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Multivariate analysis of chemical attributes of an oxisoil under Saccharum spp. and Pinus spp., Batatais, São Paulo

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Abstract. This study aims investigate the correlations of soil chemical attributes in watersheds in order to highlight the changes caused by soil management, differentiating them by multivariate statistical analysis. The watersheds of the first order of magnitude were selected three occupied with sugarcane, three with the *Pinus* reforestation and a witness with greater occupation of native forest. The composite samples of soil were collected at five points around each major source in depth 0-0,2 m, on two occasions (April and December). The first two factors aggregated 58.09% of the total variance of the initial data (F1 = 44.80%; F2 = 13.29%). The first factor shows a direct correlation between the pH, Ca, Mg, SB and V variables, which are inversely correlation with H+Al and Al variables, showing the process of soil acidity correction (lime) in the occupied watersheds with sugarcane crop. The second factor show a direct correlation between the T, OM and Cu variables, indicating high soil acidity in reforestation of *Pinus*. The multivariate analyses show the change of the agroecosystem of watersheds studied as a function of soil management.
Keywords: land use, agricultural management, liming, wealth, reforestation

Introduction

For some decades has been discussed about environmental degradation, management strategies to propose future scenarios of environment, restoration of landscape and soil losses. Study of environmental amendments regarding to land use land cover (LULC) strategies on watersheds is performed to propose efficient mechanisms for sustainable use. The management that drive the activities to be implemented in the short, medium and long term, in order to predict the impact of agriculture, aimed at ensuring the quality and quantity of surface and underground water resources (Zanata, 2013).

Multivariate exploratory analysis is a technique which aims at analysis of multiple interrelated variables, designing the relevant original information in two-dimensional planes. The probability and magnitude human activities effects will increase as human beings continue to modify the landscape. Thus, the multidisciplinary understanding of these effects on natural communities and empirical studies to provide evidence of these changes are needed (Mota et al., 2014; Blitzer et al., 2012).

The environmental monitoring in watersheds, aims to characterize important aspects that allow diagnosing the changes occurring in the LULC, making it possible to assess the effects of human activities on ecosystems (Aquino et al., 2014; Carneiro et al., 2009; Queiroz et al., 2010; Teng et al., 2014; Souza Neto et al., 2014; Pragana et al., 2012). The land use promotes marked influence on runoff and sediment supply in spring and may change the quality and availability of water (Vanzela et al., 2010).

The various soil chemical attributes behave quite differently over the cultivated areas, due, among other factors, changes caused by agricultural management (Silva et al., 2010). The effect of management and land use systems must be understood to know the variation of soil quality in order to implement management techniques with conservation practices (Rahmanipour et al., 2014; Guimarães et al., 2013, Mujuru et al., 2013).

In this context, we investigate the correlations among chemical attributes and LULC, seeking to highlight the changes caused in the agro-ecosystem at the function of soil management, to separate the processes involved using multivariate statistics.

Methods

Study area

Municipality of Batatais, São Paulo State, Brazil is located between two hydrologic regions, producing water to the basins of Pardo and Sapucaí-Mirim rivers. The study area is formed by the watershed of Prata stream, located at latitudes 20°53’35” - 20°57’54” S, longitudes 47°31’45” - 47°33’21 W, and altitude of 880 m (Zanata, 2009).

Climate is Cwa in the Köppen system (Ventura et al. 1965/1966), the average temperature in the warmest months (January and February) is about 22°C, the area has cold and dry winter with temperatures below 18°C (June and July) and average annual rainfall between 1100 and 1700 mm per year, and July is the driest month and December / January with highest rainfall (Zanata, 2013).

São Bento group with sedimentary rocks of Piramboia and Botucatu formations, which form Guarani Aquifer, the basaltic igneous rocks of Serra Geral formation and sandstone deposit of Itaqueri formation are the layers composing its geological landscape (Zanata, 2013). The subdivision adopted in the Geomorphological Map of the São Paulo State shows that the region belongs to the geomorphological Province of Cuestas Basálticas (Zanata and Pissarra, 2012). The Brazilian System of Soil Classification (Embrapa, 2006) indicates that the area has medium texture soil, as distroferric red latosol and a dystrophic Red-Yellow Latosol and Gleysols in the alluvial floodplain. The native vegetation is composed by Semideciduous forest and Cerrado (IBGE, 2012).

Among water-producing watersheds, highlights the Prata and Estiva streams as water supply source for the urban area of the municipality of Batatais. This area of strategic importance totaling 59.98 km², with 52.9 km of water courses supplied by 18 major springs (Zanata and Pissarra, 2012). The territorial units of first-order magnitude watersheds were selected according to the strategic importance to the source and distribution in the study area.

Figure 1 shows the topographic divisors of each watershed or territorial unit (Zanata et al., 2015), we highlight land use into two groups: a) predominantly occupied by watersheds with *Saccharum* spp. (sugarcane crop) (1, 2 and 3) and b) *Pinus* spp. reforestation (4, 5 and 7). Watershed 6 was considered as a reference due to higher soil cover with native forest.

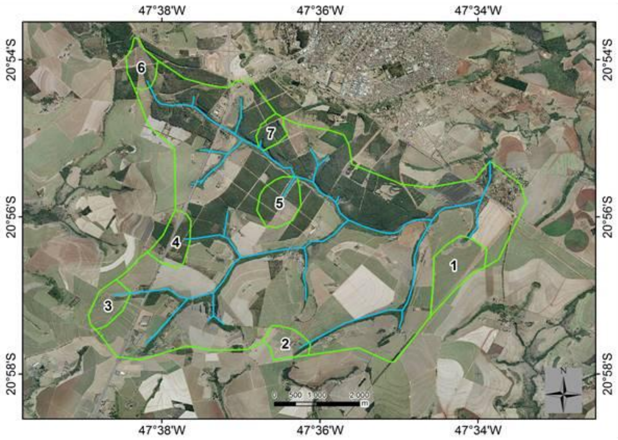

Figure 1. Watersheds 1st order of magnitude (1-7) in Silver River watershed, Batatais, SP, Brazil (www.googleearth.com.br).

Soil analysis

Soil analysis was carried out as per the procedures described by Kiehl (1979), collected at depth 0-0,2 m in five points around each spring, which were separated 10 subsamples to compose each composite sample (repetition) in two samplings, in April (1st collection) and December (2nd collection). The soil chemical variables were pH in CaCl2, organic matter (OM), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and potential acidity (H+Al) from the basic analysis and boron (B), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) by micronutrient analysis. The methods used followed recommendations of the Soil Analysis Methods Manual (Embrapa, 1997). The chemical determinations were made according to methods adopted by Raij et al. (2001). The pH was measured potentiometrically into calcium chloride 0.01 mol L-1, which used the ratio 1: 2.5. Sampling and analysis followed the rules and scientific standards accepted internationally.

Data analysis

Multivariate statistics is used to separate processes (Mota et al., 2014; Souza et al. 2012; Zanata, 2013; Zanata et al., 2015). Hermosin et al. (2013) report that principal components analysis (PCA), is very useful in environmental studies to identify patterns and pollution diffuse sources, where ecological processes that add main variability can be identified in factors analysis. Factors are extracted using the principal components method, and it is a linear combination of the original variables that aggregates the largest possible variation contained in the samples. The second factor is the second linear function of the original variables, containing the remaining variability, and so on.

The factors are independent of each other, dimensionless and standardized variables (normal distribution, mean=0, variance=1). The coefficients of the linear functions define the factors that serve and interpret their meaning, using the sign and the relative value of the coefficients as an indication of the weight of each variable. The effect of physicochemical variables of watershed water, sampling monthly, and their interaction were tested using analysis of variance (ANOVA), the factors were tested by the general linear model (GLM) and the Fisher test at 5% significance ($p<0.005$). The Eigenvalues (F1 and F2) resulting from the factor analysis, and Fischer test results ($\alpha=5\%$) the better of the Prata watershed, for water surface variables. Statistical analyses were developed in the Statistica software by Statsoft® company (2007).

Results and Discussion

The model applied of the analysis of variance (ANOVA) considering watersheds, collection month (April to December) and interaction (watershed x month) is shown in Table 1. The process contained in F1 factor indicates significant effect on the collection month ($p=0.0007$), but has no significant effect for watershed ($p=0.68$) and interaction ($p=0.73$). Thus, there is no difference between watersheds for F1 factor, but there is distinction between collecting months. The process contained in F2 factor indicates significant effect on watershed and interaction ($p=0.0007$), but has no significant effect on collection month ($p=0.17$). Therefore, there is a difference between the watersheds for the F2 factor and may be a function of collection month.

The Fisher's test ($\alpha=5\%$) for F1 (Figure 2), separates watersheds with sugarcane plantations (1, 2 and 3) those with reforested pine and forest (4-7), showing no difference between the watersheds from each use/occupation (sugarcane, pine). On the other hand, Fisher's test ($\alpha=5\%$) for watersheds from F2 (Figure 2) it does not separate the land uses, but highlights a watershed in each use / occupation of sugarcane (1) and pine (4), separating the forest (6) of other uses.

The first two factors accounted for 58.09% of the variability contained in the original variables (Table 1). The greatest variation possible in the sample is aggregated by the first factor (44.80%), with higher weight for direct correlation between V (0.99), pH (0.97), SB (0.97), Ca (0.96) and Mg (0.91) variables, which are inversely correlated with the H+Al (-0.88) and Al (-0.90) variables. The second greatest variation is aggregated by the second factor (13.29%), with higher weight for direct correlation between T (0.76), Cu (0.74) and OM (0.73) variables.

Thus, the Fischer's test for F1 factor (Figure 3) show at the higher levels from Ca (0.96), SB (0.97), V (0.99) and pH (0.97) or at low soil acidity (Figure 4), how soil management is correlated with sugarcane culture in the watersheds 1, 2 and 3. In turn, the Mg (0.91) contributes to same process in F1, but with lower influence (0.91) in watershed 2.

The inverse correlation (Figure 4) to another group H+Al (potential acidity) and Al (exchangeable acidity) of variable to F1 factor, indicate that the process related to high acidity of soil separates watersheds with pine reforestation (4, 5 and 7) and forest (6), of sugarcane culture (1, 2 and 3). We believe that this result demonstrates the process of liming with calcitic (Ca) and dolomitic (Mg) limestone in watersheds with sugarcane crops (1, 2 and 3), separating them from the other studied uses. According to Teng et al. (2014) on soil occupied by sugarcane, the agricultural management of liming with calcitic and dolomitic limestone, increases Ca, Mg and pH levels, and decreases Al. According to Carneiro et al. (2009), soil chemical attributes and their relationships are indicators of soil conservation. The watersheds with reforestation of pine and forest, are not subjected to liming there are more than 50 years, hence the inverse correlation in F1.

Results of Fisher's test (α=5%) for collection month of variables that make up F1 (Figure 5) shows that the collections average were lower in second soil collection (December), corroborated by Silva Neto et al. (2011), which concluded that organic matter, pH and CTC in the soil tend to decrease over the analyzed periods.

Zanata et al. (2015) studying the same watersheds in the same period, but with water quality samples, concluded that on watershed 3 (sugarcane) solutes would have been carted to the water resources, causing increase in electrical conductivity and consequent increase in water pH. Our work with monitoring of soil attributes attest the results obtained in the same period with water quality variables, showing the effect of the management of soil on water resources.

Table 1. Analyses of variance (ANOVA) with significance levels and eigenvalues of the factors F1 and F2, for soil chemicals variables on silver river watershed, Batatais, São Paulo, Brazil. Total of observations = 70.

Analysis of variance [a]	F1	F2
Watersheds	ns	***
Collection	***	ns
Interaction	ns	***
Variables	F1	F2
pH	0.97	0.00
OM	0.50	0.73
P	0.62	-0.22
K	0.31	-0.17
Ca	0.96	0.16
Mg	0.91	0.18
H+Al	-0.88	0.36
SB	0.97	0.16
T	-0.24	0.76
V	0.99	0.03
B	-0.08	-0.03
Cu	0.35	0.74
Fe	-0.42	0.55
Mn	-0.25	-0.02
Zn	0.35	0.14
S-SO4	-0.36	-0.14
Al	-0.90	0.02
Eigenvalues	7.62	2.26
%	44.80	13.29

[a] Significance levels: *P<0.05, **P<0.01, ***P<0.001 e ns= not significant.

The clustering of variables by Ward’s method (Figures 6 and 7), separates the processes and the weight of each variable in each process. The variables connected in a close of zero Euclidean distance start processes, and these processes other variables connect in accordance with the soil management. The line a-a' (Figure 6) indicates the Euclidean distance separating the groups of variables (pH, V, Ca, SB, Mg, OM, Cu) connected processes in the sugarcane culture (1, 2 and 3) from group of variables (M + Al, Al, T, Fe and Mn) connected to processes that occur in reforestation of *Pinus* (4, 5 and 7) and forest (6).

The line b-b' (Figure 6) indicates the Euclidean distance separating the groups of variables that compose the F1 Factor (pH, V, Ca, SB, Mg, H + Al and Al) and F2 factor (OM, Cu and T). The line a-a' (Figure 7) indicates the Euclidean distance separating the watersheds with soil management with sugarcane plantations (1, 2 and 3) with reforestation of pine and forest management (4, 5, 6 and 7). As Silva et al. (2013), separated the honey samples produced by each of the three different species of bee, it was possible to distinguish the processes due to the management of the sugarcane and reforestation.

Despite the factor F2 explain only 13.29% of the variability of the original data, this significantly makes up for the result of ANOVA (Table 1). The process explains by factor F2 (Table 1) shows a direct correlation between variables OM (0.73) T (0.76) and Cu (0.74). The Fischer's test (α=5%) for watershed and collection for the factor F2 (Figure 8) shows that OM and Cu have the same behavior between watersheds. Silva et al. (2010) studying spatial variability of chemical attributes of an Oxisol with coffee plantation, consider that H+Al, T and OM were related to organic of soil portion. Benites et al. (2010) showed that non-intervention in the soil (through preparation or correction / fertilization) or fallow is important management component for the conservation of soil organic matter. According to Hugen et al. (2013) Cu is one of the less mobile heavy metals in soil, due to its strong adsorption to organic and inorganic soil colloids. Cu is retained by humic and fulvic acids to form stable complexes.

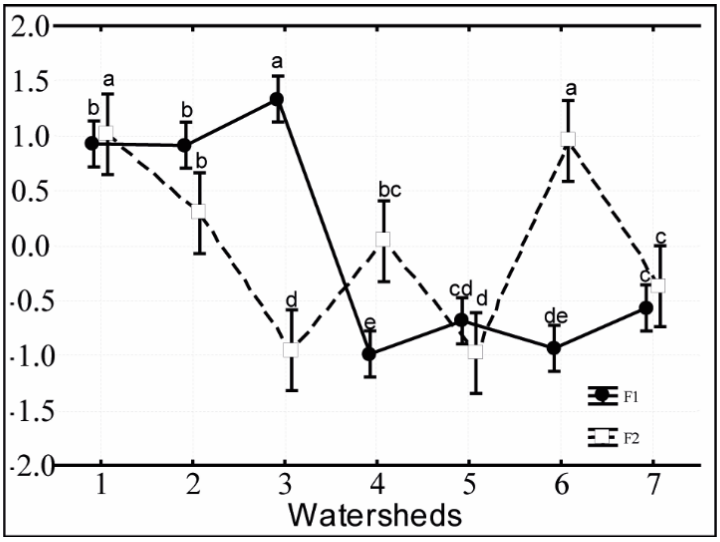

Figure 2. Averages Fisher's test (α=5%) with the scores of F1 and F2 factors for watersheds.

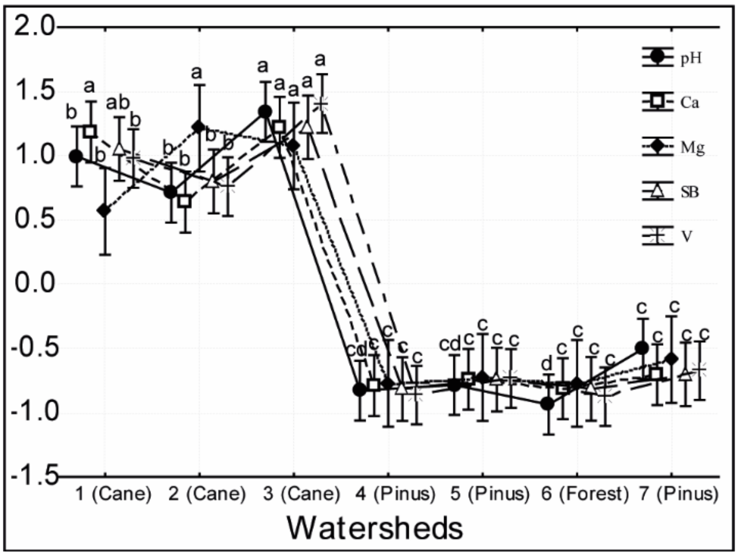

Figure 3. Fisher's test (α=5%) for variables with direct correlation in F1 factor (watersheds).

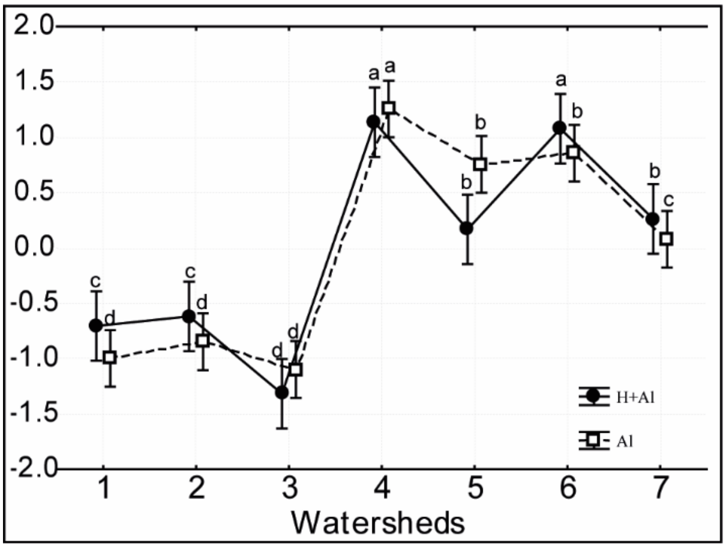

Figure 4. Fisher test (α=5%) for variables with inverse correlation in the F1 factor (watershed).

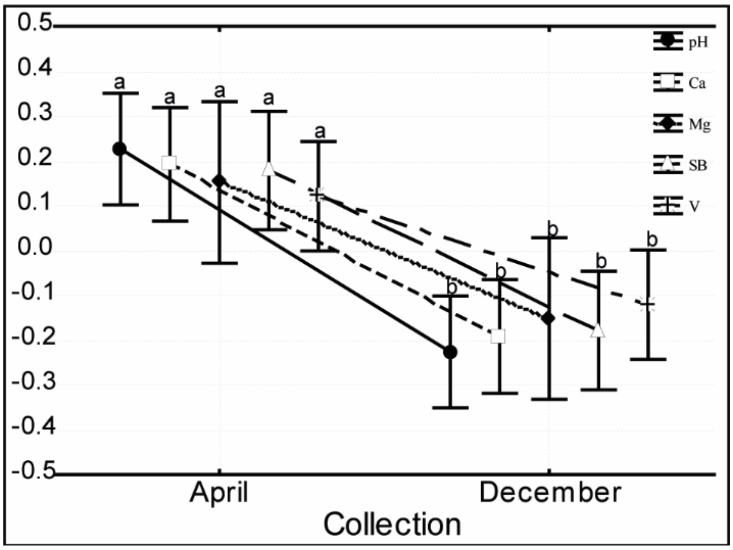

Figure 5. Fisher test (α = 5%) of variables with direct correlation in the F1 factor (collections).

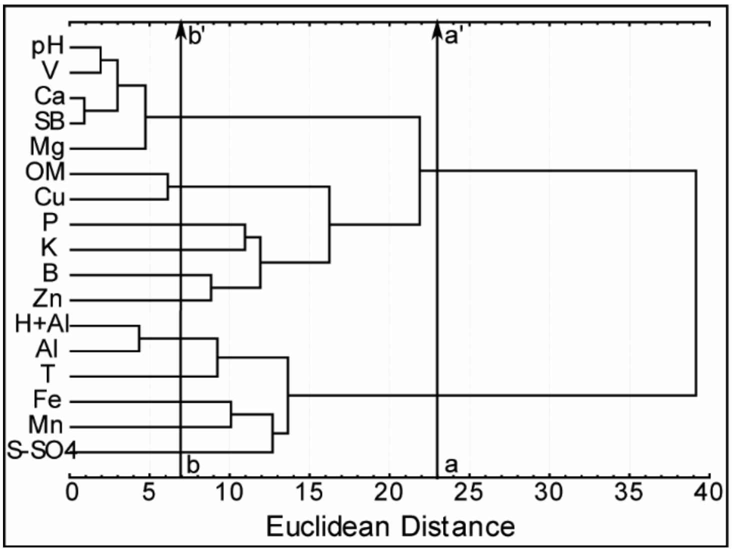

Figure 6. Dendrogram showing the hierarchy groups of variables.

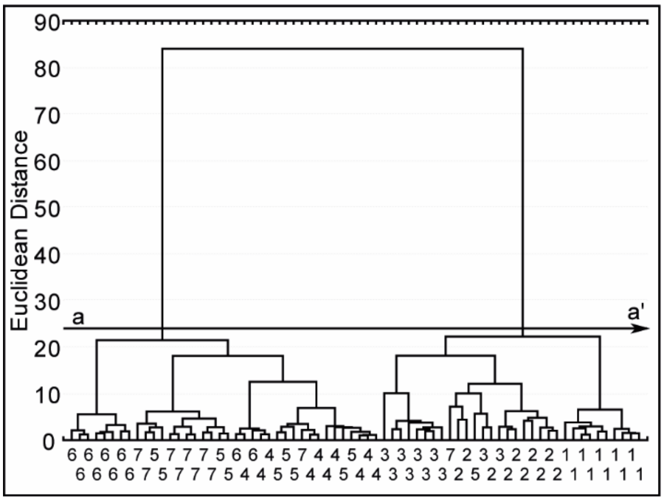

Figure 7. Dendrogram showing the hierarchy watershed groups.

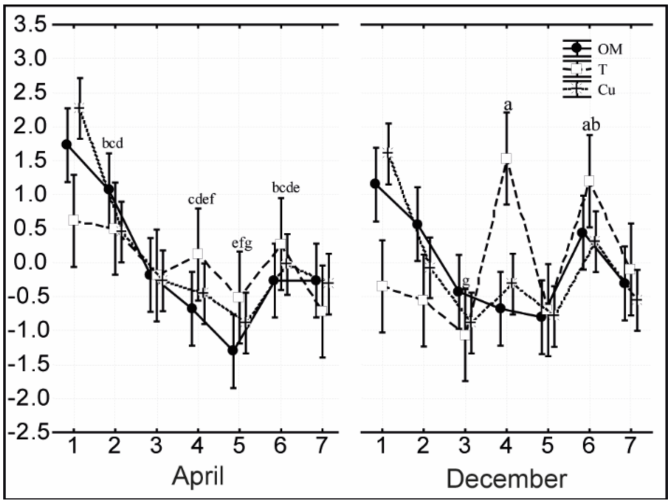

Figure 8. Fisher test (α=5%) for variables with positive correlation to the F2, highlighting the potential acidity (T) in the second collection (December) pine reforestation and forest.

The figure 8 show that T (potential soil CTC at pH=7.0) is more related to watersheds with pine reforestation (4) and larger portion of native forest (6) in the second collection (December). In our cluster analyses (Figures 6), T it is a variable of F2 factor connected with acidity soil process (H+Al and Al) which explain F1. The T variable is including in processes on watersheds with pine reforestation and native forest (control group).

Conclusion

Factor analysis indicated correlations between chemical soils variable and the type of land use land cover, separating the watersheds in two groups: those with sugarcane crops, pine reforestation and native forest. Liming in sugarcane crops and high soil acidity in pine reforestation are the processes involved in agroecosystems, depending on the type of management.

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