Spatial variability of soil properties and yield of an alfalfa pasture under grazing in Brazil

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ABSTRACT

Alfalfa is extremely demanding in fertility, and an adequate supply of nutrients is important for forage production and is essential to maintain high forage quality and profitable yields. Tropical acid soils are naturally poor in plant nutrients, therefore, soil liming and balanced nutrient supply essential to ensure high yields and high alfalfa forage quality. The knowledge of soil properties spatial variability and forage yield is useful for the rational use of inputs, as in the variable rate application of lime and fertilizers. Precision agriculture requires methods to indicate the spatial variability of soil and plant parameters. The objective of this research was to map and evaluate the spatial variability of soil properties, yield, liming and fertilizer need and economical return of an alfalfa pasture. The study was conducted in a 5.3-ha-area of irrigated alfalfa pasture, directly grazed, intensive managed in a rotational system with 270 paddocks in Sao Carlos, SP, Brazil. Alfalfa shoot dry matter yield was evaluated when the crop has 10% of flowering and before the dairy cattle grazing. Soil samples were collected at 0-0.2m depth and each one represented a group of 5 paddocks. The values of soil pH, P, K, CEC and basis saturation were analyzed by traditional soil testing. Apparent soil electrical conductivity (ECa) was measured with a contact sensor. Data of liming and fertilizer needs were used to estimate the 1-ha-alfalfa cost of production and the total cost of production dairy system. Results of alfalfa dry matter yield were used to simulate pasture stocking rate, milk yield, gross revenue and net profit. The entire variable used at the estimation was based on a Brazilian intensive dairy cattle production systems based on grazing. Spatial variability soil properties and site specific liming and fertilizer need were modeled using semivariograms with Vesper software, and the soil fertility information and economic return were obtained by SPRING software. Results showed that the geostatistics and GIS use were decisive tools to show soil and pasture spatial variability and support management strategies. Soil nutrient were used to classify the soil spatial distribution map in order to design site-specific lime and fertilizer application maps. Spatial variation of forage and estimative of stocking and milk yield are adequate pasture management tools. Spatial variation of issue needs, forage availability and economic return are management tools to avoid economic and potential environmental problems form unbalanced nutrient supplying and over- or under-grazing pressure.

Key words: soil fertility, Vesper, SPRING software, variable rate, *Medicago sativa*, profitability

Introduction

Well established, properly managed and fertilized pastures are the most practical and the main source of food for cattle, as well as the source with the least cost for cattle feeding (Camargo et al., 2002). On dairy production systems, the intensive pasture grazing allows to increase stocking rates and the productivity (Corsi and Nussio, 1993; Primavesi et al, 1999).

Among the controllable factors determining forage yield and quality, the soil fertility is one of the most important, including the fertilizer treatment. Tropical acid soils are naturally poor in plant nutrients, therefore, soil liming and balanced nutrient supply essential to ensure high yields and high forage quality (Corsi and Nussio, 1993; Primavesi et al, 1999; Camargo et al., 2002). Alfalfa is extremely demanding in fertility, and an adequate supply of nutrients is important for forage production and is essential to maintain high forage quality and profitable yields (Moreira et al., 2008; Bernardi et al., 2013a,b). However, fertilization may represent as much as 27% of the total production cost of alfalfa in typical Brazilian systems for intensive dairy cattle production (Vinholis et al., 2008).

Precision Agriculture (PA) contribute to long-term sustainability of agriculture, by managing inputs to reduce losses from excess applications and due to nutrient imbalances (Bongiovanni and Lowenberg-Deboer, 2004). But most of the known technology of PA had been developed and applied to annual crops, although all these technologies are available and can be successfully use in pasture management (Schellberg et al., 2008). Fu et al. (2010) indicate that fertilizer use efficiency, agronomic and environmental management may be increased by adjusting fertilizer inputs based on soil fertility spatial variability. According to Schellberg et al. (2008) the detection of spatial variation in the pasture is the major challenge since the primary objective of PA is the management of that heterogeneity in the field.

Knowledge of soil properties spatial variability and forage yield is useful for the rational use of inputs, as in the variable rate application of lime and fertilizers. PA and forage management require rapid low-cost sensors and methods to show spatial variability to reduce the need for expensive and intensive sampling (McBratney and Pringle, 1999). Measurement of the soil and vegetation spatial variability of pastures is the basis for management of variable rate fertilization (Serrano et al., 2010) and also for grazing management. Apparent soil electrical conductivity (ECa) measurement can provide on-the-go spatial data acquisition for soil and yield variation characterization (Kitchen et al., 2003; Serrano et al., 2010).

Apparent soil electrical conductivity (ECa) integrates texture and moisture availability, two soil characteristics that affect crop and forage yield as shown by Kitchen et al. (1999); Luchiari et al. (2001) and Serrano et al. (2010). 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.

Evaluation of PA tools to establish alfalfa fertilization needs and economic return to dairy production systems are required for establishing conditions under which the response will be maximized, especially with pastures on acid and low fertility soils. Hence, the effects of various management practices, including PA and related issues become important factors for achieving a profitable dairy production.

The objective of this research was to map and evaluate the spatial variability of soil properties, yield, liming and fertilizer need and economical return of an alfalfa pasture.

Material and methods

The study was conducted at Embrapa Pecuaria Sudeste, 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 a 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 during spring and summer seasons (CEPAGRI, 2010). Soil type was a clay red yellow latosol (Calderano et al., 1998) corresponding to a Typic Hapludox (Soil taxonomy) or an Orthic Ferralsol (FAO).

A 5.3 ha-area of irrigated alfalfa (*Medicago sativa* cv. Crioula) pasture had been intensive managed for 2 years in a rotational system with 270 paddocks divided with electric fence (Figure 1) with 80, 160 and 240 m^2 each. The pastures were managed under rotational system with one day grazing and 30 days between the cycles all over the year. Alfalfa shoot dry matter yield was evaluated when the crop has 10% of flowering and before the dairy cattle grazing.

Figure 1: Division of the 270 paddocks of alfalfa pasture under grazing in Brazil.

Soil samples were collected at 0-0.2 m depth and each one represented a group of 2 or 3 paddocks. Following Primavesi et al. (2005) the chemical properties were determined. Soil pH measurements were made in $CaCl_2$, organic carbon was determined by wet combustion, available P (resin method), exchangeable K^+,

Ca^{2+}, Mg^{2+} 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 content) were determined by the densimeter method. Soil apparent electrical conductivity was measured using the Veris model 3100 sensor manufactured by Veris Technologies of Salina, KS (Lund et al., 1999).
Liming, P and K fertilization were calculated from soil testing and the criteria were described by Moreira et al. (2008) and Bernardi et al. (2013a,b): lime to increase basis saturation to 80%, P fertilizer (super single phosphate, 18% P_2O_5) to increase soil P to 20 mg dm^{-3}; and K fertilizer (KCl, 60% K_2O) to increase exchangeable K to 5% of soil cation exchange capacity.
The amount of liming and fertilizer were used to simulate the production cost of 1 ha of alfalfa and the percentage of the alfalfa at the total cost production of a dairy system. All other fix and variable cost were based on previous data of Vinholis et al. (2008) for a Brazilian intensive dairy cattle production system, with the characteristics: cow's diet consisted of 20% of alfalfa pasture, and 80% of *Panicum maximum*. cv Tanzania (grazed during the rainy season) and maize silage (dry season).The results obtained for alfalfa dry matter yield in each paddock were used to estimate total dry matter yield in a year, and simulate pasture stocking rate, milk yield, and gross revenue. The following data were used in the simulation: a) average cow live weight (LW) = 550 kg; b) cow dry matter (DM) consumption = 3.05% of the LW, corresponding to 16.8 kg day^{-1} of DM; c) the alfalfa pasture grazing represented 20% of the forage consumption. The estimations were made using the following equations:

i) Cost of production of alfalfa:

$$\mathrm{AC} = \mathrm{AC} + \mathrm{LFC}$$

wherein:
AC = cost of production of 1ha of alfalfa, US\$ ha^{-1} per year;
CP = cost of production of 1ha of alfalfa (Vinholis et al., 2008), includes variable and fixed costs except lime and fertilizers inputs, US\$ ha^{-1} per year (AC = US\$ 1,894 ha^{-1} per year);
LFC = lime (US\$ 0.03 per kg) and fertilizer costs (SSP = US\$ 0.48 per kg and KCl = US\$ 0.39 per kg);

ii) Stocking rate:

$$\mathrm{SR} = \frac{\mathrm{DM} \times \mathrm{GE}}{\mathrm{AGN} \times \mathrm{GI} \times \mathrm{DIFC}}$$

wherein
SR = stocking rate in the alfalfa pasture, animal ha^{-1};
DM = dry matter yield, kg ha^{-1};
GE = grazing efficiency (GE = 0.7);
AGN = annual number of grazing events (12 grazing events/year);
GI = grazing interval, days (30 days);
DIFC = daily individual forage consumption, kg of dry matter/cow/day.

iii) Milk yield:

$$\mathrm{MY} = \frac{\mathrm{SR} \times \mathrm{MYd} \times 365}{1 + (\mathrm{TPIA} + \mathrm{SCIA}) \times \mathrm{SR}}$$

wherein
MY = annual milk production, liters ha^{-1} $year^{-1}$;
MYd = daily milk yield, liters cow^{-1} day^{-1} (20 liter cow^{-1}, 4% fat content);
TPIA =tropical pasture individual area, ha cow^{-1} (TPIA = 0.125 ha cow^{-1});
SCIA = sugarcane individual area, ha cow^{-1} (SCIA = 0.043 ha cow^{-1});
Obs.: TPIA and SCIA are the areas of tropical pasture and sugarcane used for feeding the cows that also graze in 1 ha of alfalfa.

iv) Gross revenue:

$$GR = MY \times MP$$

wherein:
GR = gross revenue, US$ ha^{-1};
MY = annual milk production, liters ha^{-1} $year^{-1}$;
MP = milk price, US$ L^{-1} (MP = US$ 0.40 L^{-1}).

v) Total cost of production:

$$TCP = AC + TCPD$$

wherein:
TCP = cost of production, US$ ha^{-1} per year;
AC = cost of production of 1ha of alfalfa, US$ ha^{-1} per year;
TCPD = total production cost of dairy system (Vinholis et al., 2008), US$ ha^{-1} per year (TDC = US$ US$ 6,068 ha^{-1} $year^{-1}$);

vi) Net profit:

$$NP = GR - TCP$$

wherein:
NP = net profit, US$ ha^{-1}
GR = gross revenue, US$ ha^{-1}
TCP = production cost, US$ ha^{-1}

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 using VESPER (Minasny et al., 2005) to estimate the structure of the spatial variation. Contour maps of all variables were estimated using ArcGIS 10.1 (ESRI, 2009). SPRING (Câmara et al., 1996), a free object based georefered information system - GIS (www.dpi.inpe.br/spring), was used to integrate the all the soil fertility maps. The net profit was made subtracting the cost production from gross revenue to estimate the map using the spatial analyst extension of the ArcGIS 10.1.

Results and Discussion

Descriptive 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.

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 (Carvalho et al., 2002). From the results only soil P showed skewness and kurtosis incompatible with normal distribution (Table 1). All the other parameters showed normal distribution.
Following to the classification suggested by Pimentel-Gomez (1984), coefficients of variation of soil pH, CEC, basis saturation, clay and milk yield are the variables with low variability with coefficient of variation bellow of 10%. Soil O.M., Ca, Mg, dry matter yield and stocking rate were the variables with medium variability (CV between 10 and 20%). All the others parameters showed 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 soil parameters.

Table 1. Descriptive statistics for variables of an alfalfa pasture under grazing in Brazil.

Variables	μ	σ	Minimum	Maximum	CV (%)	Curtosis	Skewness	n
pH_{CaCl2}	5.7	0.340	5.2	6.6	5.965	1.081	1.166	160
OM (g kg^{-1})	25.5	3.122	19.0	34.0	12.24	0.547	0.492	160
P mg dm^{-3}	35.0	29.82	9.0	141.0	85.20	4.298	2.096	160
K ($mmol_c$ dm^{-3})	3.5	1.345	0.6	5.4	38.43	-0.783	-0.571	160
Ca ($mmol_c$ dm^{-3})	37.0	5.509	26.0	55.0	14.89	2.161	0.763	160
Mg ($mmol_c$ dm^{-3})	17.2	3.597	12.0	25.0	20.91	-1.001	0.497	160
CEC ($mmol_c$ dm^{-3})	79.6	5.401	69.0	92.0	6.785	-0.387	-0.137	160
Basis saturation (%)	72.4	7.105	58.0	86.0	9.814	-0.889	0.109	160
Clay (g kg^{-1})	631.3	19.24	595	674	0.03	-0.258	0.245	160
EC_a (mS m^{-1})	7.7	4.642	0.0	42.8	60.29	1.273	0.622	4794
Lime (kg ha^{-1})	627.8	495.9	0.0	1584.0	78.99	-1.349	0.071	160
Super single phosphate (kg ha^{-1})	408.0	414.4	0.0	1166.7	101.6	-1.434	0.391	160
KCl (kg ha^{-1})	126.8	169.1	0.0	525.0	133.4	-0.182	1.096	160
Dry matter yield (kg ha^{-1})	18540	3279.9	9060	28710	17.69	0.362	-0.266	153
Stocking rate (cows per ha)	15	2.606	7	23	17.37	0.501	-0.265	153
Milk yield (kg ha^{-1} per year)	30610	1795.3	23483	34519	5.865	2.063	-1.204	153

*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). Geostatistics is useful tool to soil fertility to the estimation and mapping of soil attributes in areas not sampled. Results showed that the full extent of the variation of studied parameters encountered the spatial scale. The spherical model was the best adjusted to experimental variograms to soil pH, Mg, CEC, K fertilization, ECa and milk yield. Trangmar et al. (1985) already had showed this model as the best adapted to describe the behavior of variograms of soil attributes. For soil O.M., available P, exchangeable K, and dry matter yield a Gaussian model was used to fit the variogram. For soil Ca, basis saturation, lime, P fertilizer, and stocking rate an exponential model was used to describe the spatial dependence.

The ratio of nugget to total semivariance can be used as criteria to classify the spatial dependence of variables (Cambardella et al., 1994). Soil pH, O.M., P, Ca, Mg, basis saturation, lime, P and K fertilization had weak spatial dependence (>75%). Soil K, CEC, dry matter yield and stocking rate showed moderate spatial dependence with ratio between 25% and 75%. Soil ECa and milk yield showed strong spatial dependence with ratio greater than 75%. The spatial variability of soil properties may be affected by intrinsic and extrinsic factors, respectively as the soil formation factors and the soil management practices (Cambardella et al., 1994). The ranges for soil parameters were between 62 to 10,000 m. These results indicate that a grid spacing of 62 m would be adequate for the characterization of the soil parameters spatial variability for this site. So, 2.6 samples per ha could adequately show the soil spatial variation at this site.

Table 2. Parameters for semivariograms models for variables of an alfalfa pasture under grazing in Brazil.

Variable	C_0^*	C_1^*	A^*	Model	Nugget/sill $100[C_0 (C_0 + C_1)^{-1}]$	Spatial dependence
pH_{CaCl2}	0.003285	5.81	10,000	Spherical	99.9	Weak
OM (g kg^{-1})	2.664	9.34	84.81	Gaussian	77.8	Weak
P_{resine} (mg dm^{-3})	62.66	959.1	66.29	Gaussian	93.9	Weak
K (mmol$_c$ dm^{-3})	0.963	2.013	165	Gaussian	67.6	Moderate
Ca (mmol$_c$ dm^{-3})	3	39	71	Exponential	92.9	Weak
Mg (mmol$_c$ dm^{-3})	2	11.17	62.2	Spherical	84.8	Weak
CEC (mmol$_c$ dm^{-3})	9.33	20.7	64.57	Spherical	68.9	Moderate
Basis saturation (%)	1	81	102	Exponential	98.8	Weak
Clay (g kg^{-1})	9.63	535.9	208.8	Spherical	98.24	Weak
EC_a (mS m^{-1})	17.22	5.75	184.6	Spherical	25.0	Strong
Lime (kg ha^{-1})	8,363	244,748	97	Exponential	96.7	Weak
Super single phosphate (kg ha^{-1})	13,209	213,942	107	Exponential	94.2	Weak
KCl (kg ha^{-1})	4,415	18,997	90	Spherical	81.1	Weak
Dry matter yield (kg ha^{-1})	7,725,788	4,380,353	19.77	Gaussian	36.2	Moderate
Stocking rate (cows per ha)	4.543	3.026	36.33	Exponential	40.0	Moderate
Milk yield (kg ha^{-1} per year)	2,790,218	780,683	63.57	Spherical	21.9	Strong

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

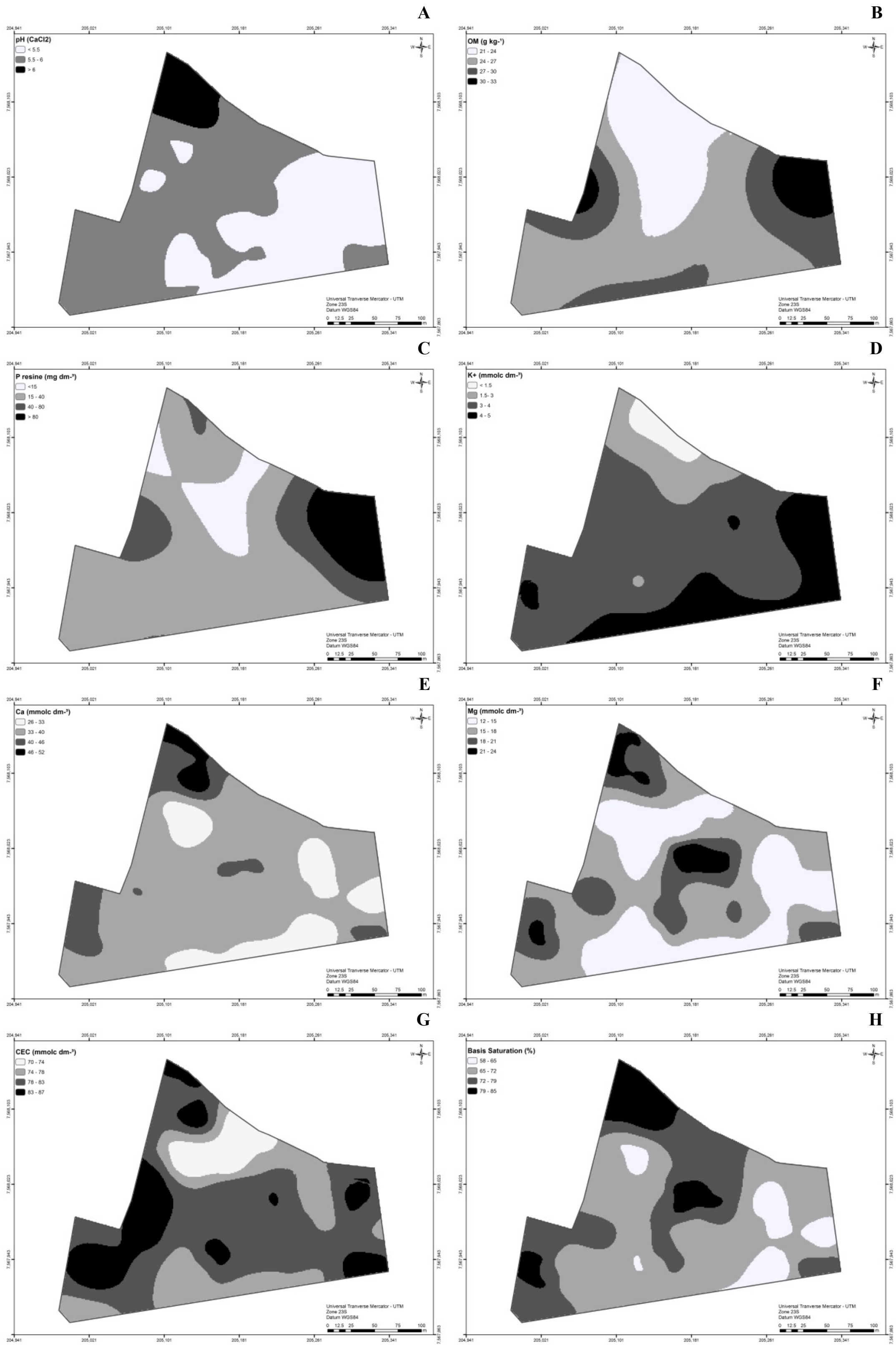

Figure 2. Kriged maps for pH (A); organic matter (B); P available (C), exchangeable K (D); Ca (E) an Mg (F); cation exchange capacity - CEC (G), basis saturation – V% (H) of an alfalfa pasture under grazing in Brazil.

Figure 2 shows the spatial patterns of the soil parameters generated by kriging from the semivariograms.

The range values for soil organic matter (from 19 to 34 g kg^{-1}) and cation exchange capacity (from 69 to 92 $mmol_c$ dm^{-3}) are considered respectively medium and high according to Alvarez Venegas et al. (1999).

The minimum value of soil Ca and Mg (26 and 12 $mmol_c$ dm^{-3}) were higher than 7 and 8 mmo_c dm^{-3}, considered high (Raij et al., 1997). This could indicated that the soil Ca and Mg were sufficient, but the lime requirement consider also the percentage of basis at the negative charges of the soil.

There is a direct relation between soil pH and basis saturation, because de negative charges formation are dependent of the soil solution pH value. So the pH values were considered low (up to 6.0) to very low (over 6.0) and basis saturation ranged from medium (51 to 70%) to high (71 to 90%) (Raij et al., 1997).

The most variable interpretation classes were obtained for soil P and K. Soil P levels (Figure 2C) matched four interpretation classes (Raij et al., 1997): low (6 to 12 mg dm^{-3}), medium (13 to 30 mg dm^{-3}), high (31 to 60 mg dm^{-3}), and very high (> 60 mg dm^{-3}). The class considered medium represented 65% of total area, and the high and very high levels represented 25%. Soil K levels also matched 4 interpretation classes: low (0.8 to 1.5 $mmol_c$ dm^{-3}), medium (1.6 to 3.0 $mmol_c$ dm^{-3}), high (3.1 to 6.0 $mmol_c$ dm^{-3}), and very high (> 6.0 $mmol_c$ dm^{-3}). However the higher K levels covered 84% of the total area. These levels will affect the fertilizer needs and the cost of the dairy system.

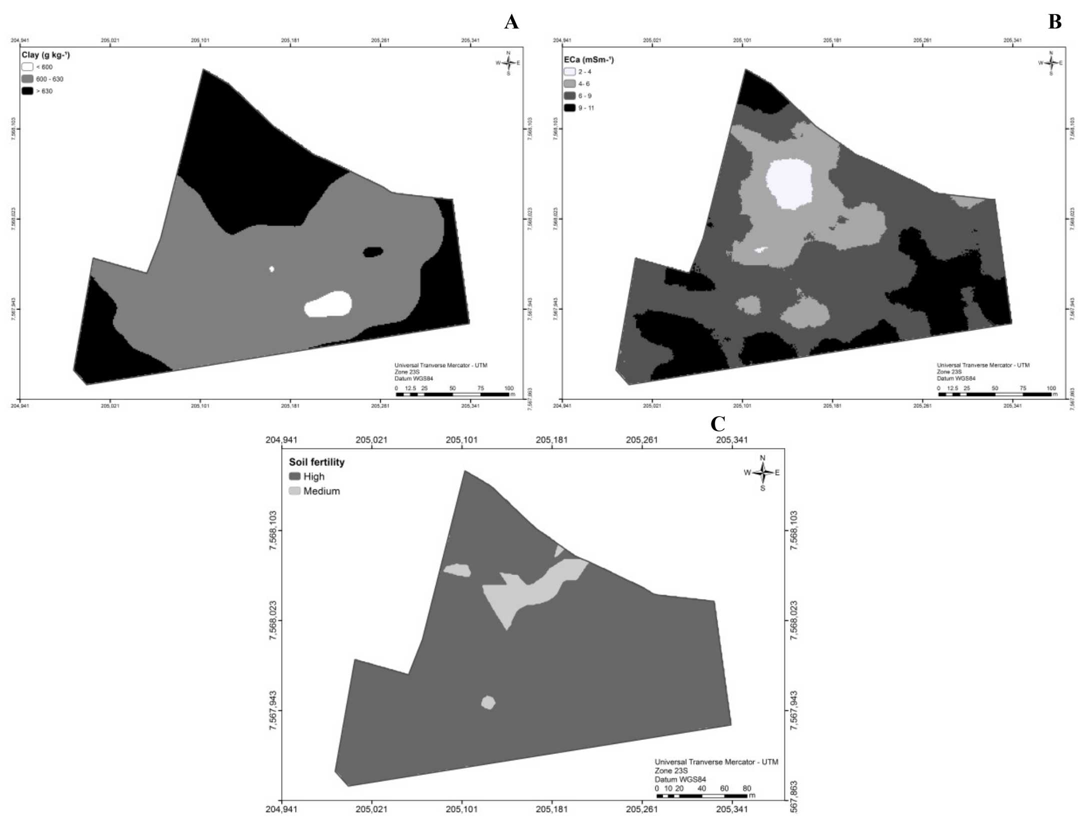

Figure 3. Kriged maps for clay (A) and soil apparent electrical conductivity ECa (B) of an alfalfa pasture under grazing in Brazil.

Krigged estimates for soil texture and ECa were contoured and mapped so that their patterns of variation on the field are shown at Figure 3. Soil texture was clay and very homogenous, since just less than 2% of the studied are presented less than 600 g kg^{-1} of clay content. ECa values ranged from 2 to 11 mS m^{-1}.
The soil fertility maps (Figure 2) obtained by the Vesper software (Minasny et al., 2005) in the raster mode were converted to vector mode at the ArcGIS software (ESRI, 2009). Vector polygons were then created for each of the soil fertility class of interpretation. Numerical values were attributed to interpretation class: 1 for low; 2 for medium, 3 for high and 4 for very high. Using the SPRING (Câmara et al., 1996) all the vector polygons were converted to matrix mode and compared to match in a soil fertility classification map (Figure 3 C), which represented the average of all polygons. Just two soil fertility interpretation classes were established: medium and high. Since soil ECa integrates soil properties as soil texture, soil organic matter, cation exchange capacity, and exchangeable basis, the region with lower values are the same at the region classified as "medium soil fertility".

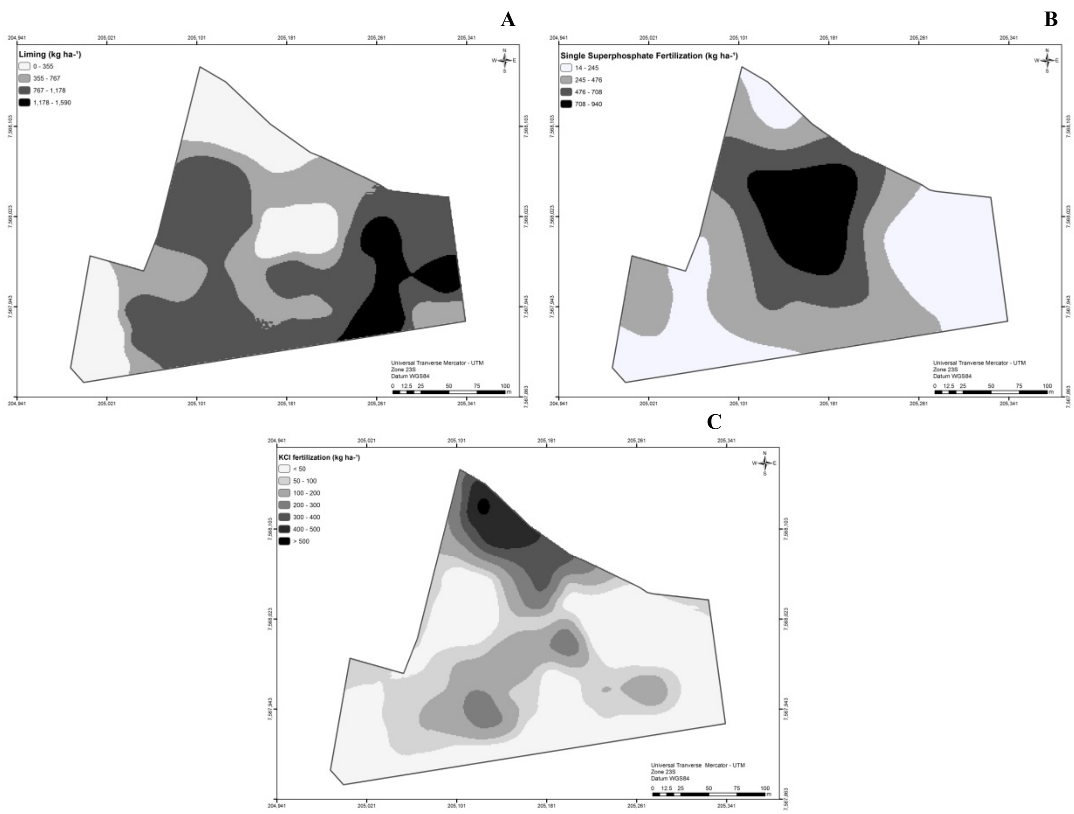

Figure 4. Kriged maps for liming (A); super single phosphate fertilization (B) and KCl fertilization (C) of an alfalfa pasture under grazing in Brazil.

Liming and fertilizer site-specific recommendations for alfalfa pasture were based mainly on soil analysis. Limestone rates are calculated to raise soil basis saturation (V%) as a percentage of the soil cation exchange capacity (CEC) at pH 7.0. For alfalfa pasture V% should be increased to 80% (Moreira et al., 2008) for the best results. Moreover liming is the lower cost and more efficient way to neutralize soil acidity, reducing Al and Mn toxicity, improving P, Ca and Mg availability, increasing CEC, promoting N_2 fixation, and improving soil structure (Moreira et al., 2008). The amounts of liming showed by Figure 4A where calculated to reach V = 80%. The liming recommendation map indicated that in 44% of the area (2,4 ha) the amount of liming should be up to 1.2 ton ha^{-1}, and just in 9% of the area lime should be applied up to 1.6 ton ha^{-1}. Twenty two percent need less than 360 kg ha^{-1}, and 25% should receive up to 770 kg ha^{-1}.

P recommendation was based on ion exchange resin-extractable P availability, and the amount to reach 20 mg dm^{-3} (Moreira et al., 2008). Site-specific map (Figure 4B) indicated that 68% of the area should receive up to 500 kg ha^{-1} of super single phosphate. The application of single superphosphate is necessary in order to increase soil P levels and in turn improve the N-fixing capacity of alfalfa pasture. Higher amount are recommended to rest of the area (42%). Potassium rates were recommended based on values of soil exchangeable K to reach 5% of the cation exchange capacity (CEC) according to Bernardi et al., 2013b) recommendation. Most of the area (85%) should receive up to 200 kg ha^{-1} of KCl (Figure 4C). Indicating that the management strategy adopted have been reached success. Fu et al (2010) also established site-specific nutrients fertilizer maps for pasture base on soil nutrient availability for dairy farms.

The stocking rate is a key management variable for determining productivity and profitability of grazing systems, since this index determines the quality and the forage use efficiency, the animal performance and the milk production per area (Fales et al., 1995).

Figure 5 illustrated that the by the simulation based on dry matter yield, allowed to estimated stocking rates and milk yield within the area. This kind of map may support the decision to avoid over- or under-grazing pressure.

And milk yield lead to the gross revenue value. The results of this simulation have shown that an alfalfa pasture adequately supplied with lime and fertilizer can support high stocking rates which results on a high milk production per hectare. Therefore, as shown by Fales et al. (1995), the optimal stocking rate for a given dairy farm depends on individual farm resources (e.g., land, buildings, cows, etc.), and can be adjusted to face these resources constraints and avoid or minimize significant adverse economic impacts. So this kind of approach can help the farm managers to predict future scenarios and support their management decision.

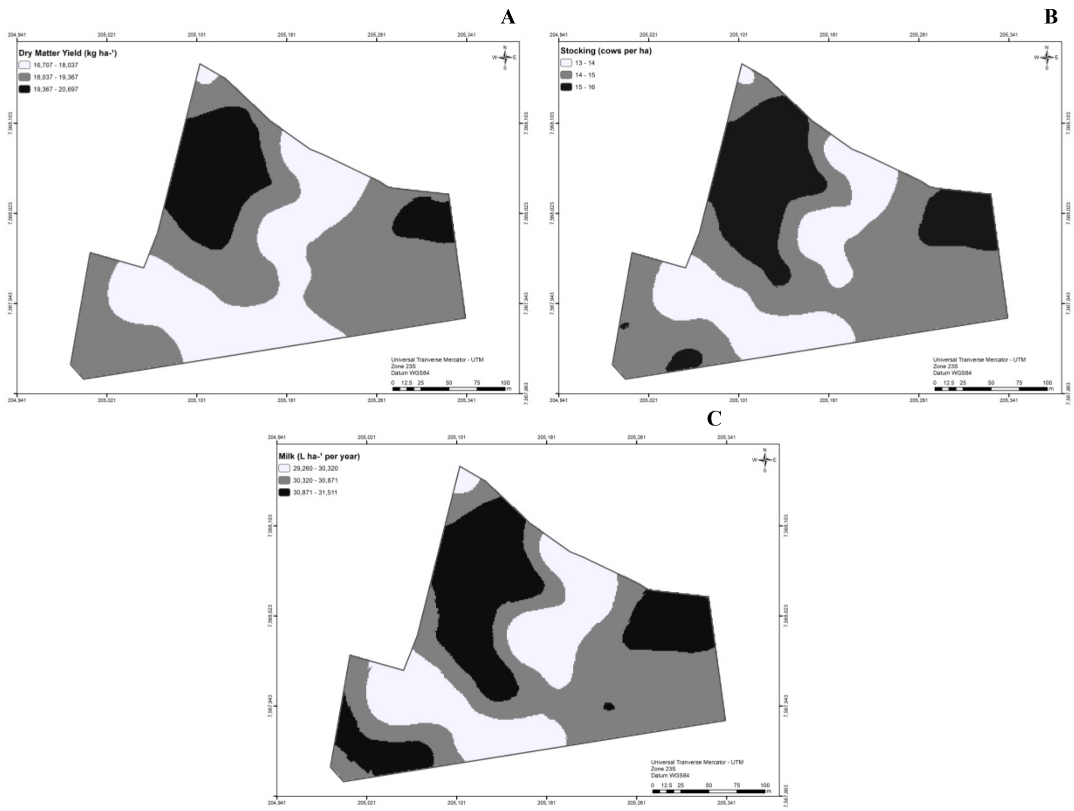

Figure 5. Kriged maps for dry matter yield (A); stocking rate (B) and milk yield (C) of an alfalfa pasture under grazing in Brazil.

The challenges for alfalfa pasture in Brazil are the persistence and unbalanced nutrition, which may lead to low forage and milk yields. Research data (Bernardi et al., 2013a,b) showed that overcoming soil fertility constraints large gains in pasture productivity and increasing persistence are possible. Precision agriculture tools helps to evidence these heterogeneity in the field (Schellberg et al., 2008) and indicate where to implement PA in competitive and cost efficient way.
In a dairy system the low economic returns may reduce farm investment and the pasture productivity especially in the alfalfa system grown on a tropical soil where the constant replenishment of nutrients is one of greater constraints. Economic profitability of this dairy system was estimated based on cost of production, considering the application of lime and P and K fertilizer on variable rates, and the revenue due to milk yield. Maps at Figure 6 illustrates the heterogeneity of costs (A), revenue (B) and net profit (C). Almost 10% of alfalfa pasture area shows profitability around 19% lower than the best area. And the cost of P fertilizer probably is decisive to the economic balance of the system. The results obtained in this research confirm the advantages of use PA tools to support management decision of pasture sistems.

A B

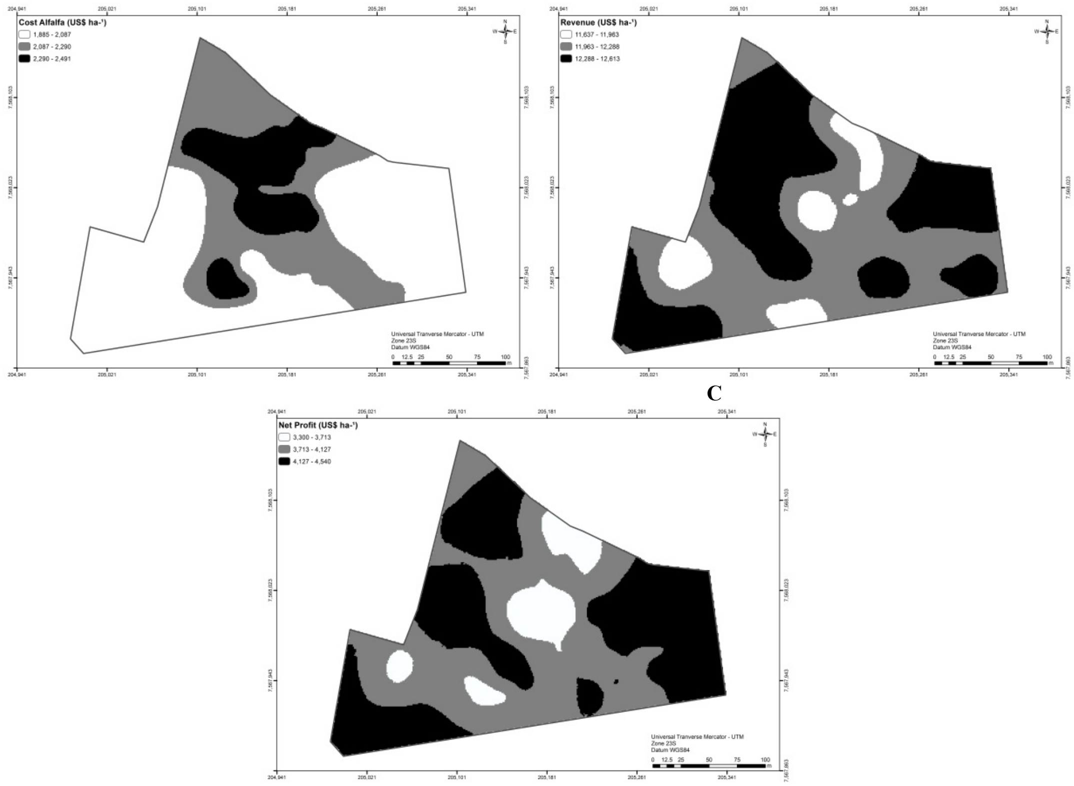

Figure 6. Kriged maps for production cost (A); gross revenue (B) and net profit (C) of an alfalfa pasture under grazing in Brazil.

Conclusions

Results showed that the geostatistics and GIS use were decisive tools to show soil and pasture spatial variability and support management strategies. Soil nutrient were used to classify the soil spatial distribution map in order to design site-specific lime and fertilizer application maps. Spatial variation of forage and estimative of stocking and milk yield are adequate pasture management tools. Spatial variation of issue needs, forage availability and economic return are management tools to avoid economic and potential environmental problems form unbalanced nutrient supplying and over- or under-grazing pressure.

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