

SPATIAL VARIABILITY OF SOIL PROPERTIES IN INTENSIVELY MANAGED TROPICAL GRASSLAND IN BRAZIL

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ABSTRACT

For the intensification of tropical grass pastures systems the soil fertility building up by liming and balanced fertilization is necessary. The knowledge of spatial variability soil properties is useful in the rational use of inputs, as in the variable rate application of lime and fertilizers. PA requires methods to indicate the spatial variability of soil and plant parameters. The objective of this work was to map and evaluate the soil properties and maps the site specific liming and fertilizer need in a irrigated tropical pasture. The study was conducted in an area of 8 ha of pasture Mombaça-grass (*Panicum maximum*) irrigated and intensive managed in a rotational system with 48 paddocks in Sao Carlos, SP, Brazil. Soil samples were collected at 0–0.2 m depth with 6 sub-samples in each paddock. The values of soil P, K, CEC and basis saturation were analyzed by traditional soil testing. Apparent soil electrical conductivity (ECa) was measured with contact sensor. Spatial variability soil properties and site specific liming and fertilizer need were modeled using semivariograms and maps were obtained by kriging with Vesper software. Crop variation at this spatial scale was not affected by topography and other soil chemical properties related. NDVI and ECa had the same tendency of dry matter estimation. Results showed that the soil properties of study area are very homogeneous, and variable rate of potassium fertilizer has the potential to be adopted in the study area.

Key words: geostatistics, soil fertility, Vesper, variable rate, soil electrical conductivity, *Panicum maximum*, field sensor, Crop Circle, NDVI.

INTRODUCTION

In Brazil the predominant beef and dairy cattle production systems are based mostly on grazing and relying on native and cultivated pastures, which are grazed at continuous stocking all year round and is the main source of animal feed. About 90% of the nutrients required by the ruminants are obtained directly through grazing (Euclides et al., 2010). Well established pastures that are properly managed and fertilized are the main source of food for cattle and most practical as a less costly source of feeding (Camargo et al., 2002).

In intensive cattle production the system allows increased rates of stocking and productivity (Corsi and Nussio, 1993; Primavesi et al, 1999) based on replanting with better grass varieties, grazing rotation, forage availability in the dry season, regulation of stocking densities, genetic improvement of cattle herds and building up soil fertility by balanced fertilizer supply.

The pasture productivity is determined by many factors as specie, climatic and soil conditions and management practices. The research in tropical and subtropical regions has highlighted the need to supply the pasture system with macro (N, P, K, Ca, Mg and S) and micronutrients (B, Cu, Mo, Mn and Zn), as well as the soil amendments, since fertilization is one of the factors that most contribute to increase forage dry matter productivity and quality (Corsi and Nussio, 1993; Primavesi et al., 1999; Camargo et al., 2002; Cantarella et al., 2002; Bernardi et al., 2012). In general, N is the nutrient that is the most limiting for plant growth and affects the productivity of pastures (Jarvis et al., 1995).

In intensively managed pastures the maximum doses of nutrients for technical and economical response are high. Research results point to economic doses around 800 kg per ha per year of N and K₂O in irrigated pastures, splitted 8 to 9 times, and 500 kg per ha per year this nutrients in no irrigated pastures (Minson et al., 1993; Martha Júnior et al., 2004; Sousa et al., 2004; Primavesi et al., 2004; Primavesi et al., 2003; Oliveira et al., 2003; Bernardi et al., 2012).

The maintenance of levels of soil fertility depends on the recycling and inputs to the system. Intensive production system requires high stocking rate, and thus higher biomass productivity and quality of the grass, is essential to correct soil acidity with lime and use fertilizer. Especially 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 the pasture.

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.

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 recent application of proximal active optical sensors as Greenseeker™ and Crop Circle™ are alternatives for the satellite imaginary measurements (Flynn et al., 2008; Trotter et al., 2010).

The objective of this work was to map and evaluate the soil chemical properties and maps the site specific liming and fertilizer need in a irrigated tropical pasture.

MATERIAL AND METHODS

The 8 ha field study was conducted at Embrapa Cattle Southeast, in Sao Carlos (21°57'15 S e 47°50'53,5 W; 840 m above sea level), State of Sao Paulo, Brazil. The climate is Cwa type (Köppen), 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 (CEPAGRI, 2010). Soil type was an Latossolo Vermelho-Amarelo distrófico textura média (Calderano et al., 1998) corresponding to a Typic Haplortox (Soil taxonomy).

Irrigated *Panicum maximum* cv. Mombaça pasture has been intensively managed since 2005. The pastures are managed under rotational system with 3 and days of grazing and 33 between the cycle in the rainy season and dry season. Pasture was fertilized after each grazing cycle with 80 and 40 kg ha of N respectively during rain and dry season, the total amount of N was 600 kg ha⁻¹ as urea (45% N). Liming, P and K fertilization were calculated from soil testing and the criteria were described by Bernardi et al. (2012). The pasture is divided with electric fence into 12 paddocks and four systems (Figure 1A) with 1,458 m² each. Soil samples were collected at 0–0.2 m depth with 6 sub-samples in each paddocks.

Following the methods of Primavesi et al. (2005) the chemical properties were determined. Soil pH measurements were made in CaCl₂, organic carbon was determined by wet combustion, available P (resin method), exchangeable K⁺, Ca²⁺, Mg²⁺ and H+Al. 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 a prototype model (Rabello et al., 2010, 2011). Measurements are carried out according to the equation 1:

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

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). Sampled points are shown in Figure 1B.

Canopy reflectance data were collected one day before harvest using a Crop Circle ACS-430 light sensor (Holland Scientific, Lincoln, NE). The equipment is characterized by three optical measurement channels and measures crop and soil reflectance at 670, 730, and 780 nm simultaneously from light emitted by a modulated polychromatic Light Emitting Diode (LED) array, so is considered an “active” sensor (Solari et al., 2008). The sensor was carried on approximately 50-cm above and perpendicular to the Tanzania-grass leaf canopy. In the previous calibration experiment reflectance was measured in each plot, providing ≈ 120 measurements per plot. In the paddocks measured the coordinates of each reflectance measurement was made on site using a global positioning system device (Garmin GPSmap 60CSx, Garmin Int. Corp., Olathe, KS).

Harvest for dry matter yield evaluation were performed every 35 day to a stubble height of 0.3 m at all the summer season. All samples were oven-dried (65°C) for 72 h and subsequently weighed.

Liming and fertilization recommendation were made with Adubapasto software (Embrapa Pecuaría Sudeste, Sao Carlos, SP, Brazil, <http://www.cppse.embrapa.br/adubapasto>). Liming need were established based on 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 6% of CEC. Phosphorus levels, as ordinary superphosphate (18% P_2O_5) was calculated to increase available P to 20 mg dm^{-3} .

Statistical parameters and geostatistical analyses were performed for all variables focusing the spatial continuity and dependence of soil and forage properties. Empirical directional semivariograms were calculated for x- and y-directions. Semivariogram models were fitted to empirical semivariograms $\hat{\gamma}(h)$ using VESPER (Minasny et al., 2005) to estimate the structure of the spatial variation of a variable V , and the semivariance with the equation 2:

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

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).

Contour maps of soil parameters properties, ECa, liming and P and K fertilizer requirements were estimated by ordinary kriging interpolation using

VESPER software (Minasny et al., 2005). NDVI and dry matter yield were obtained by natural neighbor interpolation (Sibson, 1981)

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. These values together with the other classical statistical parameters are useful to evaluate the magnitude of the data dispersion around a central tendency value.

The verification of the data normality is important since kriging performs better when there is normal data distribution (Carvalho et al., 2002). Thus, a data set that approaches the normal distribution, the values for skewness and kurtosis coefficients must be between 0 and 3 (Vieira et al., 2000; Carvalho et al., 2002). From the results only pH, CEC and clay values showed skewness and kurtosis compatible with normal (Table 1). The other parameters did not show normal distribution.

Following to the classification suggested by Pimentel-Gomez (1984), coefficients of variation of pH and OM were considered low (<10%), V% had a medium coefficient of variation (between 10% and 20%) and other soil variables (P, K, CEC, clay and ECa) showed high coefficients of variation (> 20%). 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.

The main application of geostatistics to soil fertility has been the estimation and mapping of soil attributes in unsampled areas. Experimental semivariograms for all variables were computed and all fitted models were bounded. Table 2 presented the semivariogram and fitted models

Among the studied soil variable, the semivariogram of pH, OM, K and clay were fitted for the pure nugget effect model, indicating no spatial dependence under the sampled interval. Confirming that data with lowest coefficient of variation. The results suggested that the pH, OM, K and clay were scatter distributed and had no spatial correlation. Nugget effect represents the error and field variation within the sampling spacing.

Except for P which fitted a spherical model, the semivariograms of CEC, V% and ECa were all well fitted for the Gaussian model. Nevertheless, Trangmar et al. (1985) already had showed that spherical model as the best adapted to describe the behavior of variograms of soil attributes. The ranges for P, CEC, V%, ECa and K₂O level were 219, 209, 148, 10000 and 72m, respectively. These results indicate that a grid spacing of 72 m would be adequate for the characterization of the soil parameters spatial variability for this site.

The nugget: sill ratio can be used as criteria to classify the spatial dependence of variables (Cambardella et al., 1994). The variable ECE has strong spatial dependence since the ratio less than 25%; the variables ECa and K₂O levels has moderate spatial dependence with ratio between 25% and 75%; the variable soil basis saturation and P₂O₅ recommended level showed weak spatial dependence with ratio greater than 75. The spatial variability of soil properties may be affected by intrinsic (soil formation factors) and extrinsic factors (soil management practices). These data confirms the observation of Cambardella et al. (1994) that strong dependence of soil properties can be attributed to intrinsic factors, and weak spatial dependence can be attributed to extrinsic factors.

Figure 2 shows the spatial patterns of the soil parameters P, CEC, V% and ECa generated from their semivariograms by kriging. The range values for P (from 16 to 21 mg dm⁻³) and basis saturation-V% (from 59 to 64%) are considered medium according to Rajj et al. (1996). ECa values ranged from 5,6 to 7,0 mS m⁻¹ and were to straight and the maps showed those small distinct geographical distribution.

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 besides soil ECa integrates soil properties as soil texture, soil organic matter, cation exchange capacity, and exchangeable Ca and Mg, the regions with higher values were not the same with higher soil evaluated parameters.

Besides the homogeneity of P, K and V% parameters, liming and fertilization recommendation were calculated with Adubapasto software (Embrapa, <http://www.cppse.embrapa.br/adubapasto>). Results showed that only variable rate of K fertilizer had the potential to be adopted in the study area (Table 2). These results may not support the decision-making practices of liming and P fertilization in variable rates, since uniform applying of fertilizer can be successfully carried out. Variable rates tax of K fertilizer could be applied in the area (Figure 3).

Figure 4 illustrates the map created based on natural neighbor method for pasture NDVI. 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. Confirming this the DM yield map showed the same pattern observed on NDVI map. This is also an indicative that the crop variation at this studied field is showed by vegetation index variation.

Results show a tendency of higher DM yield at same area with higher NDEVI an ECa, but data should be collected in other measurements to confirm the tendency

CONCLUSIONS

The soil parameters pH, CEC and clay were normal distributed, unlike organic matter (OM), P, K, basis saturation (V%) and ECa. The CV values for the decreased in the order of P>ECa>K>clay>CEC>V%>OM>pH. 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. The main application of geostatistics to soil fertility has been the estimation and mapping of soil attributes in unsampled areas. Geostatistical analysis indicated that the semivariograms for P were fitted with a spherical model and that CEC, V% and ECa were fitted with a Gaussian model. The semivariogram for pH, OM, K and clay, however, was fitted with the pure nugget effect model, confirming that data with lowest coefficient of variation. The evaluated soil parameters had different degrees of variability; CEC had strong spatial dependence with a range of 209 m. ECa had moderate spatial dependence with a long range of 10 km. However, P and V% showed weak spatial dependence, with range of 219 and 148 m, respectively. Crop variation at this spatial scale was not affected by topography and other soil chemical properties related. NDVI and ECa had the same tendency of dry matter estimation. Results showed that the soil properties of study area are very homogeneous, and only variable rate of potassium fertilizer has the potential to be adopted in the study area.

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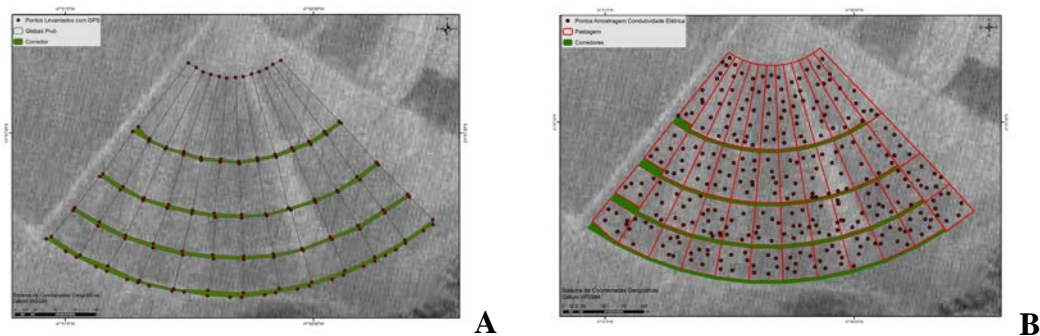


Figure 1: Division of the 1,458 m²-paddocks in the irrigated Mombaça-grass pasture (A) and sampling points for evaluation of apparent soil electrical conductivity (B).

Table 1. Descriptive statistics for soil chemical and physical properties NDVI and dry matter production of an irrigated and intensive managed pasture of Mombaça-grass (*Panicum maximum*) in Brazil.

| Statistical Parameters | pH CaCl ₂ | OM g kg ⁻¹ | P mg dm ⁻³ | K mmol _c dm ⁻³ | CEC mmol _c dm ⁻³ | V % | Clay g kg ⁻¹ | ECa mS m ⁻¹ | NDVI | DM kg ha ⁻¹ |
|------------------------|-------------------------|-----------------------------|-----------------------------|--|--|--------|----------------------------|------------------------------|------|---------------------------|
| μ | 5.6 | 24.9 | 15.6 | 3.4 | 76.5 | 60.6 | 297.0 | 6.1 | | 22,546 |
| σ | 0.2 | 1.0 | 5.8 | 1.0 | 11.5 | 6.1 | 75.1 | 2.1 | | 5840.2 |
| Minimum | 5.1 | 22.0 | 4.0 | 1.6 | 57.0 | 46.0 | 171.0 | 0.4 | | 15,357 |
| Maximum | 6.2 | 27.0 | 26.0 | 5.5 | 108.0 | 75.0 | 463.0 | 9.9 | | 31,846 |
| CV (%)* | 4.1 | 4.0 | 37.0 | 29.8 | 15.0 | 10.0 | 25.3 | 34.8 | | 25.9 |
| Curtosis | 0.1 | 0.9 | -0.6 | -0.8 | 0.9 | -0.3 | -0.2 | 0.1 | | -1.1 |
| Skewness | 0.3 | -0.5 | 0.1 | 0.1 | 0.9 | 0.1 | 0.5 | -0.6 | | 0.5 |
| N | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 320 | | 12 |

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

Table 2. Parameters for semivariograms models for EC_a and chemical properties of a irrigated and intensive managed pasture of Mombaça-grass (*Panicum maximum*) in Brazil.

| Variable | C ₀ * | C ₁ * | a* | Model | Nugget/sill 100[C ₀ (C ₀ + C ₁) ⁻¹] |
|------------------------------|------------------|------------------|-------|---------------|--|
| pH (CaCl₂) | - | - | - | Nugget effect | |
| MO | - | - | - | Nugget effect | |
| P | 57.72 | 14.51 | 218.8 | Spherical | 79.9 |
| K | - | - | - | Nugget effect | |
| CEC | 23.92 | 245.5 | 209.0 | Gaussian | 8.9 |
| V | 31.02 | 8.814 | 148.1 | Gaussian | 77.8 |
| Clay | - | - | - | Nugget | |

| | | | | | |
|-----------------------------------|--------|--------|--------|-----------|------|
| ECa | 5.091 | 496.3 | 10,000 | effect | |
| Liming | - | - | - | Gaussian | 27.3 |
| | | | | Nugget | - |
| | | | | effect | |
| K₂O | 1404.2 | 4082.6 | 71.85 | Spherical | 25.6 |
| P₂O₅ | - | - | - | Nugget | - |
| | | | | effect | |

*The parameters are: C_0 = the nugget variance, C_1 = the sill of the auto correlated variance; a = the range of the spatial dependence.

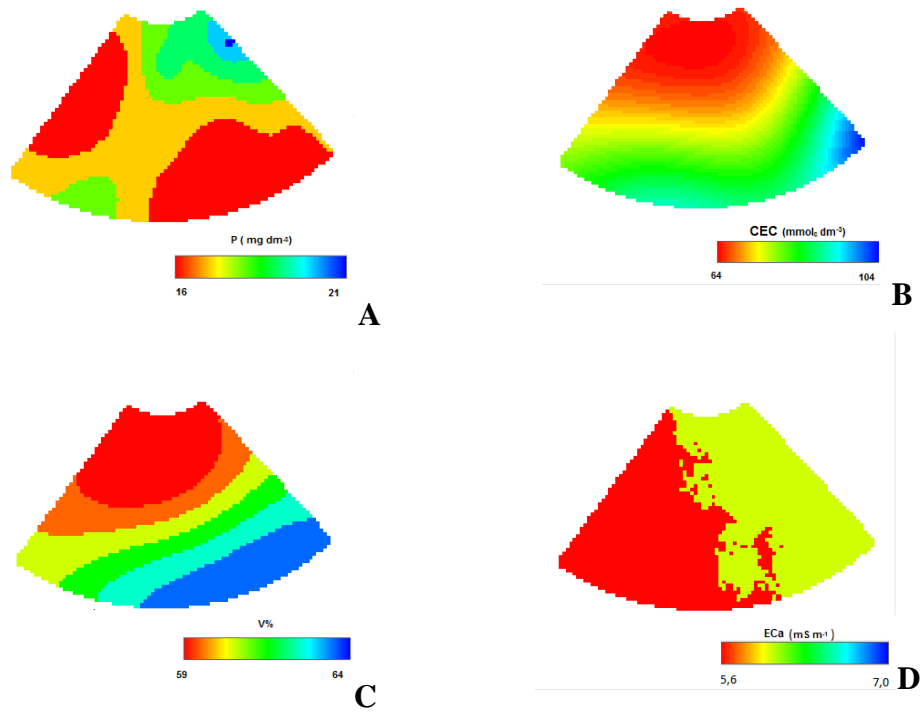


Figure 2. Maps of estimated kriged for P available (A) cation exchange capacity - CTC (B), basis saturation - V% (C) and soil apparent electrical conductivity ECa (D) of irrigated Mombaça-grass in São Carlos, SP, Brazil.

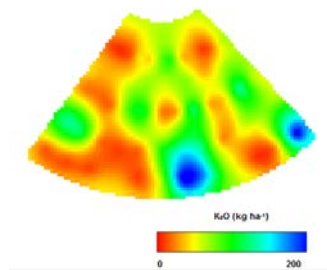


Figure 3. Map of estimated potassium fertilizer requirements of irrigated Mombaça-grass in São Carlos, SP, Brazil.

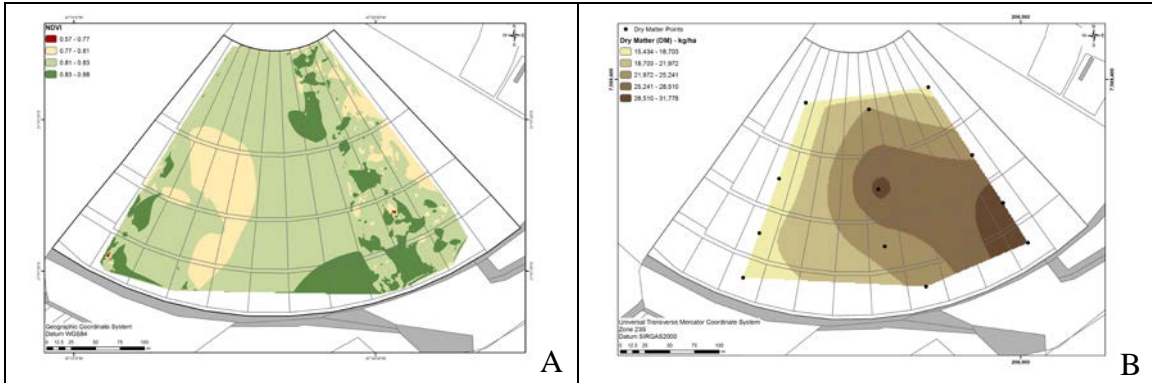


Figure 4. Map of NDVI (A) and dry matter yield (B) by natural neighbor interpolation of irrigated Mombaça-grass in São Carlos, SP, Brazil.

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