STRATEGY OF SPECIFICATION OF MANAGEMENT AREAS: RICE GRAIN YIELD AS RELATED TO SOIL FERTILITY[1]

Flávio Carlos Dalchiavon[2], Morel de Passos e Carvalho[3], Rafael Montanari[3] & Marcelo Andreotti[3]

SUMMARY

It is well-known nowadays that soil variability can influence crop yields. Therefore, to determine specific areas of soil management, we studied the Pearson and spatial correlations of rice grain yield with organic matter content and pH of an Oxisol (Typic Acrustox) under no- tillage, in the 2009/10 growing season, in Selvíria, State of Mato Grosso do Sul, in the Brazilian Cerrado (longitude 51º 24' 21" W, latitude 20º 20' 56" S). The upland rice cultivar IAC 202 was used as test plant. A geostatistical grid was installed for soil and plant data collection, with 120 sampling points in an area of 3.0 ha with a homogeneous slope of 0.055 m m^{-1}. The properties rice grain yield and organic matter content, pH and potential acidity and aluminum content were analyzed in the 0-0.10 and 0.10-0.20 m soil layers. Spatially, two specific areas of agricultural land management were discriminated, differing in the value of organic matter and rice grain yield, respectively with fertilization at variable rates in the second zone, a substantial increase in agricultural productivity can be obtained. The organic matter content was confirmed as a good indicator of soil quality, when spatially correlated with rice grain yield.

Index terms: precision agriculture, soil fertility, geostatistics, spatial variability, *Oryza sativa*.

---

(1) Part of the first author's dissertation Masters in Agronomy, concentration area in Production Systems, presented at the Universidade Estadual Paulista "Julio de Mesquita Filho". Received for publication on June 8, 2012 and approved on December 5, 2012.

(2) Professor Doutor, Instituto Federal de Mato Grosso, Campus Campo Novo do Parecis, Departamento de Agronomia, Rodovia MT 235, Km 12, Zona Rural, Caixa Postal 100. CEP 78360-000. Campo Novo do Parecis (MT). E-mail: flavio.dalchiavon@cnp.ifmt.edu.br

(3) Professor Doutor, UNESP/FEIS - Departamento de Fitossanidade, Engenharia Rural e Solos, Av. Brasil, 56, Centro. CEP 15385-000, Ilha Solteira. (SP), Brasil. E-mail: morel@agr.feis.unesp.br; montanari@agr.feis.unesp.br; dreotti@agr.feis.unesp.br

RESUMO: *ESTRATÉGIA PARA A CRIAÇÃO DE ZONAS ESPECÍFICAS DE MANEJO: A PRODUTIVIDADE DE GRÃOS DE ARROZ EM FUNÇÃO DA FERTILIDADE DO SOLO*

Atualmente, sabe-se que a variabilidade do solo pode influenciar a produtividade das culturas agrícolas. Assim, durante o ano agrícola 2009 / 10, no município de Selvíria, Estado do Mato Grosso do Sul, situado no Cerrado brasileiro (longitude 51º 24' 21" W e latitude 20º 20' 56" S), foram estudadas as correlações (Pearson e a espacial) da produtividade de grãos de arroz com o teor de matéria orgânica e pH de um Latossolo Vermelho distroférrico (Typic Acrustox), sob plantio direto, objetivando-se determinar zonas específicas de manejo do solo. A planta-teste empregada foi o cultivar de arroz de terras altas IAC 202. Instalou-sea malha geoestatística para a coleta de dados do solo e da planta, com 120 pontos amostrais, numa área de 3,0 ha e declive homogêneo de 0,055 m m^{-1}. Os atributos pesquisados foram a produtividade de grãos de arroz e os teores de matéria orgânica, pH e acidez potencial e o teor de alumínio, nas camadas de 0-0,10 e 0,10-0,20 m do solo. Espacialmente, observaram-se duas zonas específicas de manejo agrícola do solo. A primeira, com os maiores valores da matéria orgânica e da produtividade de grãos de arroz; e, a segunda, com os menores. Efetuando-se adubações com taxas variáveis na segunda zona, poderá ser obtido substancial aumento dessa produtividade agrícola. O teor de matéria orgânica confirmou ser bom indicador da qualidade do solo, quando correlacionado espacialmente com a produtividade de grãos de arroz.

Termos de indexação: agricultura de precisão, geoestatística, variabilidade espacial, Oryza sativa.

INTRODUCTION

Rice (*Oryza sativa* L.) is a staple food of mankind (Walter et al., 2008). In Brazil, in areas where the agricultural technology level is high, upland rice can yield up to 4,000 kg ha^{-1}. However, in the 2009/10 growing season, the average national yield of upland and irrigated rice together was 4,073 kg ha^{-1} and on average 5,490 kg ha^{-1} in the State of Mato Grosso do Sul (CONAB, 2010). Due to economic reasons, the new upland rice cultivars are being grown in no-tillage (NT) systems, representing a viable option for a more sustainable agriculture in the Cerrado (Brazilian savannah-like region) (Cazetta et al., 2008).

Under natural conditions, the Brazilian agricultural soils are little fertile, typically with low contents of exchangeable cations, high acidity and aluminum toxicity. Specifically with regard to Oxisol, under natural conditions and with minimal human intervention, the surface values of bulk density are 0.98-1.13 kg dm^{-3}, total porosity 0.61-0.67 m^3 m^{-3} and penetration resistance of around 1.32 MPa (Carneiro et al., 2009).

In Brazil, precision agriculture is at a stage where farmers are seeking solutions to the problems of implementation(Molin & Rabello, 2011). One of the most urgent needs is to obtain plant yield maps that are spatially correlated with maps of soil nutrients, in order to define specific management areas (Coelho, 2003; Molin et al., 2007; Werner et al., 2007). For this purpose, geostatistics is used inanalyses of the spatial variability of yield-related soil properties, represented by ageostatistical model (Corá et al., 2004; Barbieriet al., 2008; Amado et al., 2009; Rosa Filho et al., 2009; Montanari et al., 2012). Some of thestudiedvalues were: a) range of the rice yield (Yanai et al., 2001) and b) of common bean yield (Amado et al., 2009), with ranges between 14.7 and 561.0 m.

In view of the evident lack of studies involving rice cultivation, from the point of view of precision agriculture, the objective of this work was to study the Pearson and spatial correlations of rice grain yield with organic matter content and pH of an Oxisol - Latossolo Vermelho distroférrico (Typic Acrustox) of the Cerrado, in order to determine specific areas of land management to obtain higher agricultural yields.

MATERIAL AND METHODS

The study was conducted in Selvíria, Mato Grosso do Sul, (longitude 51º 24' 21" W and latitude 20º 20' 56" S, average altitude 342 m asl). The local soil is a dystropherric Red Latosol - Latossolo Vermelho distroférrico (Typic Acrustox).Particle-size analysis (of the 0.0-0.30 m layer) indicated the contents: 620 g kg^{-1} clay, 100 g kg^{-1} silt, 60 g kg^{-1} coarse sand, and 220 g kg^{-1} fine sand.The regional climate is megathermic tropical humid (A_w), characterized by rainy summers with high temperatures and dry winters. The average annual rainfall, temperature and relative humidity are, respectively,1,232 mm; 24.5 ºC and 70-80 %.In the experimental period (from sowing on 11/13/2009 toharvest on 03/01/2010), there was a total of 822 mm of rain.

The experimental areahad been used for 11 years for no-tillage crop rotation, with corn and soybean in the summer and common bean, corn and millet in the winter (physicochemical characterization of 06/15/2009 in tables 1 and 2).

The crops that preceded the experiment were soybean (summer) and corn (winter).Since the experimental area was initially infested by weeds, it was first desiccated (11/09/2009) with200 L $ha^{-1}$of the glyphosate (N-phosphonomethyl glycine) mixture,4 L ha^{-1}, and 2.4-D (2,4-dichlorophenoxy acetic acid), 1 L ha^{-1}. The rice cultivar IAC 202 was sown(11/13/2009) in no-tillage, in a row spacing of 0.34 m and density of 230 seeds m^{-2}. At sowing,100 kg ha^{-1} of NPK fertilizer (08-28-16) was applied. Top dressing was performed 20 and 44 days after sowing (DAS),when 200 kg $ha^{-1}$of ammonium sulfate was applied each time. During the grain filling stage(93 DAS, 02/14/2009), the experimental area was flooded (water depth 13 mm). The crop was harvested by hand 108 DAS (03/01/2010), followed by mechanical threshing and natural drying of the grains in the shade.

The experimental area consisted of three agricultural terraces, outlining two areas with a general soil slope of 0.055 m m^{-1}.The width,in the slope direction, was 93.35 m (axis y), and the length 322.00 m (x axis), i.e., a totalarea of 30,058.7 m^2. For the establishment of the experimental points on the area 15 DAS, a common optical level and Cartesian coordinates (x, y) were used to make the evaluation of the spatial dependence among the observed values possible.Next, (20 DAS) 120 random sample points were distributed over the entire experimental area, marking each location with bamboo poles. The shortest and longest distance between the points was, respectively, 5.4 and 34.0 m, averaging a total area of 250.00 m^2 (15.81 x 15.81 m). Figure 1 shows the diagram with the experimental points, determined according to the cardinal directions: N (north), NE (northeast), NW (northwest), S (south), SE (southeast), SW (southwest), E (east), W (west) and Center.

For all soil and plant properties, individual samples were collected from the crop interrows and close to the points (stakes). The following soil chemical properties were analyzed: organic matter (OM), hydrogen potential (pH in $CaCl_2$), potential acidity (H+Al) and exchangeable aluminum (Al^{3+}), according

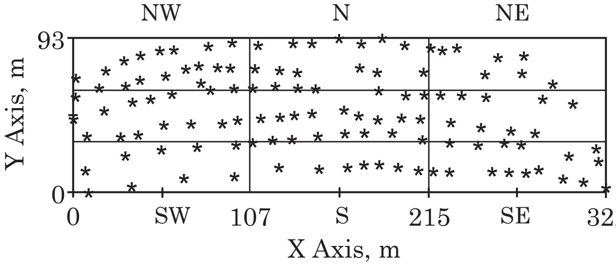

Figure 1. Diagram of the experimental geostatistical field.

to Raij et al. (2001). The soil physical properties for the initial soil characterization were determined according to Embrapa (1997). For this purpose, the deformed samples were collected with a hand auger (diameter = 0.08 m, height = 0.20 m, volume = 0.001 m^3), on 03/04/2010, from two layers, where (1) represented layer 0-0.10 m and (2) layer 0.10-0.20 m. Of the plants, the rice grain yield (GY) was measured at harvest time. Thus, the following nine properties were studied: GY, OM1, OM2, pH1, pH2, H+Al1, H+Al2, Al1 and Al2. The GY was determined by weighing the grains harvested in the vicinity of the sampling points, in four plant rows in an area of 1.85 m^2 (1.36 x 1.36 m) and calculated as kg ha^{-1} of husked grains, based on a moisture content of 13 %.

For each property, classical descriptive analysis was performed using SAS (Schlotzhaver & Littell, 1997), in which the mean, median, minimum and maximum values, standard deviation, coefficient of variation, kurtosis, asymmetry and frequency were calculated. Next, the outlierswere identified, replacing them by the averageof the neighboringvalues in the geostatistical mesh. To test the hypothesis of normality, or lognormality of the properties, the Shapiro & Wilk (1965) test was applied.

The Pearson correlation matrix was prepared to correlate the linear combinations, two by two, for all properties studied, and also to present the analysis of regressions for the pairs of major interest. Those with higher linear correlations, and that could present cross-semivariograms and resulting co-kriging were selected. The spatial dependence was analyzed by calculating the semivariogram for each property separately. However, for those with spatial interdependence, their cross-semivariograms were also calculated, based on intrinsic stationarity hypothesis assumptions, using the *Gamma Design Software7.0* (GS^+, 2004). The simple and cross-semivariograms, depending on their models, were adapted according to: 1) lower residual squared sums (RSS); 2) highest coefficient of determination (r^2), and 3) spatial dependence evaluation (highest value)(SDE). However, for the properties (ATR) with no spatial dependence, that is, in the absence of stationarity, the data trend was removed by the polynomial multiple regression technique. Thus, they were preceded by the symbol # when referred to in the semivariographic analysis and cross-validation (#ATR). However when referred to in the kriging and/or co-kriging map, they were preceded by £ (£ATR).

The final decision of the model, which represented the adaptation, was performed by cross-validation. To define the size of the neighborhood that provided the best kriging or co-kriging mesh, block kriging was performed. For each property, the nugget effect (C_o), the range (A_o) and sill ($C_o + C$) were related. The spatial dependence evaluation (SDE) wasclassified as follows: a) SDE < 20 % = very low spatial dependence of the variable (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 known that cross-validation is a tool to evaluate alternative models of simple and cross semivariograms, for kriging and co-kriging. During the analysis, each point within the 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. The correlation coefficient (r) between these values reflects the adjustment efficiency, given by the sum of squared deviations 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 the perfect model, i.e., with a linear coefficient of zero and angle of 1 (GS^+, 2004). Thus, in order to obtain the optimal number of neighboring points, kriging and co-kriging maps were obtained through interpolation for the analysis of dependence and interdependence between the spatial properties. The geostatistical components simple semivariogram, cross semivariogram, cross-validation, kriging and co-kriging were established.

RESULTS AND DISCUSSION

The data showed an average organic matter content, medium and high acidity pH, medium P content, high to very high K content, high Ca and Mg, and average base saturationof the soil (Table 1) (Raij et al., 1997). The average base saturation, measured between the two layers, was51%. Therefore, lime was not applied in the area since the recommended threshold for rice cultivation suggests raising base saturation to 50 %. In terms of soil fertility, no nutritional limitations for rice were detected in the study area. However, from the standpoint of soil physics (Table 2), the compaction level was high (PR = 2.98 MPa), soil density high (Ds = 1.50 kg dm^{-3}) and total porosity low (TP = 0.44 $m^3 m^{-3}$) (Oliveira & Moniz, 1975; Arshad et al., 1996; Montanari et al., 2012).

The properties studied (Table 3) showed low pH variability, with coefficients of variation (CV) between 6.9 and 7.8 %, average organic matter variability (CV = 12.9-14.8 %), high variability for grain yield and potential acidity (CV = 22.2-24.0 %),and very high variability for aluminum (CV = 63.4-86.3 %). The high variability of the latter was due to the high frequency of null values observed.

Carvalho-Pupatto et al. (2004) reported agrain yield of the rice cultivar (IAC 202) of 5491 kg ha^{-1}, which is substantially lower than the average yield of 5980 kg ha^{-1} (Table 3) obtained in this study. Compared to the national average (4073 kg ha^{-1}) and the average for Mato Grosso do Sul (5490 kg ha^{-1}) (CONAB, 2010), the rice yield in this study was 47 and 9 % higher, respectively.

The yield in this study was high (Table 3), in agreement with the considerable soil nutrient contents (Table 1). However, the high yield was unexpected in view of thedata of soil physical properties, since the values of PR, Dsand TP (Oliveira & Moniz, 1975; Arshad et al., 1996) (Table 2) indicated a drastic soil compaction level, which usually results in a substantial decrease of the cellular respiration rate of the plantsand a consequent yield drop. Thus, knowing that the total pluvial precipitation in the experimental period (822 mm) was 37 % higher than necessary for upland rice (600 mm), it can be assumed that despite the drastic soil compaction, the high GY may have been a result of the overall good conditions, soil fertility as well as rainfall, which prevailed during the test period. The reason is that, according to Medeiros et al. (2005), since rice is highly responsive to irrigation, the amount of precipitation during its development cycle induced the yield increase under no-tillage (NT). Also, according to Guimarães et al. (2006), soil compaction under NT causes no major problems for rice cultivation, as long as fertility and water availability are granted.

The Pearson correlation matrix (Table 4) showed that GY was not significantly related with all soil properties studied. However, for organic matter (OM) at both depths, GY was directly and inversely correlated with pH and Al, respectively. The lack of significance between GY and OM contents was due to the high number of observations (n=120), as well as the lack of variation required for the geostatistical study (Dalchiavon et al., 2011). In similar studies,

Table 1. Analysis of some chemical propertiesof the fertility of the Typic Acrustox soil studied

Depth	OM	pH ($CaCl_2$)	P	K^+	Ca^{2+}	Mg^{2+}	H+Al	Al^{3+}	SB	CEC	V	m
m	g dm^{-3}		mg dm^{-3}				$mmol_c$ dm^{-3}				%	
0-0.10	32	5.2	34	6.6	27	20	40	0	53.6	93.6	57.0	0
0.10-0.20	24	4.8	36	4.3	19	13	47	4.0	36.3	83.3	44.0	10.0

(1) OM: organic matter, SB: sum of bases, CEC: cation exchange capacity, V%: base saturation index, m%: aluminum saturation index.

this fact had already been observed for soybean yield and macroporosity, microporosity, total porosity, and soil density (Andreotti et al., 2010), as well as for the volume of eucalyptus wood and soil OM (Lima et al., 2010). Therefore, although no significance was observed in this study, one can infer, according to Silva & Mendonça (2007), a likely crop yield increase, also due to the increased organic matter content in

Table 2. Analysis of some physical properties of theTypic Acrustox studied

Depth	Porosity[(1)]			BD	PR	GM	VM
	MA	MI	TP				
m		$m^3\ m^{-3}$		$kg\ dm^{-3}$	MPa	$kg\ kg^{-1}$	$m^3\ m^{-3}$
0-0.10	0.072	0.367	0.439	1.511	2.989	0.214	0.323
0.10-0.20	0.075	0.362	0.437	1.493	2.958	0.221	0.330

(1) MA: macroporosity, MI: microporosity, TP: total porosity, BD: bulk density, PR: penetration resistance, GM: gravimetric moisture, VM: volumetric moisture.

Table 3. Descriptive analysis of rice grain yield and some chemical properties of Typic Acrustox under no tillage

Property[(1)]	Descriptive statistical									
	Mean	Average	Valor		Standard deviation	Coefficient			Test probability[(2)]	
			Minimum	Maximum		Variation (%)	Kurtosis	Asymmetry	Pr<w	FD
GY ($kg\ ha^{-1}$)	5980	5933	2365	9117	1328	22.2	0.069	0.071	0.715	NO
OM1 ($g\ dm^{-3}$)	25.6	25.0	19.0	34.0	3.30	12.93	-0.323	0.342	0.001	UD
OM2 ($g\ dm^{-3}$)	20.1	20.0	12.0	28.0	2.96	14.76	0.223	0.126	0.005	UD
pH1	4.9	4.8	4.2	6.0	0.38	7.80	0.096	0.666	0.001	UD
pH2	4.6	4.6	4.0	5.6	0.32	6.91	0.605	0.726	$5x10^{-4}$	UD
H+Al1 ($mmol_c\ dm^{-3}$)	49.8	50.0	16.0	80.0	11.14	22.40	0.510	-0.036	0.134	NO
H+Al2 ($mmol_c\ dm^{-3}$)	58.3	58.0	15.0	98.0	14.00	24.01	0.678	-0.155	0.357	NO
Al1 ($mmol_c\ dm^{-3}$)	5.7	4.0	0	19.0	4.91	86.32	-0.019	0.877	10^{-4}	UD
Al2 ($mmol_c\ dm^{-3}$)	11.6	10.0	0	31.0	7.35	63.36	0.558	-0.247	0.023	TL

(1)GY, OM, pH, H+Al and Al, 1 and 2, are respectively the rice grain yield, organic matter content, hydrogen potential, acidity potential and exchangeable aluminum,at 0-0.10 and 0.10-0.20 m; (2)FD: frequency distribution; NO,UD and TL stand for,respectively, normal,undetermined and lognormal FD.

Table 4. Matrix of simple linear correlation between rice grain yield and some chemical properties of a Typic Acrustoxunderno-tillage

Property[(1)]	Coefficient of correlation[(1)]							
	GY	OM1	OM2	pH1	pH2	H+Al1	H+Al2	Al1
OM1	-0.08							
OM2	0.03	0.57**						
pH1	-0.13	0.24**	0.24**					
pH2	-0.07	0.20*	0.29**	0.77**				
H+Al1	0.14	-0.11	-0.04	-0.90**	-0.69**			
H+Al2	-0.07	-0.01	-0.02	-0.66**	-0.83**	0.74**		
Al1	0.14	-0.33**	-0.27**	-0.86**	-0.67**	0.85**	0.59**	
Al2	-0.04	-0.21*	-0.30**	-0.71**	-0.89**	0.67**	0.89**	0.70**

(1)GY, OM, pH, H+Al and Al, 1 and 2, are respectively, the rice grain yield, organic matter content, hydrogen potential, acidity potential and exchangeable aluminum, at depths of 0-0.10 and 0.10-0.20 m; (2) ** and *: significant at 1 and 5 %, respectively.

the soil, especially by the observed correlations between OM and pH and Al.

Although the normality of the data studied is one of the assumptions of classical statistics, it is not a geostatistical requirement. More important than data normality is the occurrence or non-occurrence of the proportional effect, where the mean and variance of the data are not constant in the study area. An analysis of our results (Table 5) showed that all properties studied were spatially dependent. In other words, the behavior of regionalized variables was not random, and the distances used in the observations were sufficient to detect this dependence.

Thus, the performance of the semivariograms, analyzed by the decreasing spatial correlation coefficients (r^2), was: 1) OM2 (0.993), 2) pH1 (0.969), 3) pH2 (0.942), 4) H+Al1 (0.942), 5) Al1 (0.940), 6) OM1 (0.883), 7) Al2 (0.788), 8) #GY (0.771) and 9) H+Al2 (0.684). As shown, only for #GY a tendency was detected in the data. On the other hand, in decreasing order, the geostatistical ranges were: 1) OM2 (73.2 m), 2) pH1 (62.0 m), 3) pH2 (60.0 m), 4) H+Al2 (58.6 m), 5) H+Al1 (55.5 m), 6) Al2 (53.4 m), 7) OM1 (50.1 m), 8) Al1 (47.2 m) and 9) #GY (47.0 m), with an average value of 56.3 m between the fourth (H+Al2) and fifth (H+Al1) ranges.

The properties OM2, pH1, pH2 and H+Al2 showed, in decreasing order, the largest ranges, with values between 73.2 m (OM2) and 58.6 m (H+Al2). Similarly, the properties H+Al1, Al2, OM1, Al1 and #GY (Table 5) showed, in decreasing order, the smallest ranges, with values between 55.5 m (H+Al1) and 47.0 m (# GY), suggesting, based on the proximity of values, that rice yield can be spatially associated with Al toxicity in the area. However, this assumption was in contradiction with Corá et al. (2004), whostated that the range value can influence the quality of the kriging map, as it determines the number of values used for interpolation. Accordingly, for the estimates based on kriging interpolation, the highest ranges tend to be more reliable, resulting inmore realistic maps. In similar studies in the future, the distance ranges to be used in geostatistical packages to feed the precision agriculture software should, in general, not be less than 47.0 m. However, in relation to the spatial dependence evaluation (SDE), according to the new suggestion proposed in this study, the properties were classified as: 1) very high: pH2 and Al2, 2) high: OM1, pH1, H+Al1, H+Al2 and Al1, and 3) average: #GY and OM2.

Figure 2 shows the simple kriging maps of the soil properties OM1, pH1, pH2, H+Al1, H+Al2, Al1 and Al2. Figure 3 shows the semivariograms and simple kriging maps of £GY and OM2. Figure 2b (pH1) and figure 2c (pH2) exhibited clear spatial similarity, as in figures 2d, 2e, 2f and 2g as well. However, figure 3b showed the highest rice yield (£GY) (7616-5879 kg ha^{-1}) in the ninths in NW, SW, S, E and NE. In contrast, in the other ninths (N, W, SE and Center) yields were lower (5300-3563 kg ha^{-1}). Similarly, the levels of organic matter (24.0-20.5 g dm^{-3}) (OM2) were also highest in the NW, SW, S and E ninths, and lowest (19.3-15.7 g dm^{-3}) in N, W, SE and Center-NE ninths (Figure 3d). However, the situation in the SE ninths (Figure 3b,d) was inversed, that is,values of £GY were lowest (Figure 3b) and OM2 highest (Figure 3d). Although these spatial similarities were less evident, with minor adverse and intricate characteristics, it can be stated that the sites with the highest OM2 levels also had the highest £GYs, and vice versa.Therefore, this fact was in agreement with the study of Carvalho et al. (2010), on the spatial

Table 5. Parameters of simple semivariograms of rice grain yield and some chemical properties of Typic Acrustox under no-tillage

Property[(1)]	Adjustment parameter										
	Model[(2)]	C_o	C_o+C	A_o(m)	r^2	SSR[(3)]	SDE[(4)]		Cross-validation		
							%	Class	a	b	r
#GY	sph (76)	$7.65x10^5$	$1.61x10^6$	47.0	0.771	$1.03x10^{11}$	52.3	AVD	2.61	0.926	0.423
OM1	sph (138)	4.22	1.06x10	50.1	0.883	2.17	60.3	HID	3.68	0.857	0.425
OM2	sph (194)	3.75	8.87	73.2	0.993	$1.09x10^{-1}$	57.7	AVD	$7.00x10^{-2}$	0.998	0.518
pH1	sph (278)	$3.06x10^{-2}$	$1.34x10^{-1}$	62.0	0.969	$1.28x10^{-4}$	77.2	HID	$4.50x10^{-1}$	0.906	0.597
pH2	sph (287)	$6.90x10^{-3}$	$8.50x10^{-2}$	60.0	0.942	$1.32x10^{-4}$	91.9	VHD	$8.60x10^{-1}$	0.813	0.609
H+Al1	sph (98)	2.65x10	$1.00x10^2$	55.5	0.942	$1.73x10^2$	73.5	HID	1.28x10	0.747	0.448
H+Al2	sph (161)	4.19x10	$1.27x10^2$	58.6	0.684	$1.43x10^3$	67.1	HID	5.16	0.915	0.574
Al1	sph (193)	4.57	2.19x10	47.2	0.940	5.51	79.2	HID	1.22	0.789	0.503
Al2	sph (255)	4.20	$4.75x10^1$	53.4	0.788	$1.43x10^2$	91.2	VHD	2.09	0.825	0.636

(1) #GY:rice grain yield, OM: organic matter, pH: hydrogen potential, H+Al: acidity potential, Al: exchangeable aluminum; parentheses after model: number of pairs in the first *lag*; (2) sph: spherical, (3) SSR: sum of squared residuals, (4) SDE: spatial dependence evaluator,and AVD: medium, HID: high, and VHD: very high dependence.

correlation of sugar cane (*Saccharum officinarum* L.) stalk yield with organic matter content of a Typic Tropudalfin Suzanápolis (SP).

Studies on Pearson and spatial correlations of agricultural yield with soil properties (Andreotti et al., 2010; Cavallini et al., 2010; Lima et al., 2010; Dalchiavon et al., 2012) showed that: a) when there is a low and, or, average value of r between agricultural yield and soil property, though highly significant, if both are robust semivariograms, they will probably be co-kriged and b) when there is a non-significant correlation (r) between agricultural yield and soil property, if both are robust semivariograms, there may be, or not, co-kriging between them. Thus, table 6 and figure 4 show the resulting co-kriging of £GY and the properties of the soil under study.The facts observed by the above authors were corroborated by the substantial co-kriging of both OM2 as well as H+Al2 with £GY, whereas the superiority of £GY=f(OM2) was given bythe highest coefficient of spatial determination (r^2 = 0.950). However, in the correlation matrix (Table 4) both soil properties resulted in non-significant correlations of r with £GY. Therefore, in this paper, the analysis of table 6 and figure 4 spatially confirmed the direct correlation between £GY and OM2 [£GY=f(OM2)], so that at the sites with highest OM2 levels,the values of £GYwere also highest, and vice versa.

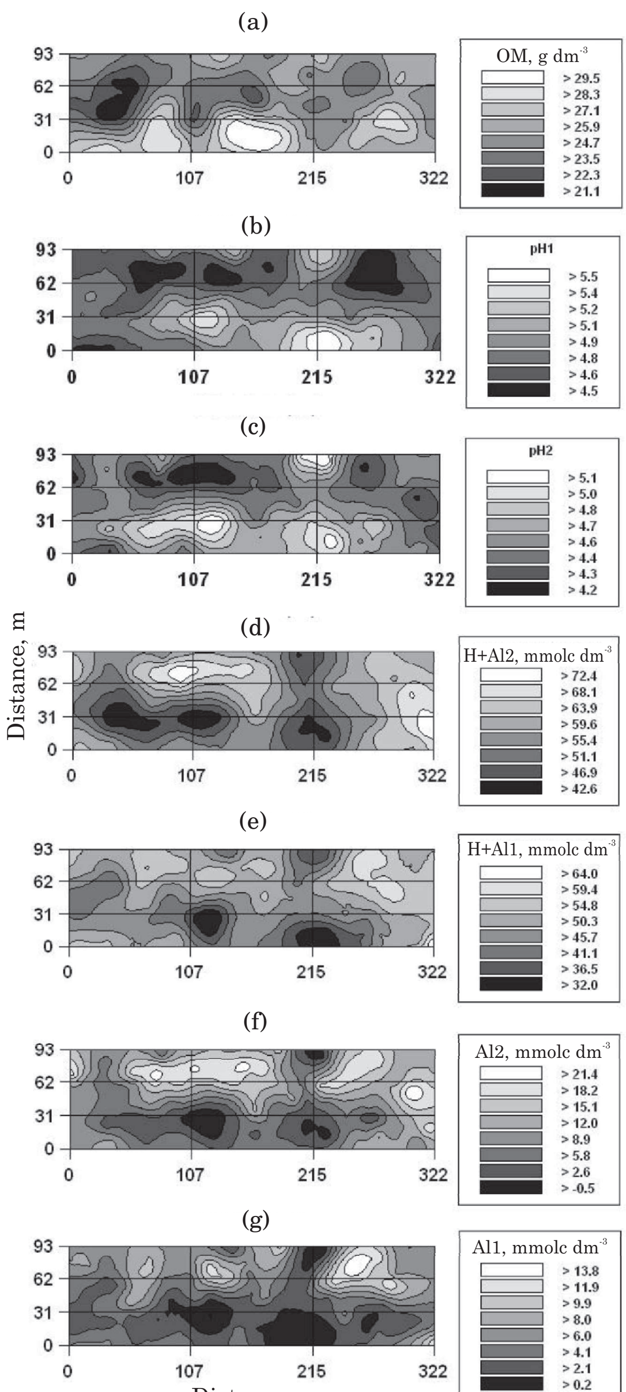

Figure 2. Kriging maps of the chemical properties of a Typic Acrustoxunder no-tillage.

The direct spatial relationship detected between OM2 and £GY (Table 6 and Figure 4) showed, according to Coelho (2003), two different *specific areas of management* (Figure 3).The first was characterized by the spatial coincidence of the highest £GY values (7616-5879 kg ha^{-1}, on average 6748 kg ha^{-1}) with highest OM2 values (24.0-20.5 g dm^{-3}, on average 22.3 g dm^{-3}). In the second, £GY values were lowest (5300-3563 kg ha^{-1}, on average 4432 kg ha^{-1}) with lowest OM2 (19.3-15.7 g dm^{-3}, on average 17.5 g dm^{-3}). Therefore, based on the concept of *applying inputs at variable rates,* according to the same author, which can be included in any conservation practice, one can infer that if agronomic techniques were applied (organic fertilization, green fertilization, crop rotation, cover crops, mineral fertilizers) in the second *specific area of management,* the OM2 content could be raised to an average value of 22.3 g dm^{-3}, which would result in an average £GY of 6748 kg ha^{-1}. Then, the experimental area would produce an average rice yield of 6748 kg ha^{-1}, which is 13 % higher than the estimated yield of 5980 kg ha^{-1} (Table 3).

CONCLUSIONS

1. Spatially, two specific zones of agricultural soil management were discriminated, the first with higher organic matter and rice grain yield, and the second with lower values. By fertilizing the second areaat variable rates, a substantial increase in the aforementioned agricultural yield can be obtained, and

2. The organic matter content was confirmed as a good indicator of soil quality when spatially correlated with rice yield.

Table 6. Parameters of cross-semivariograms of rice grain yield and some chemical properties of a Typic Acrustox under no-tillage

Property[(1)]	Adjustment parameter										
	Model[(2)]	C_o	C_o+C	A_o(m)	r^2	SSR[(3)]	SDE[(4)]		Cross-validation		
							%	Class	a	b	r
#GY=f(OM2)	exp (210)	4.00	7.23x102	138.3	0.950	1.67x104	99.4	VHD	2.69	0.603	0.421
#GY=f(H+Al2)	gau (158)	-1.00	-1.84x104	99.8	0.641	2.37x106	99.9	VHD	8.38	0.573	0.404

(1)#GY: rice grain yield, OM: organic matter, H+Al: potential acidity; parentheses after model: number of pairs in the first lag; (2)exp: exponential; gau: gaussian; (3)SSR: sum of squared residuals; (4)SDE: spatial dependence evaluator, and VHD: very high dependence.

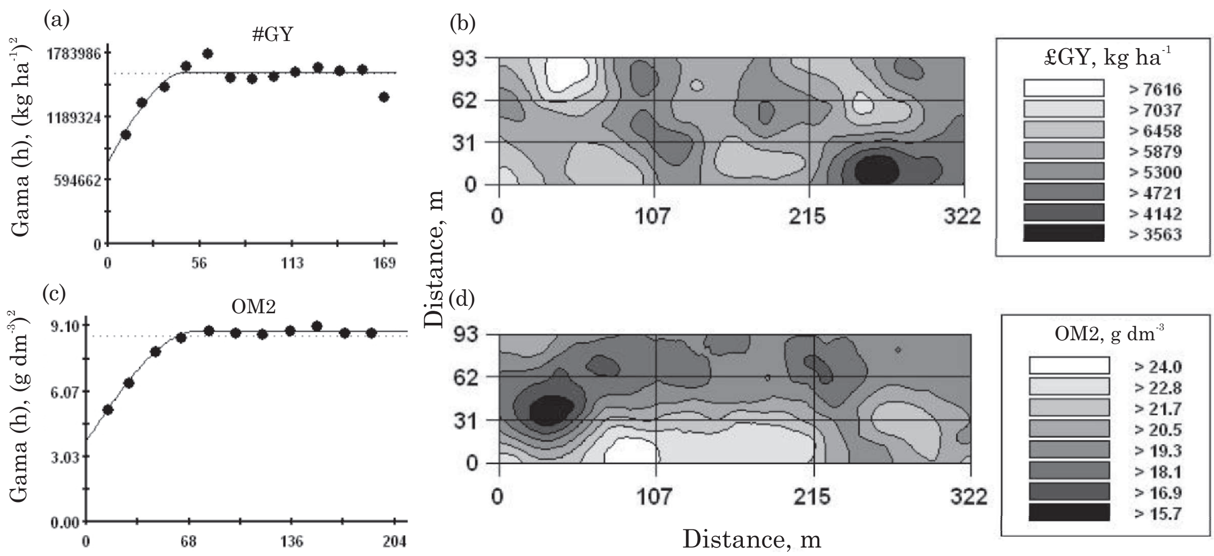

Figure 3. Simple semivariograms, cross-validation and kriging maps of rice grain yield and organic matter content of a Typic Acrustox under no-tillage.

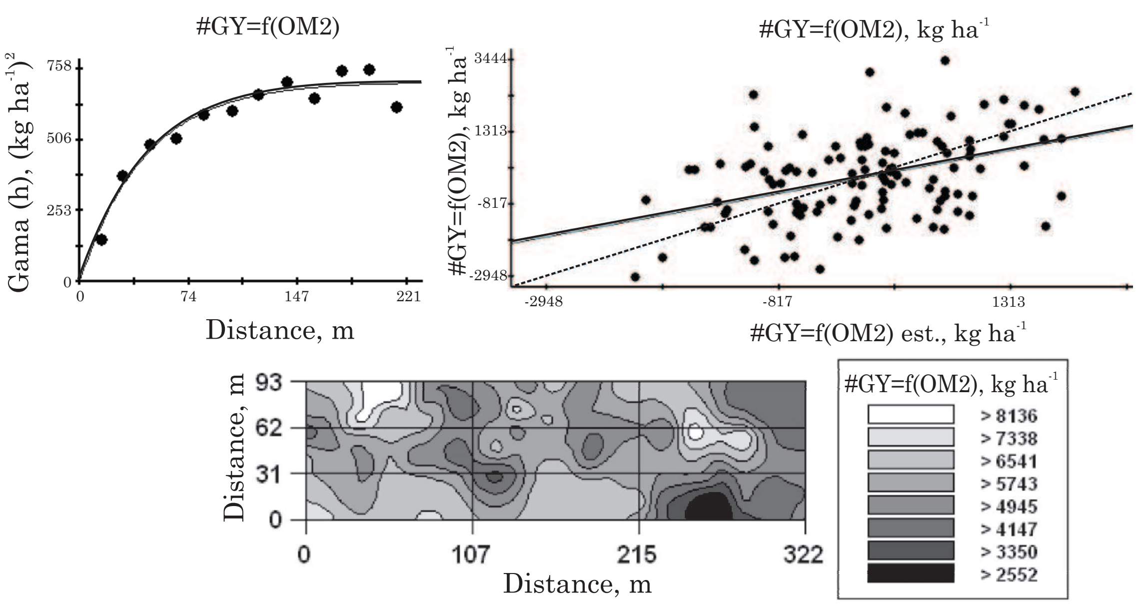

Figure 4. Cross-semivariograms, cross-validation and co-kriging maps of rice grain yield as related to organic matter content of a Typic Acrustox under no-tillage.

ACKNOWLEDGEMENT

The authors are grateful to the Coordination for Improvement of Higher Education Personnel (CAPES) for the financial support of the first author.

LITERATURE CITED

AMADO, T.J.C.; PES, L.Z.; LEMAINSKI, C.L. & SCHENATO, R.B. Atributos químicos e físicos de Latossolos e sua relação com os rendimentos de milho e feijão irrigados. R. Bras. Ci. Solo, 33:831-843, 2009.

ANDREOTTI, M.; CARVALHO, M.P.; MONTANARI, R.; BASSO, F.C.; PARIZ, C.M.; AZENHA, M.V. & VERCESE, F. Produtividade da soja correlacionada com a porosidade e a densidade de um Latossolo Vermelho do Cerrado Brasileiro. Ci. Rural, 40:520-526, 2010.

ARSHAD, M.A.; LOWER, B. & GROSSMAN, B. Physical tests for monitoring soil quality. In: DORAN, J.W. & JONES, A.J., eds. Methods for assessing soil quality. Madison, Soil Science Society America, 1996. p.123-141. (Special Publication, 49)

BARBIERI, D.M.; MARQUES JR, J. & PEREIRA, G.T. Variabilidade espacial de atributos químicos de um Argissolo para aplicação de insumos à taxa variável em deferentes formas de relevo. Eng. Agríc., 28:645-653, 2008.

CARNEIRO, M.A.C.; SOUZA, E.D.; REIS, E.F.; PEREIRA, H.S. & AZEVEDO, W.R. Atributos físicos, químicos e biológicos de solo de cerrado sob diferentes sistemas de uso e manejo. R. Bras. Ci. Solo, 33:147-157, 2009.

CARVALHO, M.P.; DALCHIAVON, F.C.; GIOIA, M.T. & BRAGA, J.A. Inter-relações da resistência mecânica, umidade e do teor de matéria orgânica de um Argissolo Vermelho paulista sobre a produtividade da cana-de-açúcar. In: REUNIÃO BRASILEIRA DE FERTILIDADE DO SOLO E NUTRIÇÃO DE PLANTAS, 29., Guarapari, 2010. Anais... Guarapari, Sociedade Brasileira de Ciência do Solo, 2010. CD ROM.

CARVALHO-PUPATTO, J.G.; BÜLL, L.T. & CRUSCIOL, C.A.C. Atributos químicos do solo, crescimento radicular e produtividade do arroz de acordo com a aplicação de escórias. Pesq. Agropec. Bras., 39:1213-1218, 2004.

CAVALLINI, M.C.; ANDREOTTI, M.; OLIVEIRA, L.L.; PARIZ, C.M. & CARVALHO, M.P. Relações entre produtividade *Brachiaria brizantha* e atributos físicos de um Latossolo do cerrado. R. Bras. Ci. Solo, 34:1007-1015, 2010.

CAZETTA, D.A.; ARF, O.; BUZETTI, S.; SÁ, M.E. & RODRIGUES, R.A.F. Desempenho do arroz de terras altas com a aplicação de doses de nitrogênio e em sucessão às culturas de cobertura do solo em sistema de plantio direto. Bragantia, 67:471-479, 2008.

COELHO, A.M. Agricultura de precisão: Manejo da variabilidade espacial e temporal dos solos e das culturas. In: CURI, N.; MARQUES, J.J.; GUILHERME, L.R.G.; LIMA, J.M.; LOPES, A.S. & ALVAREZ V., V.H., eds. Tópicos em ciência do solo. Viçosa, MG, Sociedade Brasileira de Ciência do Solo, 2003. v.3. p.249-290.

COMPANHIA NACIONAL DE ABASTECIMENTO - CONAB. Acompanhamento da safra brasileira: grãos – décimosegundo levantamento,setembro 2010. Brasília, 2010. 41p.

CORÁ, J.E.; ARAUJO, A.V.; PEREIRA, G.T. &BERALDO, J.M.G. Variabilidade espacial de atributos do solo para adoção do sistema de agricultura de precisão na cultura de cana-de-açúcar. R. Bras. Ci. Solo, 28:1013-1021, 2004.

DALCHIAVON, F.C. & CARVALHO, M.P. Correlação linear e espacial dos componentes de produção e produtividade da soja. Sem. Ci. Agrar., 33:541-552, 2012.

DALCHIAVON, F.C.; CARVALHO, M.P.; FREDDI, O.S.; ANDREOTTI, M. & MONTANARI, R. Variabilidade espacial da produtividade do feijoeiro correlacionada com atributos químicos de um Latossolo Vermelho distroférrico sob sistema de semeadura direta. Bragantia, 70:908-916, 2011.

DALCHIAVON, F.C.; CARVALHO, M.P.; ANDREOTTI, M. & MONTANARI, R. Variabilidade espacial de atributos da fertilidade de um Latossolo Vermelho distroférrico sob sistema plantio direto. R. Ci. Agron., 43:453-461, 2012.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA - EMBRAPA. Centro Nacional de Pesquisa de Solos. Manual de métodos de análise do solo. 2.ed. Rio de Janeiro, 1997. 212p.

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

GUIMARÃES, C.M.; STONE, L.F. & CASTRO, E.M. Comportamento de cultivares de arroz de terras altas no sistema plantio direto em duas profundidades de adubação. Biosci. J., 22:53-59, 2006.

LIMA, C.G.R.; CARVALHO, M.P.; NARIMATSU, K.C.P.; SILVA, M.G. & QUEIROZ, H.A. Atributos físico-químicos de um Latossolo do cerrado brasileiro e sua relação com características dendrométricas do eucalipto. R. Bras. Ci. Solo, 34:163-173, 2010.

MEDEIROS, R.D.; SOARES, A.A. & GUIMARÃES, R.M. Compactação do solo e manejo da água. I: Efeitos sobre a absorção de N, P, K, massa seca de raízes e parte aérea de plantas de arroz. Ci. Agrotec., 29:940-947, 2005.

MOLIN, J.P. & RABELLO, L.M. Estudos sobre a mensuração da condutividade elétrica do solo. Eng. Agríc., 31:90-101, 2011.

MOLIN, J.P.; VIEIRA JR, P.A.; DOURADO NETO, D.; FAULIN, G.C. & MASCARIN, L. Variação espacial na produtividade de milho safrinha devido aos macronutrientes e à população de plantas. RBMS, 6:309-324, 2007.

MONTANARI, R.; ZAMBIANCO, E.C.; CORRÊA, A.R.; PELLIN, D.M.P.; CARVALHO, M.P. & DALCHIAVON, F.C. Atributos físicos de um Latossolo Vermelho correlacionados linear e espacialmente com a consorciação de guandu com milheto. R. Ceres, 59:125-135, 2012.

OLIVEIRA, J.B. & MONIZ, A.C. Levantamento pedológico detalhado da estação experimental de Ribeirão Preto, SP. Bragantia, 34:59-114, 1975.

RAIJ, B.van.; ANDRADE, J.C.; CANTARELLA, H. & QUAGGIO, J.A. Análise química para avaliação da fertilidade de solos tropicais. Campinas, Instituto Agronômico de Campinas, 2001. 285p.

RAIJ, B.van.; CANTARELLA, H.; QUAGGIO, J.A. & FURLANI, A.M.C. Recomendações de adubação e calagem para o Estado de São Paulo. Campinas, Instituto Agronômico de Campinas, 1997. 285p.

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. R. Bras. Ci. Solo, 33:287-295, 2009.

SCHLOTZHAVER, S.D. & LITTELL, R.C. SAS system for elementary statistical analysis. 2.ed. Cary, SAS, 1997. 441p.

SHAPIRO, S.S. & WILK, M.B. An analysis of variance test for normality: Complete samples. Biometrika, 52:591-611, 1965.

SILVA, I.R. & MENDONÇA, E.S. Matéria orgânica do solo. In: NOVAIS, R.F.; ALVAREZ V., V.H.; BARROS, N.F.; FONTES, R.L.F.; CANTARUTTI, R.B. & NEVES, J.C.L., eds. Fertilidade do solo. Viçosa, MG, Sociedade Brasileira de Ciência do Solo, 2007. p.275-374.

WALTER, M.; MARCHEZAN, E. & AVILA, L.A. Arroz: Composição e características nutricionais.Ci. Rural, 38:1184-1192, 2008.

WERNER, V.; SCHLOSSER, J.F.; ROZIN, D.; PINHEIRO, E.D. & DORNELLES, M.E.C. Aplicação de fertilizantes a taxa variável em agricultura de precisão variando a velocidade de deslocamento. R. Bras. Eng. Agríc. Amb., 11:658-663, 2007.

YANAI, J.; LEE, C.K.; KAHO, T.; IIDA, M.; MATSUI, T.; UMEDA, M. & KOSAKI, T.Geostatistical analysis of soil chemical properties and rice yield in a paddy field and application to the analysis of yield-determining factors. Soil Sci.Plant Nutr., 47:291-301, 2001.