CHEMICAL AND MICROBIOLOGICAL PROPERTIES OF AN EUTROPHIC OXISOL UNDER RIPARIAN FOREST BUFFER REFORESTATION AND PASTURE[1]

PROPRIEDADES QUÍMICAS E MICROBIOLÓGICAS DE UM LATOSSOLO VERMELHO EUTRÓFICO SOB REFLORESTAMENTO DE MATA CILIAR E PASTAGEM

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ABSTRACT − Regardless of their ecological importance, riparian forest strips are frequently suppressed to allow greater expansion of arable and urban areas. Agroforestry might be an effective alternative to recompose riparian forests. Soil chemical and microbial properties are important environmental indicators to evaluate the reclamation process. This study tested the hypothesis that, in the course of time, reforestation by means of agroforestry improved soil microbial and chemical properties in a riparian forest buffer. Soil samples were collected from three layers (0.0-2.5; 2.5-7.5; 7.5-20 cm) in two sectors of a reforested riparian buffer strip in Cananéia Farm, São Paulo state, Brazil, one 18 years old and other 28 years old, and in an adjacent pasture area. The samples were assessed for pH_{H2O}, available P and K, exchangeable, Ca, Mg and Al, H+Al, sum of bases (SB), pH 7.0 CEC, percent base saturation (V), soil organic matter (SOM) and light organic matter (LOM). Microbial biomass carbon (MBC) and nitrogen (MBN) were analyzed only in the first layer. The pattern for Ca, Mg, SB and V (all layers) was 28-year-old sector = 18-year-old-sector > pasture. The SOM at 0.0-2.5 cm was higher in the 28-year-old sector. The LOM pattern was 28-year-old sector > 18-year-old sector > pasture. MBC did not differ among areas. MBN was significantly higher comparing the 28-year-old sector and the pasture area. The results probably reflected the higher litterfall and the N-richer organic matter in the reforested sectors. Reforestation by means of agroforestry improved soil quality, contributing to the ecosystem sustainability.

Keywords: land reclamation; soil quality; environmental indicators; agroforestry; semideciduous forest; soil organic matter.

RESUMO − Independentemente de sua importância ecológica, matas ciliares são frequentemente suprimidas e ocupadas por lavouras e cidades. Agroflorestas podem ser eficazes para a recomposição dessas áreas. Propriedades químicas e microbiológicas do solo são importantes indicadores ambientais para avaliar o processo de recomposição. Este estudo testou a hipótese: com o tempo, a recomposição de mata ciliar por meio de agrofloresta melhorou propriedades microbiológicas e químicas do solo. Amostras foram coletadas nas camadas 0,0-2,5; 2,5-7,5; 7,5-20 cm, em dois setores da mata ciliar revegetada na Fazenda Cananéia, SP, um com 18 anos e outro com 28 anos, e em área de pastagem adjacente. As amostras foram avaliadas quanto ao pH_{H2O}, P e K disponíveis, Ca, Mg e Al trocáveis, H+Al, soma de bases, CTC a pH 7,0, saturação por bases (V), matéria orgânica do solo (SOM) e matéria orgânica leve (LOM). O carbono (MBC) e o nitrogênio (MBN) da biomassa microbiana foram analisados somente na primeira camada. O padrão para Ca, Mg, SB e V (todas as profundidades) foi: 28 anos = 18 anos > pastagem. A SOM na camada 0,0-2,5 cm foi maior no setor com 28 anos. O padrão para LOM foi 28 anos > 18 anos > pastagem. O MBC não diferiu entre as áreas. O MBN foi maior no setor com 28 anos em comparação à pastagem. Os resultados refletiram a maior produção de serapilheira e a matéria orgânica mais rica em N nos setores reflorestados. A revegetação melhorou a qualidade do solo, contribuindo para a sustentabilidade do ecossistema.

Palavras-chave: recuperação de áreas degradadas; qualidade do solo; indicadores ambientais; sistemas agroflorestais; floresta estacional semidecidual; matéria orgânica do solo.

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1 INTRODUCTION

Riparian forest buffers are implemented to mitigate the impact of land use on streams, springs and lakes. A well-established riparian forest buffer can, besides protecting water quality, provide food and shelter for upland wildlife, link the land and aquatic environment, and give landscape a more pleasant aspect (Gênova et al., 2007; Pires et al., 2009; Faria and Silveira, 2011; Lóis et al., 2011). Recently, studies have also been addressing the importance of riparian forest buffers for carbon sequestration (Melo and Durigan, 2006; Velasco and Higuchi, 2009). However, regardless of their ecological importance, riparian forest buffers are usually suppressed to allow greater expansion of arable and urban areas, in neglect to their protection by Federal Law (Brasil, 2012).

Agroforestry systems might be an effective alternative to the common reforestation practices used to recompose riparian forest buffers, which do not provide financial income to farmers. These tree-crop consortia have proved to be financially feasible and might even have some advantages over single crops, such as lower vulnerability to price drops (Souza et al., 2007; Coelho Júnior et al., 2008; Rodrigues et al., 2008; Pye-Smith, 2010). Since, in general, riparian forest buffers cannot be exploited directly (Brasil, 2012), after some years the crops would be removed, allowing the native forest to regenerate. Nevertheless, some financial income would have been made from the consortium before that.

Regardless of the strategy adopted, the main purpose of the riparian forest buffer reclamation is to ensure environmental welfare and habitat for wildlife. The reclamation process must lead the ecosystem to a stage of self-sustainability. This is a complex task and many indicators have been proposed to evaluate it, comprising mainly vegetation and soil properties (Ignácio et al., 2007; Melo et al., 2007, 2009; Gil et al., 2009; Vezzani and Mielniczuk, 2009; Seely et al., 2010; Gomide et al., 2011; Cotler et al., 2013; Liu et al., 2013).

Pulitano et al. (2004) evaluated vegetation indicators in the riparian forest buffer in Cananéia Farm and showed positive results, such as increasing plant diversity and canopy cover. However, in land reclamation processes, the soil fertility is also an important indicator, since the nutrient content in the soil allows inferring about the soil-vegetation relationship and possible limiting factors for the vegetation establishment.

In this regard, soil microbial properties are valuable information, since they are very sensible to soil disturbances and might act as nutrient source, influencing soil quality and nutrient cycling (Tótola and Chaer, 2002; Gama-Rodrigues and Gama-Rodrigues, 2008; Siqueira et al., 2008; Vezzani and Mielniczuk, 2009). Thereupon, this study tested the hypothesis that, in the course of time, reforestation by means of agroforestry improved soil microbial and chemical properties at a riparian forest buffer in Cananéia Farm.

2 MATERIALS AND METHODS

The studied area is located at Cananéia Farm, Cândido Mota city, São Paulo state, Brazil, within the coordinates 22º46' – 22º28'S and 50º27' – 50º29'W. The average altitude is 430 m. The local climate is of Cwa type, according to Köppen classification, i.e., mesothermal with dry Winter and rainy Summer, coldest-month temperature between -3 and 18 ºC and hottest-month temperature higher than 22 ºC. The average annual precipitation is 1,550 mm. A seasonal semideciduous forest on a eutrophic Oxisol composes the remaining vegetation.

Reforestation at Cananéia Farm began in 1972 around the banks and streams of Água Nova brook, a small Paranapanema River tributary. Before planting, the entire area had undergone a careful terracing operation to minimize erosion. The soil was plowed and harrowed in isoline curves. Native (from all over Brazil) and exotic species were continually planted through the years until 2000, using seedlings produced at Cananéia Farm or local nurseries. The species distribution in the area was random. Ant control was also done continually through the years.

Between-line spacing was 4 m to allow intercropping with rice, maize, soy and cassava until shading reached a prohibitive level, from when trees were planted in substitution for the crops. Besides helping funding the riparian forest buffer recomposition, intercropping allowed the area to remain free from weeds, facilitating the second stage of revegetation (planting in between-lines).

The reclaimed riparian forest buffer was divided in two sectors: one 18 years old and other 28 years old. The sectors occupied approximately 30,000 and 4,400 m², respectively, and were 500 m distant from each other. The younger sector had 37.0 m² ha^{-1} of basal area and 84% of canopy cover, whereas the older one had 51.3 m² ha^{-1} of basal area and 93% of canopy cover (Pulitano et al., 2004). Details on the phytosociology and other characteristics of the reclaimed riparian forest buffer can be found in Pulitano et al. (2004).

The assessments were made in the two sectors aforementioned and in a pasture area adjacent to the forest buffer. Before the studied area had been reforested, it was occupied by pasture. Therefore, the pasture area soil properties might be an indicative of the conditions previously found in the studied area.

In each sector, five composite soil samples (composed of three subsamples each) were randomly collected, comprising three layers (0.0-2.5, 2.5-7.5 and 7.5-20.0 cm). In the pasture area, three composite soil samples were randomly collected at the same layers. The samples were collected in August, 2000.

The samples were assessed for pH_{H2O}, available P and K, exchangeable Ca, Mg and Al, potential acidity (H+Al), sum of bases (SB), pH 7.0 cation exchange capacity (CEC), percent base saturation (V), organic matter (SOM), light organic matter (LOM), microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN). The MBC and MBN were analyzed only in the 0-2.5 cm layer. The methodologies utilized are described in: Ingram and Anderson (1993) for LOM, Ferreira et al. (1999) for MBC, Joergensen and Brookes (1990) for MBN, and Embrapa (1997) for the other analyses. All analyses were performed at Laboratório de Análises de Solos of Universidade Federal de Viçosa.

The data normality and homoscedasticity were verified by Ryan-Joiner and Bartlett tests, respectively, at 1% significance level. To correct possible deviations from normality or heteroscedasticity, the Box-Cox transformation was applied. The data were then subjected to analysis of variance and the Tukey's test at the 5% significance level to compare the different layers within each sector and the same layer among sectors. All statistical analyses were processed using Sisvar and Minitab 16 software.

3 RESULTS AND DISCUSSION

Considering the same layer, there was no significant difference among areas regarding pH_{H2O}, available P and K and H+Al (Table 1). On the other hand, Ca, Mg, SB and V values differed among areas, showing similar pattern (28-year-old sector = 18-year-old sector > pasture) (Table 1). The CEC pattern was 28 years > 18 years > pasture, except at the 7.5-20.0 cm layer, where the 18-year-old sector value did not differ from the values of the other sectors, but the 28-year-old sector value was greater than the pasture value. Exchangeable Al was equal to 0.0 $cmol_c$ dm^{-3} for all areas and layers due to the high pH_{H2O} observed.

Soil pH and potential acidity (H+Al) affect plant growth and soil physical, chemical and microbiological properties (Sousa et al., 2007), being assessed often as indicators of soil quality (Gomide et al., 2011; Cotler et al., 2013; Liu et al., 2013). The lack of significant difference in soil pH_{H2O} and H+Al among layers and sectors is probably due to the characteristically low acidity of the studied area soil and the management applied to the pasture.

Table 1. Soil chemical properties of two riparian forest buffer sectors and pasture in Cananéia Farm, Cândido Mota, São Paulo, Brazil.

Tabela 1. Propriedades químicas do solo em dois setores de mata ciliar e pastagem na Fazenda Cananéia, Cândido Mota, São Paulo, Brasil.

Area	Layer	pH_{H2O}	P	K	Ca	Mg	H+Al	SB	CEC	V	SOM	LOM
	cm		-------- mg dm^{-3} --------		---------------------------- $cmol_c$ dm^{-3} ----------------------------					%	------ dag kg^{-1} ------	
18 years old	0.0-2.5	5.84 Aa	1.66 Aa	133.20 Aa	9.47 Aa	3.75 Aa	4.16 Aa	13.57 Aa	17.72 Ba	76.54 Aa	5.50 Ba	0.09 Ba
	2.5-7.5	5.78 Aa	0.70 Aab	86.76 Aab	7.79 Aa	2.76 Ab	4.49 Aa	10.77 Aab	15.26 Bab	70.04 Ab	3.66 Aa	0.03 Bb
	7.5-20.0	5.88 Aa	0.46 Ab	71.38 Ab	7.20 Aa	2.88 Aab	4.16 Aa	10.26 Ab	14.42 ABb	70.84 Aab	2.86 Ab	0.03 Bb
28 years old	0.0-2.5	6.40 Aa	5.02 Aa	164.08 Aa	12.46 Aa	3.83 Aa	3.83 Aa	16.70 Aa	20.53 Aa	80.68 Aa	8.00 Aa	0.15 Aa
	2.5-7.5	6.20 Aa	2.87 Aab	121.40 Aab	10.45 Aa	3.25 Aab	4.38 Aa	14.01 Aab	18.39 Aab	71.5 Aab	6.10 Ab	0.06 Ab
	7.5-20.0	5.90 Aa	0.90 Ab	70.58 Ab	7.79 Aa	2.62 Ab	5.21 Aa	10.59 Ab	15.80 Ab	65.64 Ab	4.12 Ab	0.05 Ab
Pasture	0.0-2.5	5.97 Aa	5.90 Aa	222.93 Aa	5.03 Ba	2.02 Ba	4.18 Aa	7.62 Ba	11.80 Ca	64.57 Ba	5.41 Ba	0.05 Ca
	2.5-7.5	5.90 Aa	3.97 Aab	129.60 Aab	4.79 Ba	1.77 Bab	4.73 Aa	6.89 Bab	11.62 Cab	59.23 Bb	4.91 Aa	0.02 Cb
	7.5-20.0	5.87Aa	2.1 Ab	99.37 Ab	4.94 Ba	1.40 Bb	4.29 Aa	6.6 Bb	6.60 Bb	60.6 Bab	4.80 Aa	0.01 Cb

H+Al = potential acidity; SB = sum of bases; CEC = cation exchange capacity at pH 7.0; V = base saturation; SOM = soil organic matter; LOM = light organic matter. Exchangeable Al was equal to 0.0 $cmol_c$ dm^{-3} for all areas and depths. Means followed by the same capital (same layer among areas) and small (layers within each area) letters are not different according to the Tukey's test at the 5% significance level.

H+Al = acidez potencial; SB = soma de bases; CEC = capacidade de troca catiônica a pH 7,0; V = saturação por bases; SOM = matéria orgânica do solo; LOM = matéria orgânica leve. O teor de Al trocável foi igual a 0,0 $cmol_c$ dm^{-3} em todas as áreas e profundidades. Médias seguidas pelas mesmas letras maiúsculas (entre áreas na mesma camada) e minúsculas (entre profundidades na mesma área) não diferem entre si pelo teste de Tukey a 5% de significância.

Available P and K are indicators of soil fertility (Cantarutti et al., 2007). However, they might not be efficient to monitor soil reclamation due to their high spatial variability, requiring a large number of samples to be accurately assessed (Barreto et al., 1974; Souza et al., 1998). Also, these variables might have been influenced by eventual fertilizer applications to the pasture. The values observed (Table 1) can be considered low for P and high for K (Cantarutti et al., 2007), which is normal for eutrophic Oxisols.

Lower values of Ca, Mg, SB and V were observed in the pasture area, whereas there was no difference between the 28-year-old and the 18-year-old sectors (Table 1). Besides foraging, which contributes to base exporting, pasture residues usually return less Ca and Mg to the soil than forest residues (Markewitz et al., 2004). This reflects directly in SB and V values, since these variables are strictly related to Ca and Mg contents in the soil (Sousa et al., 2007).

In Oxisols, the cation exchange capacity is highly correlated to the soil organic matter (Bayer and Mielniczuk, 2008). However, the CEC rank did not follow the SOM rank in this study (Table 1). This might be due to the influence of bases, mainly Ca and Mg, and also the quality of soil organic matter in CEC. In general, CEC was high in all layers and areas, reflecting the eutrophic soil's character.

Soil organic matter in the 0.0-2.5 cm layer was significantly higher in the 28-year-old sector, whereas the 18-year-old sector and the pasture area showed statistically similar values (Table 1). Considering the other layers, no significant difference was found for SOM among the areas. The LOM pattern, however, was 28-year-old sector > 18-year-old sector > pasture for all layers (Table 1).

The higher SOM and LOM values in the 28-year-old sector probably resulted from the higher organic matter accumulation in soil through the years, especially due to litterfall. Between March, 1999 and February, 2000, litterfall in the 18-year-old sector was 10.2 Mg ha^{-1}, whereas in the 28 year-old sector, literfall reached 11.8 Mg ha^{-1} (Pulitano, 2003). Pulrolnik et al. (2009) found higher LOM in eucalypt stands, in comparison to cerrado and pasture areas, reinforcing the contribution of litterfall to the soil LOM. This is one of the reasons why nutrient availability generally diminishes with increasing depth (Table 1).

In addition to the lower litterfall, the soil disturbance in intensively-managed systems contributes to the shortening of the organic matter turnover (Roscoe and Buurman, 2003; Siqueira et al., 2008; Guareschi et al., 2012). Therefore, the conversion of forests to pasture usually leads to a reduction in organic matter, with consequent loss of fertility (Cerri et al., 2008; Siqueira et al., 2008). In fact, the SOM is considered the main attribute of soil quality (Siqueira et al., 2008; Vezzani and Mielniczuk, 2009; Seely et al., 2010). On the other hand, the SOM is a complex attribute (Silva and Mendonça, 2007) and the analysis of its content alone might not be the best indicator for the riparian forest buffer reclamation process.

The light organic matter is the SOM fraction partially humified, composed mainly of plant residues in various stages of alteration (Silva and Mendonça, 2007). It is characterized by its high availability to soil microorganisms and sensibility to disturbances in the environment (Roscoe and Buurman, 2003; Silva and Mendonça, 2007). This is why the LOM content have been assessed more frequently in the monitoring of soil quality (Guareschi et al., 2012; Potes et al., 2012; Rangel-Vasconcelos et al., 2012).

In this study the higher sensibility of LOM as an indicator could be observed. Significant improvement in SOM could be detected only in the 0.0-2.5 cm layer of the 28-year-old sector; whereas LOM was significantly higher than pasture in the 18-year-old sector, which was lower than in the 28-year-old-sector. The results also indicated that SOM showed significant improvement more than 18 years after reforestation, reinforcing the importance to adopt conservationist cultivation systems to avoid SOM reduction.

No significant difference was found for microbial biomass carbon (MBC) among the areas (Table 2). Usually, MBC is strictly related to soil organic matter (Anderson and Domsch, 1989). In this study, however, MBC did not follow the pattern for SOM or LOM (Table 1). On the other hand, the microbial biomass nitrogen (MBN) differed significantly between the 28-year-old sector and the pasture area, with not significantly different value in the 18-year-old sector (Table 2).

Table 2. Soil microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) in the 0.0-2.5 cm layer of two riparian forest buffer sectors and pasture in Cananéia Farm, Cândido Mota, São Paulo, Brazil.

Tabela 2. Carbono (MBC) e nitrogênio (MBN) da biomassa microbiana do solo, na camada de 0,0-2,5 cm, em dois setores de mata ciliar e pastagem na Fazenda Cananéia, Cândido Mota, São Paulo, Brasil.

Area	MBC	MBN
	------ $\mu g\ g^{-1}$ ------	
18 years old	79.9 a	12.9 ab
28 years old	98.6 a	29.4 a
Pasture	68.4 a	1.0 b

Means followed by the same letters at the column are not different according to the Tukey's test at the 5% significance level.

Médias seguidas pelas mesmas letras na coluna não diferem entre si pelo teste de Tukey a 5% de significância.

The soil microbial biomass is defined as the living part of the soil organic matter, including bacteria, actinomycetes, fungi, algae and microfauna (Gama-Rodrigues and Gama-Rodrigues, 2008). The quantification of the soil microbial biomass is important to understand the dynamics of carbon and nitrogen. It has fast turnover, comparing to other organic matter compartments, being more responsive to soil disturbances than SOM (Sparling, 1992; Tótola and Chaer, 2002; Gama-Rodrigues and Gama-Rodrigues, 2008). Aragão et al. (2012), for instance, concluded that MBC and MBN were more sensible to treatment effects than SOM while testing different techniques of soil reclamation.

The results for MBC and MBN reflect the quality of the soil organic matter present in each area. The reforested sectors probably have more lignified residues, such as tree branches, and also residues with higher N content, due to the greater plant diversity (Pulitano et al., 2004). Usually, the higher the lignin content, the lower the decomposition rate of the residue (Berg, 2000; Silva and Mendonça, 2007). In addition, in spite of improving the initial decomposition rate of the residue, higher N content in the litter might retard decomposition at further stages (Berg, 2000).

Therefore, higher SOM or LOM might not imply, necessarily, in higher MBC, since microbial growth is also dependent on the quality of the residue (Sparling, 1992; Gama-Rodrigues and Gama-Rodrigues, 2008). The higher MBN might also indicate a greater N soil reserve for the plants in the reforested sectors (Gama-Rodrigues and Gama-Rodrigues, 2008), conducive to the riparian forest buffer sustainability.

The soil properties assessed in this study complemented the vegetation variables evaluated by Pulitano et al. (2004) in Cananéia Farm. The latter showed that the riparian forest buffer vegetation is established and regenerating naturally; the former exhibited the improvement of soil quality after reforestation. Although some analyses, such as LOM, MBC and MBN, may not be considered of easy replicability, they are valuable tools to assess the effectiveness of the reclamation process and to monitor possible disturbances. The assessment of these variables should be encouraged whenever possible.

4 CONCLUSIONS

Reforestation by means of agroforestry improved soil microbial and chemical properties at the riparian forest buffer in Cananéia Farm, contributing to the ecosystem sustainability.

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