SPATIAL VARIABILITY OF CROP AND SOIL PROPERTIES IN A CROP-LIVESTOCK INTEGRATED SYSTEM

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ABSTRACT

The knowledge of spatial variability soil properties is useful in the rational use of inputs, as in the site specific application of lime and fertilizer. The objective of this work was to map and evaluate the spatial variability of the corn and pasture, soil chemical and physical properties in crop-livestock integrated system. The study was conducted in an area of 6.9 ha of a Typic Paleudult in Sao Carlos, SP, Brazil. The summer crop corn was sowed together with the forage crop *Brachiaria brizantha* in the system of crop-livestock rotation. A regular hexagon sampling grid design with 6 sub-samples was adopted for each hectare. The values of soil P, K, Ca, Mg, and CEC, basis saturation, clay and sand were analyzed by traditional soil testing in georreferenced samples collected at 0–0.2 m depth. Soil electrical conductivity (EC) was measured with a contact sensor. The site was evaluated at the end of the corn season (April) and for the forage (October) by imageries from the Landsat 5 using remote sensing techniques and a geographic information system. Normalized difference vegetation index (NDVI) was used to interpret imageries. Spatial continuity of crop and soil properties was modeled using semivariograms. Maps contours of crop and forage were obtained by kriging, and maps of soil properties by using inverse distance weighting interpolation. Results from this study showed that the NDVI was associated with ECa and soil parameters indicating crop and pasture variations on crop-livestock integrated system. Sampling density adopted was insufficient for an adequate characterization of the spatial variability of soil parameters as pH, O.M., P, K, V%, CEC, clay and sand. Estimated VRT maps compared to estimated uniformly applied lime and P and K fertilizer recommendation indicate that VRT could be more adequate to lime and potash recommendation, and and would have little effect on P fertilization.

Key words: geostatistics, soil fertility, soil texture, electrical conductivity, field sensor, VERIS, Landsat 5, NDVI.

INTRODUCTION

Brazil has 180 million ha under low productive degraded pasture system, and most of these pastures are in degradation process (Vilela et al., 2005). Due to the high investments required for the formation or reform the pastures, the crop-livestock integrated system have been used to reducing these investments and increasing productivity with simultaneous conservation of environmental services such as climate change mitigation, efficient water use, and preservation of biodiversity. So, crop-livestock integrated system is a strategy of sustainable agricultural production which integrates crop and livestock activities on a same area and in the same season, applying agricultural techniques such as crop rotation, succession, double cropping, and intercropping, searching for synergistic effects among the components of the agroecosystems, contemplating environment aspects, human value, and economical viability (Embrapa, 2010). According to Kluthcouski and Aidar (2003) this system may be used in rotation between grain and pasture to improve grass quality or even recuperate degraded pasture, feed the animals in the dry season or to improve grain yield by no-tillage management.

Providing an adequate supply of nutrients is important for corn and forage production and is essential to maintain high quality and profitable yields in crop-livestock integrated system. Lime and fertilizer are common inputs in the high weathered, low-fertile and acids soils of Brazilian tropical region and soil testing is the tool for adequate nutrients recommendation. However, soil fertility management without taking account of spatial variation within fields may directly affect crop yield.

Precision agriculture assists growers in making precise management decisions for different cropping systems (Koch and Khosla, 2003). But, Precision Agriculture requires a method of gathering information about the spatial variability of soil that reduces the need for expensive and intensive sampling (McBratney and Pringle, 1999). Soil sensors linked to global positioning systems (GPS) can provide on-the-go spatial data acquisition and could help to characterize yield variation (Kitchen et al., 2003).

Apparent soil electrical conductivity integrates texture and moisture availability, two soil characteristics that affect productivity, it can help to interpret spatial grain yield variations, at least in certain soils (Kitchen et al., 1999) and was related to variation in crop production (Kitchen et al., 1999; Luchiari et al., 2001). In Brazil, Machado et al. (2006) verified that values of soil EC reflected soil clay content spatial variation and was adequate for establishing the limits of management zones.

Satellite-derived vegetation indices have been widely used to estimate crop and grassland biomass, since remote sensing provides temporal and spatial patterns of ecosystem change and has been used to estimate biophysical characteristics of crops and grasslands (Moges et al., 2004; Numata et al. 2007). Normalized difference vegetative indexes (NDVI) based on red or green reflectances are commonly used to evaluate plant health, biomass, and nutrient content.

The objective of this work was to map and evaluate the spatial variability of the corn and pasture, soil chemical and physical properties in crop-livestock integrated system.

MATERIAL AND METHODS

The 6.9 ha field study was conducted at Embrapa Cattle Southeast, in Sao Carlos (22^{o}01' S and 47^{o}54' W; 856 m above sea level), State of Sao Paulo, Brazil. The climate is Cwa type (Köeppen), with yearly average of low and high temperatures of 16.3 and 23.0°C, respectively, and a total precipitation of 1502 mm falling mostly in summer. Soil type was an Argissolo Vermelho-Amarelo distrófico textura média/argilosa (Calderano et al., 1998) corresponding to a Typic Paleudult (Soil taxonomy).

A regular hexagon georreferenced sampling grid design with 6 sub-samples collected at 0–0.2 m depth was adopted for each hectare, 3 samples more were taken in a transection along the field. Soil samples was carried out with an all-terrain vehicle - ATV equipped with GPS and a stainless steel screw auger, with adjustable depth and electrical activation, which possibilities the demarcation of the points with their respective geographical coordinates.

Following the methods of Primavesi et al. (2005) the chemical properties were determined. Soil pH measurements were made in water, organic carbon was determined by wet combustion, available P (resin method), exchangeable K^+. Cation exchange capacity (CEC) was measured at the actual soil pH value and basis saturation (%V) was determined. Soil particle size fractions (clay and sand content) were determined by the densimeter method.

Soil electrical conductivity was measured using the Veris model 3100 sensor manufactured by Veris Technologies of Salina, KS (Lund et al., 1999). Measurements are carried out according to the equation 1:

$$\rho = \frac{IL}{AV} \qquad (1)$$

where ρ is the soil electrical conductivity (mS m^{-1}), I is the electric current applied by the sensor to the ground (Ampere), L is the spacing between the pairs of measuring electrodes (meters), A is area cross section of the measurement electrodes (of the rotating discs) in contact with the ground (m^2) and V is the potential difference of the electromagnetic field generated in the soil measured by pairs of measuring electrodes (volts).

The summer crop corn (*Zea mays* L. cv. BRS 3060) was sowed together with the forage crop *Brachiaria brizantha* cv. Piatã in the crop-livestock rotation system with no tillage after 3 *Brachiaria brizantha*-cv. Marandu pasture growing seasons. Corn crop was sowed with a 0.8-m interlinear space, using five plants per meter; *B. brizantha* pasture was sowed between rows of corn in a density of 5 kg of seed per ha. Dolomite lime was uniformly applied to increase basis saturation at 70% before planting. Corn was uniformity fertilized at planting with 30 kg ha^{-1} of N, 100 kg ha^{-1} of P_2O_5, 55 kg ha^{-1} of K_2O and 1.4 kg ha^{-1} of Zn, and forage received no fertilizer at planting. Nitrogen and K, as urea and KCl, were broadcast fertilized 60 days after planting in the amount of 100 kg ha^{-1} of N and 100 kg ha^{-1} of K_2O.

Silage corn harvest was initiated in May 2009, when whole-plant water concentration was between 600 and 700 mg kg^{-1}. After silage harvest the pasture developed and was formed to animal grazing on the next season.

Two Landsat Thematic Mapper 5 (TM5) scenes were used in this study: 04/22/2009 and 10/31/2009, respectively corresponding to the end of the corn season (April) and for the beginning of forage (October) Images were coregistered to the digital base maps provided by Instituto Nacional de Pesquisas Espaciais (INPE — the Brazilian Space Agency). NDVI was calculated with Erdas Imagine 9.3 (Erdas Inc, Atlanta, Georgia, USA) in three steps: radiometric digital inter-calibration, monochromatic reflectance calculation and NDVI calculation. Landsat TM images were inter-calibrated to the corresponding Landsat ETM+ reflectance images using a relative radiometric calibration ($L_{\lambda i}$) approach calculated by the equation:

$$L_{\lambda i} = L\min + \frac{L\max - L\min}{255}\mathrm{ND} \qquad (2)$$

where, *ND* is the digital number of each pixel, *L*max and *L*min are the maximum and minimum spectral radiances (Wm^{-2}sr^{-1}µm^{-1}) after 05/05/2003 (Chander and Markham, 2003).

After the monochromatic reflectance calculation of each band ($\rho_{\lambda i}$) were accomplished with the equation 3 proposed by Allen et al. (2002):

$$\rho_{\lambda i} = \frac{\pi\, L_{\lambda i}}{E_{\lambda i}\, \cos\theta_z\, d_r} \qquad (3)$$

where, $L_{\lambda i}$ is the spectral radiance of each band; $E_{\lambda i}$ is the spectral solar irradiance of each band in the atmosphere (W m^{-2} µm^{-1}), accord Allen et al. (2002), θ_z is the solar zenith angle and d_r is the relative distance earth-sun (in astronomical unit - UA).

Then, Normalized Difference Vegetation Index (NDVI) was calculated by the equation 4 (Choudhury, 1987):

$$\mathrm{NDVI} = \frac{\rho_{NIR} - \rho_{R}}{\rho_{NIR} + \rho_{R}} \qquad (4)$$

where, ρ_{IV} and ρ_{V} are the percent near infrared and red reflectance (nm).

Statistical parameters and geostatistical analyses were performed for all variables focusing the spatial continuity and dependence of soil and crop properties. Empirical directional semivariograms were calculated for x- and y-directions. Semivariogram models were fitted to empirical semivariograms $\hat{\gamma}(h)$ using GEOEST (Vieira et al., 2002) to estimate the structure of the spatial variation of a variable *V*, and the semivariance with the equation 5:

$$\hat{\gamma}(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[Z(x_i) - Z(x_i + h) \right]^2 \qquad (5)$$

where $Z(x_i)$ and $Z(x_i + h)$ are the observed values of Z at location x and $x + h$, respectively, h is the separation distance, and N (h) is the number of paired comparisons at the distance h. The range is the separation distance beyond which two observations are independent of each other. From the adjustment of the mathematical model, the coefficients of the theoretical model for the semivariogram $\hat{\gamma}(h)$ were calculated: nugget effect (C_0), sill of the auto correlated variance (C); range of the spatial dependence (a).

NDVI and ECa were estimated by ordinary kriging and soil parameters properties by using inverse distance weighting interpolation. Contour maps of estimates were prepared using Arc Gis 9 (Arc Map 9.2 - ESRI, Inc., Redlands, CA).

Calculation of liming need used the formula proposed by Raij et al. (1996), which considers the current soil acidity, buffering capacity of the soil (expressed by the CEC at pH 7.0), and the ideal basis saturation for corn (V = 70%). Calculation of the dose of potassium fertilizer (KCl 60% of K_2O) considered the amount necessary to increase the nutrient until 3% of CEC. Phosphorus levels, as ordinary superphosphate (18% P_2O_5) was calculated to increase available P to 10 mg dm^{-3}. The spatialization of liming and P and K fertilizer requirements were accomplished with SSToolbox v.3.4 (SST Development Group).

RESULTS AND DISCUSSION

Statistical parameters of all the analyzed variables are given in Table 1. These statistical parameters as mean, variance, coefficient of variation, minimum value, maximum value, skewness, and kurtosis were obtained in order to verify existence of a central tendency and dispersion of the data. According to Vieira et al. (2000) a data set that approaches the normal distribution, the values for skewness and kurtosis coefficients will approach zero. These values together with the other classical statistical parameters are useful to evaluate the magnitude of the data dispersion around a central tendency value. For most of the variables studied was normally distributed as indicated by the close to zero coefficients of skewness and kurtosis, exception of ECa.

Soil pH, CEC, sand represented soil properties with low variability with coefficient of variation bellow of 10%. Soil O.M., K, P and clay contents and basis saturation represented soil properties with medium variability (CV < 30%). ECa represented soil properties with high variability. According to Kravchenko (2003) the level of data variability is of importance in site-specific management, since soil properties with high variability are potentially better candidates to be managed on a site specific basis than the more uniformly distributed soil properties. On the other hand, mapping soil properties with higher variability can be less accurate than that of soil properties with lower variability. Trends in the variation of soil attributes obtained in this study are consistent to those observed by Mulla and McBratney (2000) and Machado et al. (2004) for various soil parameters.

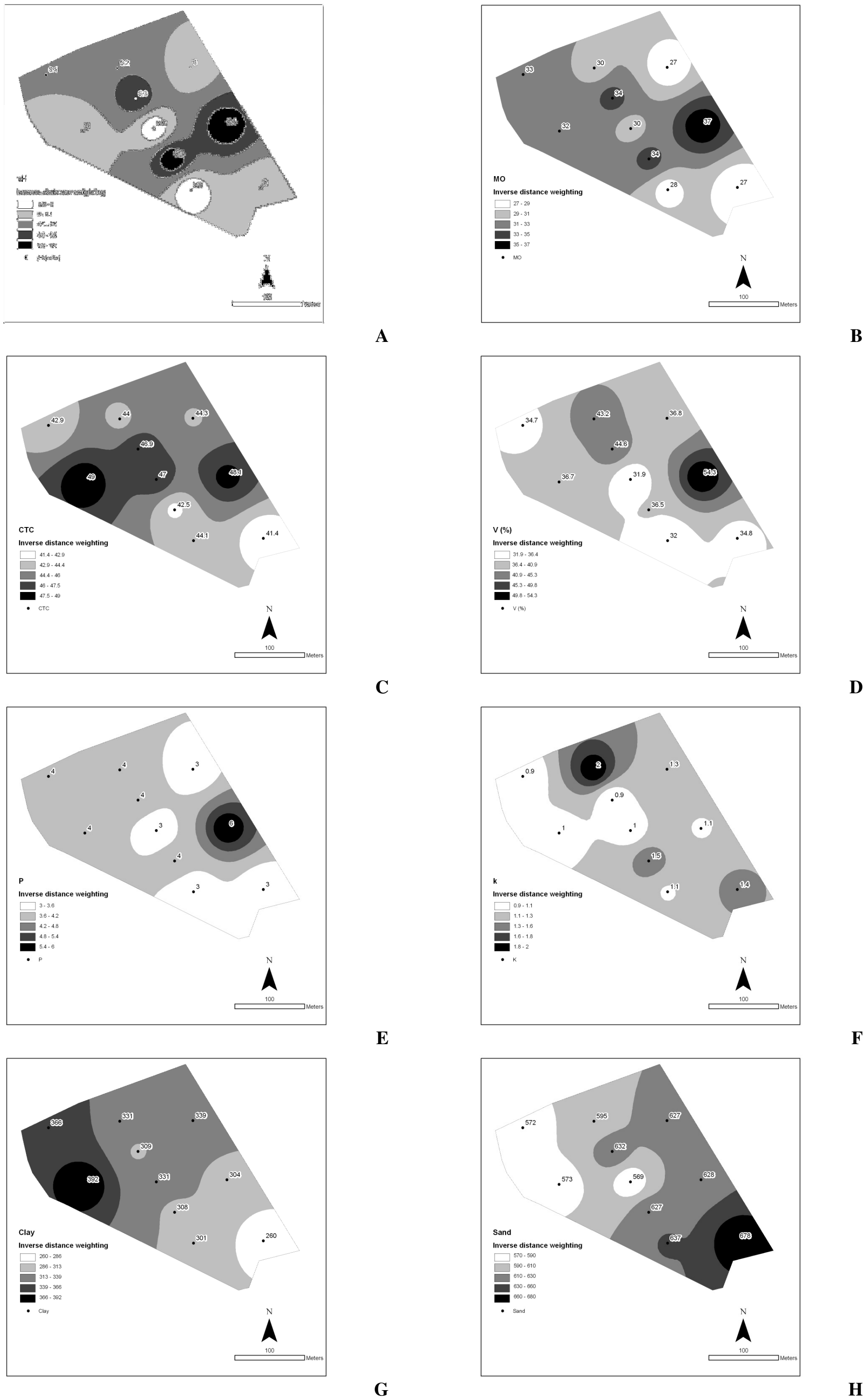
Table 1. Descriptive statistics for NDVI, EC_a and chemical properties of a crop-livestock integrated system in Brazil.

Statistical	**NDVI**	**NDVI**	**EC_a**	**pH_{H2O}**	**OM**	**P**	**K**	**CEC**	**V (%)**	**Clay**	**Sand**
parameters	(22/04/2009)	(31/10/2009)	mS m^{-1}		g kg^{-1}	mg dm^{-3}	$cmol_c$ dm^{-3}		%	g kg^{-1}	
n	79	74	9922	10	10	10	10	10	10	10	10
Minimum	0.628	0.3169	0.400	5.90	27.00	3.0	0.80	10.70	21.64	215.0	569.0
Maximum	0.764	0.8163	9.900	6.70	55.00	6.0	2.20	12.50	40.74	392.0	691.0
μ	0.711	0.728609	1.342	6.26	39.47	3.8	1..20	11.69	30.53	297.6	640.2
Median	0.712	0.7548	1.300	6.30	40.50	4.0	1.10	11.70	29.76	304.5	637.5
σ	0.029	0.081379	0.485	0.20	7.38	0,92	0.35	0.51	5.12	42.0	31.5
Variance	0.001	0.006622	0.236	0.04	54.40	0.84	0.12	0.26	26.21	1763.6	992.1
CV (%)	4.03	11.17	36.16	3.27	18.69	24.2	25.64	4.35	16.77	14.11	4.92
Curtosis	0.931	9.421384	72.106	-0.56	-0.67	3.32	0.20	-0.68	-0.60	-0.30	0.43
Skewness	-0.834	-2.61833	5.529	-0.01	-0.01	1.00	0.65	-0.40	0.35	0.07	-0.81

*CV: coefficient of variation equals standard deviation (σ) divided by sample mean (μ).

Experimental semivariograms for all variables were computed and all fitted models were bounded (Table 2). Results showed that the full extent of the variation of NDVI and EC has been encountered at the spatial scale of this study. The parameters fitted to the semivariograms are shown in Table 2. The soil parameters measured (pH, O.M., P, K, CEC, V%, clay and sand) had pure nugget effects and had weak spatial dependence. Probably due the low density grid adopted with 10 samples.

The spherical model was the best adjusted to experimental variograms of NDVI (both dates) and ECa. Trangmar et al. (1985) already had showed this model as the best adapted to describe the behavior of variograms of soil attributes. Ranges of spatial dependence from the semivariogram models were higher to NDVI, with values of 214 and 128 m, than to ECa (34 m).



A B C D E F G H

Figure 1: Maps of estimated inverse distance weighting of pH$_{water}$ (A), O.M. - g kg^{-1} (B), CEC - cmol$_c$ dm^{-3} (C), V% (D), P - mg dm^{-3} (E), K - cmol$_c$ dm^{-3} (F), clay - g kg^{-1} (G) and sand - g kg^{-1} (H) of a crop-livestock integrated system in Brazil.

These results indicate that a grid spacing of 128 would be adequate for the characterization of the spatial variability of NDVI for this site. Then the 30 X 30 m resolution of imageries from the Landsat 5 is adequate for this propose. Crop variation at this spatial scale probably reflects variables as topography, soil type, and other soil properties related.

The same occurs for ECa, that a grid spacing of 34 m would characterize the spatial variability and the high density sampling process with Veris in parallel transects with that distance would provide the necessary results.

The maps presented in Figure 1 refer to the spatial distribution of the values of pH in water; organic matter; resin P, K, clay, sand, V% and CEC measured in at 0 to 20 cm depth. According to Raij et al. (1996), values of P were considered very low (0 to 6 mg dm^{-3}), values of K were low (0.8 to 1.5 mmol$_c$ dm^{-3}) to medium (1.6 to 3.0 mmol$_c$ dm^{-3}), and basis saturation were low (26 to 50%). This shows that, in practice, the soil does not offer the plants enough quantities and proportion of these elements. There is an area on the middle-right side where values of pH, O.M., P, V%, and CEC are a little higher than the rest of the studied area. These results may support the decision-making practices of liming and fertilization, correcting successfully soil acidity and nutrient availability.

Table 2. Parameters for semivariograms models for NDVI and ECa of a crop-livestock integrated system in Brazil.

Variable	C$_o$	C	a	Model
NDVI 04/22/2009	0.00020518	0.00081176	214.639	Spherical
NDVI 10/31/2009	0.00068261	0.0054747	128.387	Spherical
ECa	0.10169	0.077365	34.0573	Spherical

* The parameters are “C$_o$“ the nugget variance, “C” the sill of the auto correlated variance; “a” the range of the spatial dependence.

Krigged estimates for ECa were contoured and mapped so that their patterns of variation on the field could be examined (Figure 2). This map shows that since soil ECa integrates soil properties as soil texture, soil organic matter, cation exchange capacity, and exchangeable Ca and Mg, the regions with higher values are the same with higher soil evaluated parameters (pH, O.M., pH, P, CEC and V%). The stain of high-ECa (2.5 to 10 mS m^{-1}) on the top right of the area was due a feedlot of animals in the area that occurred in the previous year. At this place animals were fed at the trough and showed a high concentration range of manure.

Figure 3 illustrates the krigged map created based on semivariance analysis of NDVI for corn and pasture. Since NDVI relies on the spectral contrast between red and near-infrared bands and is sensitive to leaf-chlorophyll content and leaf area index - LAI of vegetation (Numata et al., 2007) these results suggest that higher pasture NDVI indicates higher shoot production. The satellite image for corn showed the same pattern observed on soil parameters and ECa. This is also an indicative that the crop variation at this studied field reflects soil properties variation.

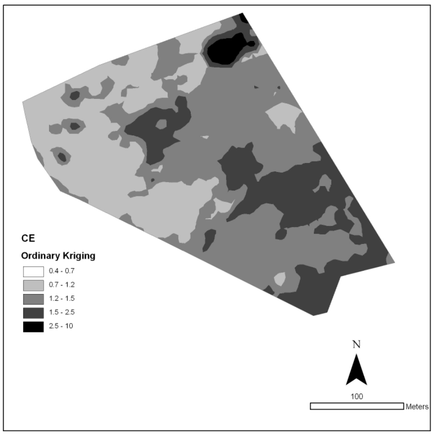


Figure 2. Map of estimated kriged for soil apparent electrical conductivity (ECa - mS m^{-1}) of a crop-livestock integrated system in Brazil.

There was an inverse relationship of the NDVI values between the first evaluated date (corn - A) for the second evaluated date (forage - B), ie areas of higher NDVI of corn were the regions with lower NDVI of grass and otherwise.

This apparent controversy can be explained by the fact that corn and grass are sowed together (in different rows), but the corn growth is favored by fertilization in the sowing rows. Due to the shading caused by corn during the period of cultivation, the grass grows slowly, especially because both species have C4 metabolism of CO_2 fixation, a characteristic that makes them light-demanding and possibilities the corn crop complete the cycle and produce satisfactorily (Portes et al., 2000). After corn harvest the competition for light ends and the forage grows. So where there was major development of corn, due to better soil fertility, there were more shading of the grass and consequently less vegetative growth. In the areas with lower corn NDVI, pasture had better vegetative growth indicated by the highest NDVI.

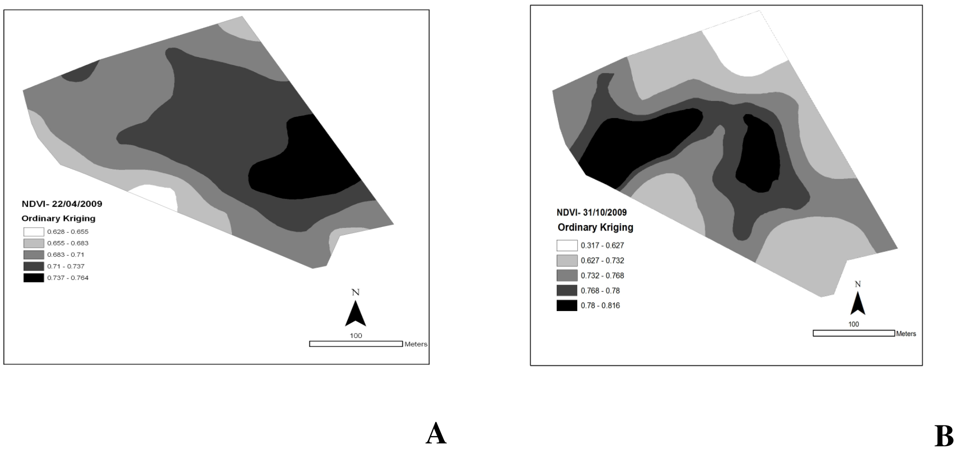


Figure 3. Map of estimated kriged for NDVI of corn (A) and pasture (B) in a crop-livestock integrated system in Brazil.

Variable rates tax of lime and fertilizer could be applied in the area (Figure 4). Estimates of lime doses vary from 800 to 1,800 kg ha^{-1} (Figure 4A), and the average dose of 1,500 kg ha^{-1} should be applied to 3.0 ha, and mean doses of 1,300 and 1,700 kg kg ha^{-1} should be applied at 1.9 and 1.2 ha, respectively, according the liming recommendation of Raij et al. (1996). Considering the VRT of liming, total amount of lime applied in the area would be 10,220 kg. If the lime need would calculated by the mean the lime doses would be 460 kg and the total amount applied would be 3,186 kg in the area, probably leading to a problem of low soil acidity correction with losses in corn productivity.

Considering P fertilization proposed by Raij et al. (1996), the corn recommendation is 90 kg ha^{-1} of P_2O_5 uniformly applied in the field, which represents 500 kg ha^{-1} of ordinary superphosphate and a total amount of 3,450 of the product kg ha^{-1}. Estimated VRT map (Figure 4B) indicated that P fertilizer levels would vary from 413 to 550 kg ha^{-1} of ordinary superphosphate and total amount would be 3,586 kg, indicting that little or none differences could be obtained with P fertilizer VRT. Based on the same recommendation (Raij et al., 1996) K fertilizer should be uniformly applied at 50 kg ha^{-1} of K_2O at sowing and plus 100 kg ha^{-1} of K_2O at 45 days after emergence, which is equivalent to 250 kg ha^{-1} of KCl and a total amount of 1,725 kg ha^{-1} in the area. Estimated VRT map (Figure 4C) indicated that K fertilizer should be applied just in 4.1 ha with a total amount o 560 kg ha^{-1} of KCl.

CONCLUSIONS

Results from this study showed that the NDVI was associated with ECa and soil parameters indicating crop and pasture variations on crop-livestock integrated system.

Sampling density adopted was insufficient for an adequate characterization of the spatial variability of soil parameters as pH, O.M., P, K, V%, CEC, clay and sand.

Estimated VRT maps compared to estimated uniformly applied lime and P and K fertilizer recommendation indicate that VRT could be more adequate to lime and potash recommendation, and and would have little effect on P fertilization.

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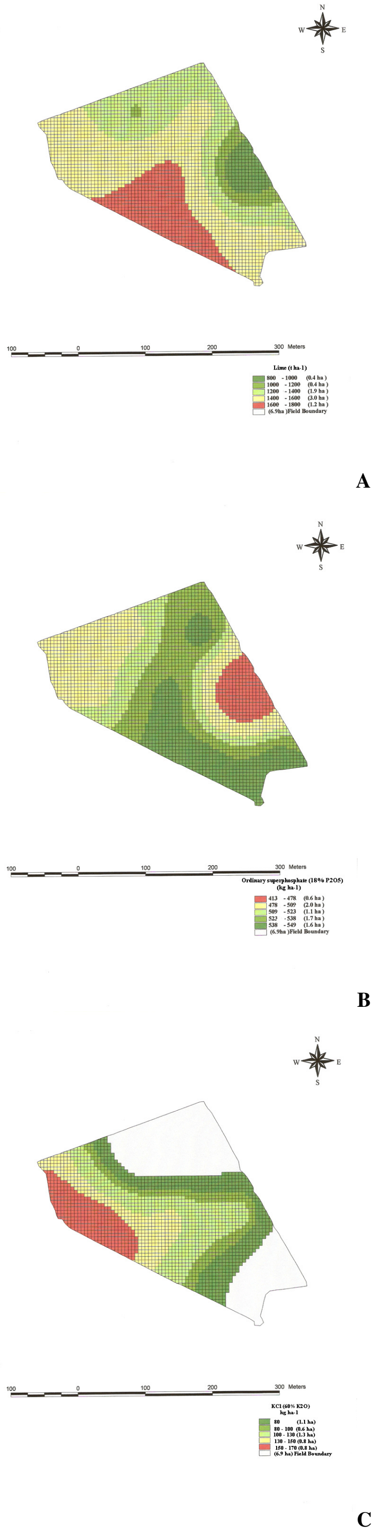

Figure 4. Map of estimated lime (A), phosphorus (B) and potassium (C) fertilizer requirements f corn in a crop-livestock integrated system in Brazil.

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