621**	-	-
SILT1	0.193	0.324*	0.220	-0.045	-0.009	0.001	0.150	0.098	0.191	0.101	0.181	0.035	-0.189	0.135	-0.221	0.005	-0.451**	-0.097	-0.109	0.066	-
SILT2	0.020	-0.086	0.030	0.007	0.281*	0.181	0.042	0.062	0.016	0.049	0.074	0.047	0.176	0.050	0.122	0.056	-0.103	-0.230	0.054	-0.288*	0.055

[1]NL, Diam, HEI, TILL, are respectively the number of leaves, diameter, height and tiller; PR, GM, VM, BD, RD, TP, SAND, CLAY and SILT, 1 and 2, are respectively the penetration resistance, gravimetric moisture, volumetric moisture, bulk density, real density, total porosity, sand, clay and silt, at depths of 0-0.10 and 0.10-0.20 m; [2] ** and *: significant at 1 and 5 %, respectively.

The inverse relationship (that is, when some attribute value increases another one decreases) of presented pairs shows that when Diam and Hei increase, the number of leaves also do. The inverse correlation between plant and soil moisture shows that pupunha not tolerate saturated soils, which leads to a decrease in plant development due to lack of oxygen in the soil.

Following the conventional classification by Will (2002), attribute combinations: NL × Clay1; Diam × Silt1; Diam × Sand2; Diam × PR1; Diam × GM1; Diam × GM2; Hei × PR1; Hei × GM2; Hei × Sand2; and Hei × Clay2 have presented moderate significance. However, combinations: Diam × Clay1, Hei × GM1 and Hei × Clay1 got great significance, while NL × Diam and NL × Hei had very high and Diam × Hei was the one with the best significance level, being presented as ideal.

In Table 2, another soil attribute that showed significant and positive correlation with productive components were resistance to penetration at 0.00-0.10 m and sand at 0.10-0.20 m depth. However, the clay presented positive and negative correlation with the vegetative components of peach palm In Figure 1, regression equations of the attributes are presented, given the following models: a) direct potential and b) direct exponential.

In Figure 1, it is observed a minimum PR1 value of 0.801 MPa, what is related to a palm stem diameter of 4.35 cm. In this way, a maximum PR1 of 1.562 MPa, reached a maximum diameter of 8.13 cm. As for Figure 1b, when occur the minimum value of PR1 (0.801 MPa) involve a minimum

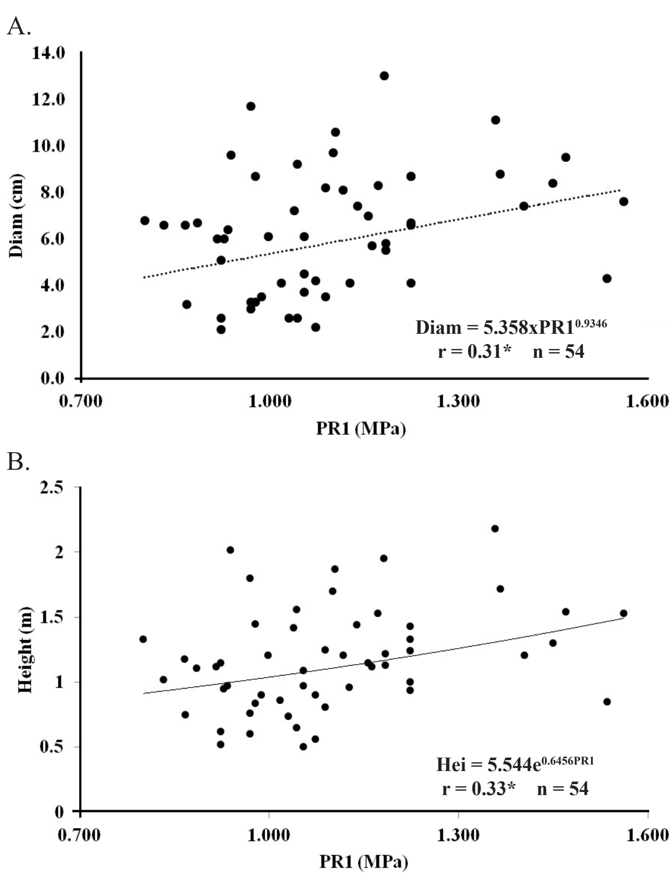

Figure 1. Regression equation between productive components of peach palm stem diameter (Diam, a) and plant height (Hei, b) with soil physical penetration resistance established for 0.00-0.10 m layer for Eutrochrept soils in Registro-SP, Brazil

height of peach palm (0.91 m). Thus, for RP1 maximum value (1.562 MPa), it will present the maximum palm height (1.49 m). Finally, when there is a greater resistance to penetration, diameter will increase and therefore the time for peach palm to adapt in a large variety of soils and be quite vigorous, enabling its use for degraded area recovery.

In the Table 3, the attributes NL, DIAM, PR1, GM2, VM2, SD1, TP1 and SILT1 showed very high spatial dependence (SDE=83.3 - 99.8 %) and PR2 high (SDE=78.8%), whose semivariogram models were exponential, spherical and gaussian. Moreover, those remaining (HEI, TILL, GM1, VM1, SD2, RD1, RD2, TP2, SAND1, SAND2, CLAY1, CLAY2 and SILT2) showed pure nugget effect.

Regarding semivariogram performance, there was a decreased ratio, analyzed by spatial coefficient of determination (r^2), which was as follows: 1) NL (0.972); 2) TP1 (0.965); 3) SD1 (0.919); 4) DIAM (0.894); 5) VM2 (0.805); 6) GM2 (0.768); 7) PR1 (0.649); 8) PR2 (0.555) and 9) SILT1 (0.435). In addition, with respect to spatial dependence evaluator (SDE), this ratio was: 1) DIAM (96.9); 2) PR1 (94.1); 3) SD1 (92.5); 4) GM2 (90.2); 5) SILT1 (90.1); 6) VM2 (87.6); 7) TP1 (84.3); 8) NL (83.3) and 9) PR2 (78.8).

In Table 3, the decreasing ratio of ranges of spatial dependence was as follows: 1) NL (13.3 m), 2) TP1 (12.42 m), 3) GM2 (10.95 m), 4) SILT1 (10.6) 5) VM2 (9.6 m), 6) SD (9.25 m), 7) Diam (8.3 m), 8) PR1 (7.2 m) and 9) PR2 (6.3 m). Therefore, solely on the basis of this research, as well as seeking to support future research in which the same attributes are involved, the values of the ranges of spatial dependence to be used in geostatistical packages that will feed the computer packages used in precision agriculture in general should not be smaller than 6.3 m for the soil attributes. On the other hand, solely for the attribute of the plant, not less than 8.43 m. According to Bottega et al. (2013), the range of values influencing the estimation of local not observed, since it determines the number of values used in interpolation. Thus, estimates with interpolation by ordinary kriging using larger ranges of values tend to be more reliable, with maps that better represent reality. Thus, estimates with kriging interpolation using larger ranges of values tend to be more accurate, with kriging maps that better represent reality.

In an initial comparison of simple kriging map for the production component (NL), whose parameters are semivariogramas in Table 3, it can be noted that there was high spatial direct similarity between NL and PR1. Thus, in Figure 2, it could be observed that in places where there were larger and/or smaller PR1, the same happened with NL. However, for the other soil attributes, such similarity has not occurred.

Co-kriging existing between NL × PR1 (Table 3, Fig. 2) may suggest that such attributes are good indicators of plant and soil physical quality, when we want to cultivate peach palm crop. Therefore, it can be recommended specific conservation tillage practices, targeted at certain areas, where PR1 resulted in the highest values, aiming to raise crop yield. These results are in agreement with Silva et al. (2010) who described the co-kriging as the spatial and/or temporal simultaneous two random variables that are strongly associated with each other making it possible to use this technique in estimating unsampled values.

Table 3. Parameters of simple and cross semivariograms for productive component of peach palm and soil physical attributes of Eutrochrept in Registro-SP, Brazil

Attributes [1]	Attributes										
	Model [2]	Nugget effect (C_0)	Sill ($C_0 + C$)	Range (A_0) (m)	r^2	RSS[3]	SDE[4]		Cross-validation		
							%	Class	a	b	r
γ(h) simple attributes of the plant											
NL	exp. (51)	$2.280x10^{-1}$	1.367	13.3	0.972	$3.430x10^{-3}$	83.3	VHD	2.15	0.620	0.33
DIAM	sph. (51)	$2.200x10^{-1}$	7.126	8.43	0.894	$2.96x10^{1}$	96.9	VHD	5.32	0.161	0.09
HEI	pne.	$1.532x10^{-1}$	$1.532x10^{1}$	-	-	-	-	-	-	-	-
TILL	pne.	6.56	6.56	-	-	-	-	-	-	-	-
γ(h) simple attributes of physical soil											
PR1	sph. (51)	$1.600x10^{-3}$	$2.73x10^{-2}$	7,2	0.649	$7.504x10^{-6}$	94.1	VHD	1.10	-0.012	0.00
PR2	gaus. (50)	$2.690x10^{-2}$	$1.268x10^{-1}$	6.3	0.555	$2.545x10^{-4}$	78.8	HID	1.37	0.310	0.109
GM1	pne.	$7.860x10^{-4}$	$7.860x10^{-4}$	-	-	-	-	-	-	-	-
GM2	exp. (51)	$5.600x10^{-5}$	$5.710x10^{-4}$	10.95	0.768	$4.110x10^{-9}$	90.2	VHD	$2.1x10^{1}$	0.074	0.032
VM1	pne.	$1.540x10^{-3}$	$1.540x10^{-3}$	-	-	-	-	-	-	-	-
VM2	exp. (51)	$1.940x10^{-4}$	$1.568x10^{-3}$	9.6	0.805	$1.620x10^{-8}$	87.6	VHD	$1.2x10^{1}$	0.581	0.237
SD1	gaus. (51)	$3.100x10^{-4}$	$4.160x10^{-3}$	9.25	0.919	$2.289x10^{-7}$	92.5	VHD	$1.2x10^{1}$	0.908	0.962
SD2	pne.	$7.210x10^{-3}$	$7.210x10^{-3}$	-	-	-	-	-	-	-	-
RD1	pne.	$5.800x10^{-4}$	$5.800x10^{-4}$	-	-	-	-	-	-	-	-
RD2	pne.	$6,630x10^{-4}$	$6.630x10^{-4}$	-	-	-	-	-	-	-	-
TP1	sph. (51)	$1.340x10^{-4}$	$8.510x10^{-4}$	12.42	0.965	$2.966x10^{-9}$	84.3	VHD	$1.0x10^{1}$	0.795	0.474
TP2	pne.	$1.156x10^{-3}$	$1.156x10^{-3}$	-	-	-	-	-	-	-	-
SAND1	pne.	$5.243x10^{2}$	$5.243x10^{2}$	-	-	-	-	-	-	-	-
SAND2	pne.	$9.945x10^{2}$	$9.945x10^{2}$	-	-	-	-	-	-	-	-
CLAY1	pne.	$3.377x10^{2}$	$3.377x10^{2}$	-	-	-	-	-	-	-	-
CLAY2	pne.	$1.036x10^{3}$	$1.036x10^{3}$	-	-	-	-	-	-	-	-
SILT1	exp. (51)	$1.450x10^{1}$	$1.459x10^{2}$	10.6	0.435	$5.100x10^{2}$	90.1	VHD	$1.24x10^{2}$	0.179	0.077
SILT2	pne.	$2.356x10^{2}$	$2.356x10^{2}$	-	-	-	-	-	-	-	-
y(h) cross plant x soil											
NL=f(PR1)	gaus. (51)	$1.000x10^{-2}$	$5.870x10^{-2}$	9.94	0.619	$6.394x10^{-4}$	99.8	VHD	3.51	0.372	0.279

[1] NL, Diam, HEI, TILL, are respectively the number of leaves, diameter, height and tiller; PR, GM, VM, BD, RD, TP, SAND, CLAY and SILT, 1 and 2, are respectively the penetration resistance, gravimetric moisture, volumetric moisture, bulk density, real density, total porosity, sand, clay and silt, at depths of 0-0.10 and 0.10-0.20 m; parentheses after model: number of pairs in the first lag; [2] sph: spherical, exp: exponential, gaus: gaussian, pne: pure nugget effect [3] RSS: sum of squared residuals, [4] SDE: spatial dependence evaluator, and HID: high dependence, and VHD: very high dependence.

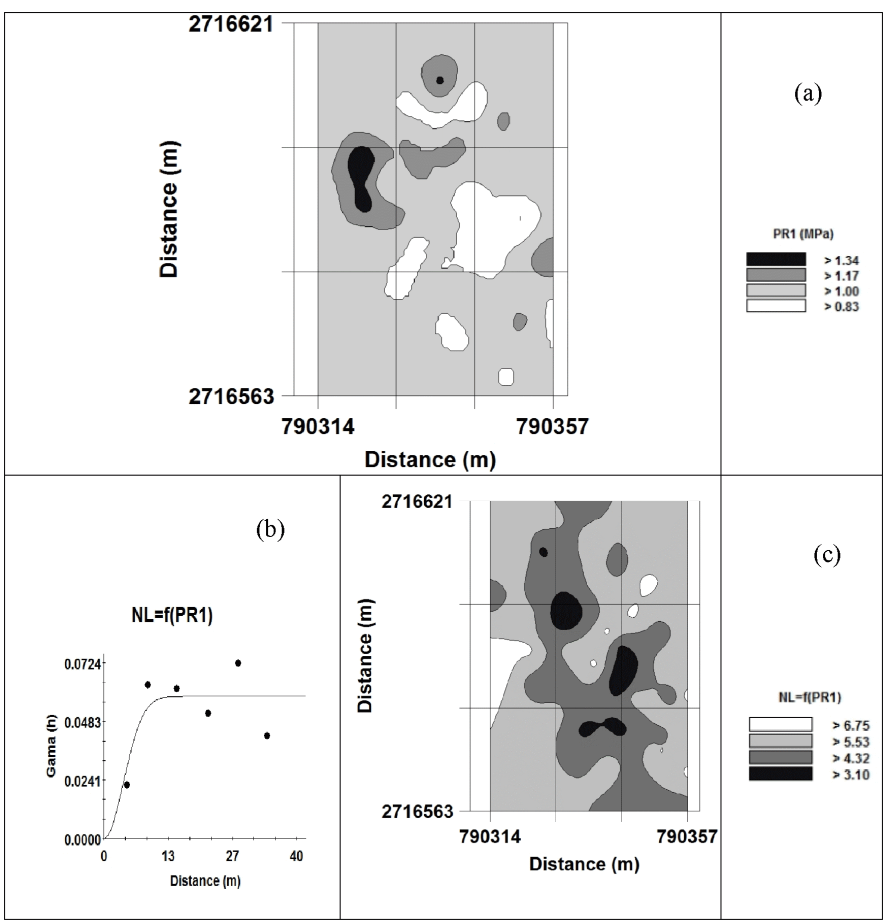

Figure 2. Kriging map of PR1 (a), cross-semivariogram (b) and co-kriging map of number of leaves (NL) (c) in function of penetration resistance at 0.00-0.10 m depth

Conclusions

Average values of soil bulk density and penetration resistance were in the respective ranges of 1,254 - 1,261 kg dm^{-3} and 1,095 - 2,007 MPa, promoted a substantial decrease of peach palm productive components.

With regard to linear point of view, stem diameter and palm height was explained by direct and exponential model, which was highly significant, due to mechanical resistance to penetration.

Spatially speaking, number of leaves could be estimated through direct co-kriging by mechanical penetration resistance. Thus, values higher than 1.00 MPa for this soil attribute have indicated sites with greater yield.

Literature Cited

Bottega, E. L.; Queiroz, D. M.; Pinto, F. A. C.; Souza, C. M. A. Variabilidade espacial de atributos do solo em sistema de semeadura direta com rotação de culturas no cerrado brasileiro. Revista Ciência Agronômica, v. 44, n. 1, p. 1-9, 2013. <http://dx.doi.org/10.1590/S1806-66902013000100001>.

Bovi, M. L. A.; Júnior, G. G.; Costa, E. A. D.; Berton, R. S.; Spiering, S. H.; Vega, F. V. A.; Cembranelli, M. A. R.; Maldonado, C. A. B. Lodo de esgoto e produção de palimito em pupunheira. Revista Brasileira de Ciência do Solo, v. 3, n. 1, p. 153-166, 2007. <http://dx.doi.org/10.1590/S0100-06832007000100016>.

Carvalho, G. J.; Carvalho, M. P.; Freddi, O. S.; Martins, M. V. Correlação da produtividade do feijão com a resistência à penetração do solo sob plantio direto. Revista Brasileira de Engenharia Agrícola e Ambiental, v. 10, n. 3, p. 765-771, 2006. <http://dx.doi.org/10.1590/S1415-43662006000300033>.

Casalinho, H. D.; Martins, S. R. Qualidade do solo como indicador de sustentabilidade em agroecossistemas: avaliações integrando os conhecimentos acadêmicos e não-acadêmicos. In: Canuto, J. C.; Costabeber, J. A. (Eds.). Agroecologia: Conquistando a soberania alimentar. Porto Alegre: Emater/RS; Ascar, 2004. p. 212-225.

Cavallini, M. R.; Andreotti, M.; Oliveira, L. L.; Pariz, C. M.; Carvalho, M. P. Relações entre produtividade de *Brachiaria brizantha* e atributos físicos de um Latossolo do Cerrado. Revista Brasileira de Ciência do Solo, v. 34, n. 4, p. 1007-2015, 2010. <http://dx.doi.org/10.1590/S0100-06832010000400001>.

Dalchiavon, F. C.; Carvalho, M. P. Correlação linear e espacial dos componentes de produção e produtividade da soja. Semina: Ciências Agrárias, v. 33, n. 2, p. 541-552, 2012. <http://dx.doi.org/10.5433/1679-0359.2012v33n2p541>.

Empresa Brasileira de Pesquisa Agropecuária - Embrapa. Manual de métodos de análise de solos. 2ed. Rio de Janeiro: Embrapa, 1997. 212p.

Empresa Brasileira de Pesquisa Agropecuária - Embrapa. Sistema brasileiro de classificação de solos. 3. ed. Rio de Janeiro: Embrapa, 2013. 306 p.

Falcão, N. P. S.; Silva, J. R. A.; Clement, C. R. Caracterização de sintomatologia de carências nutricionais em mudas de pupunheira (*Bactris gasipaes* Kunth), cultivada em solução nutritiva. In: Reunião Brasileira de Fertilidade do Solo e Nutrição de Plantas, 23., Caxambu, 1998. Anais... Lavras: UFLA; SBS; SBM, 1998. p.11-16.

Freddi, O. S.; Carvalho, M. P.; Centurion, J. F.; Barbosa, G. F. Variabilidade espacial da produtividade do feijão em um Latossolo Vermelho distroférrico sob preparo convencional e plantio direto. Acta Scientiarum. Agronomy, v. 27, n. 1 p. 61-67, 2005. <http://dx.doi.org/10.4025/actasciagron.v27i1.1924>.

GS+. Geostatistics for environmental sciences. 7.ed. Plainwell: Gamma Design Software, 2004. 159p.

Instituto Brasileiro de Geografia e Estatística - IBGE. Censo agropecuário 2006. - Brasil, grandes regiões e unidades da federação. Rio de Janeiro: IBGE, 2009. 775p. <http://biblioteca.ibge.gov.br/visualizacao/periodicos/51/agro_2006.pdf>. 04 Jul. 2014.

Kiehl, E. J. Manual de edafologia. São Paulo: Agronômica Ceres, 1979. 262p.

Martins, M. V.; Carvalho, M. P.; Andreotti, M.; Montanari, R. Correlação linear e espacial entre a produtividade do feijoeiro e atributos físicos de um Latossolo Vermelho distroférrico de Selvíria, Estado de Mato Grosso do Sul. Acta Scientiarum. Agronomy, v. 31, n. 1, p. 147-154, 2009. <http://dx.doi.org/10.4025/actasciagron.v31i1.6641>.

Montanari, R.; Carvalho, M. P.; Andreotti, M.; Dalchiavon, F. C.; Lovera, L. H.; Honorato, M. A. O. Aspectos da produtividade do feijão correlacionados com atributos físicos do solo sob elevado nível tecnológico de manejo. Revista Brasileira de Ciência do Solo, v. 34, n. 6, p. 1811-1822, 2010.<http://dx.doi.org/10.1590/S0100-06832010000600005>.

Pimentel-Gomes, F. P.; Garcia, C. H. Estatística aplicada a experimentos agronômicos e florestais. Piracicaba: FEALQ, 2002. 309p.

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, v. 33, n. 2, p. 283-293, 2009. <http://dx.doi.org/10.1590/S0100-06832009000200006>.

Santos, P. A.; Carvalho, M. P.; Freddi, O. S.; Kitamura, A. E.; Freitas, E. E.; Vanzela, L. S. Correlação linear e espacial entre o rendimento de grãos do feijoeiro e a resistência mecânica à penetração em um Latossolo Vermelho distroférrico. Revista Brasileira de Ciência do Solo, v. 29, n. 2, p. 287-295, 2005. <http://dx.doi.org/10.1590/S0100-06832005000200014>.

Schlotzhaver, S. D.; Littell, R. C. SAS system for elementary statistical analysis. 2.ed. Cary, SAS, 1997. 456p.

Silva, S. A.; Lima, J. S. S.; Souza, G. S.; Oliveira, R. B.; Silva, A. F. Variabilidade espacial do fósforo e das frações granulométricas de um Latossolo Vermelho Amarelo. Revista Ciência Agronômica, v. 41, n. 1, p. 1-8, 2010. <http://www.ccarevista.ufc.br/seer/index.php/ccarevista/article/view/442>. 31 Jan. 2016.

Souza, M. Z.; Leite, J. A.; Beutler, A. N. Comportamento de atributos físicos de um Latossolo Amarelo sob agroecossistemas do Amazonas. Engenharia Agrícola, v. 24, n. 3, p. 654-662, 2004. <http://dx.doi.org/10.1590/S0100-69162004000300017>.

Stolf, R. Teoria e teste experimental de fórmulas de transformação dos dados de penetrômetro de impacto em resistência do solo. Revista Brasileira de Ciência do Solo, v. 15, n. 3, p. 229-235, 1991.

Trintinalio, J.; Tormena, C. A.; Oliveira, J. R. R.; Machado, J. L. Constantin, J. Alterações nas propriedades físicas e químicas de um Latossolo Vermelho distrófico por diferentes manejos na entrelinha da cultura da pupunha (*Bactris gasipaes* Kunth). Acta Scientiarum. Agronomy, v. 27, n.4,p.753-759,2005. <http://dx.doi.org/10.4025/actasciagron.v27i4.1343>.

Will, G. H. A new view of statistics - a scale of magnitudes for effect statistics. 2002. <http://www.sportsci.org/resource/stats/effectmag.html>. 04 Jun. 2015.