Soil attributes along an agricultural-forested gradient in a riparian zone

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Abstract
This study was carried out from January 2008 to December 2008 and aimed to evaluate modifications caused by the recovery of riparian vegetation on soil attributes. Transactions were defined in two margins of a dam, in order to represent continuous types of occupation (sugarcane-recent forest-old forest). Topsoil (0-0.2 m) and subsoil (0.2-0.4 m) samples were collected for evaluation of soil quality through chemical [pH, cation exchange capacity (CEC), and organic matter (OM), P, Ca and Al contents], physical (total porosity and apparent density) and microbiologic (basal respiration rate) attributes. Physical attributes were not affected for the soil use type and for vegetation cover. Significant differences ($p<0.05$) were observed for CEC, OM content and microorganisms activity according to soil use. CEC and OM content increased from the sugarcane plantation to the old forest, suggesting that the input of vegetal biomass through the recovered forest contributed to the improvement of chemical soil quality. Microbiological activity also indicated that the period of replacement of sugarcane plantation for recent forest was not still enough to cause changes in biological soil attributes. There was increase of the soil quality with the decrease of the use intensity and with the recovery of the natural vegetation.

Key Words
Rehabilitation of degraded areas, soil fertility, soil attributes, riparian forest.

Introduction
The concern and interest to preserve natural ecosystems and restore degraded ecosystems have been growing both in science and in public opinion. Native forests, represented by different biomes, are important ecosystems that have been exploited in an unsustainable way. The removal of natural vegetation and the establishment of crops, combined with inadequate management practices, cause disturbances in the interaction soil-plant by changes in the chemical, physical and microbiological soil attributes, limiting the use for agriculture and resulting an environment more susceptible to degradation (Centurion *et al*. 2004). This condition is aggravated when the surrounding agroecosystems affect natural forests, especially in riparian zones, since these plant communities provide the proper flow and/or drainage of water in watersheds, protect the riparian zone, mitigate the effects of excess of nutrients and of xenobiotic molecules, retain sediment, and prevent siltation of water bodies (Lima 1989). In the State of São Paulo, Brazil, there are one million ha of riparian areas that need to be recovered and reforested. In the season 2008/2009, approximately 4.43 million ha in the State of São Paulo were cultivated with sugarcane, which represent an important agroecosystem surrounding forest areas. The objective of this study was to evaluate changes in the chemical, physical and microbiological soil attributes promoted by restoration of native riparian vegetation and compare them with an agroecosystem intensively disturbed and cultivated with sugarcane.

Methods
Study areas
The study was conducted in two tracts of riparian ecosystems of 2 ha each, composed of two populations of semideciduous mesophytic forest, and an agroecosystem cultivated with sugarcane (SC), which concentrically bordering the dam of Santa Lucia sugar mill, located in the State of São Paulo, Brazil (22º18'00"S and 47º23'03" W; 611 m). The area has been cultivated with sugarcane during 30 years with conventional tillage and residue burning at harvest. The forested areas differ in age [a 9-year-old recent forest (RF) and a 18-year-old old forest (OF)], and with regard the soil type [Typic Hapludox (TH) and Arenic Hapludult (AH)], constituting six treatments (Figure 1).

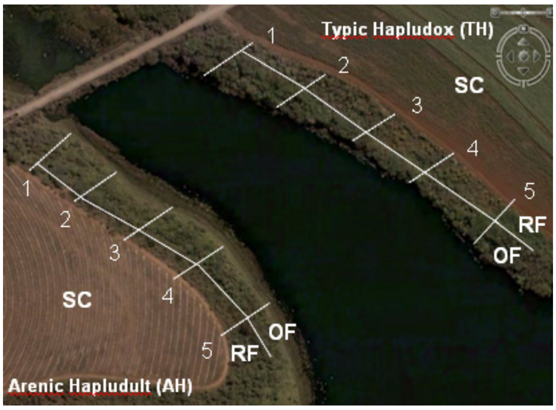

Figure 1. Representation of the transects in the experimental area (OF - old forest; RF - recent forest; SC – sugarcane) (Google Earth).

The climate is CWA (Köppen), i.e., mesothermal with hot and rainy summers and cold and dry winters. The average annual temperature is 21.4 º C and annual rainfall is 1448.8 mm (Brasil 1992).

Experimental characterization

For soil chemical and physical characterization, topsoil (0-0.2 m) and subsoil (0.2-0.4 m) samples were collected along five transects (Camargo *et al.* 1986; Raij *et al.* 2001) (Figure 1). To evaluate the evolution of soil quality by restoring riparian vegetation, the following attributes were considered: chemical - pH, cation exchange capacity (CEC), and organic matter (OM), phosphorus (P), calcium (Ca) and aluminum (Al) contents; physical – texture, bulk density (Da), total porosity (Pt), water retention capacity and field moisture measured *in situ* by time-domain reflectometer (TDR). Soil samples (0-0.1m) were collected along the transects 2, 3 and 4 for microbiological characterization, through basal respiration rate (Anderson and Domsh 1978). Results were submitted to analysis of variance and differences between means determined by Tukey test at 5% probability.

Results

Chemical attributes

Soil chemical characteristics are modified with the removal of natural vegetation and cultivation, especially in the topsoil. In general, a decrease of soil pH with the cultivation time is observed (Cerri 1986). However, in both soils (TH and AH), the pH of topsoil was higher in OF than in other environments. In the area planted with sugarcane, soil pH was higher in subsoil, which identified the likely acidifying effects action of fertilizers in topsoil and the deepening of the corrective effect of lime in the subsoil. With the establishment of natural vegetation, Ca levels increased in both depths of the TH. Higher Ca concentrations were observed in the cultivated area on AH, probably due to the recent liming. Low levels of Al were observed in TH, but in RF area of AH, Al contents were close to 10 $mmol_c/dm^3$, that is, a serious limiting factor for plant development. The concentration of P was higher in the area cultivated with sugarcane, especially in AH (Table 1).

Table 1. Selected chemical attributes of topsoil and subsoil samples of Typic Hapludox (TH) and Arenic Hapludult (AH) under different soil uses.

Depth(m)	Area	P	OM	pH	K	Ca	Mg	H+Al	Al	SB	CEC	V	S	B	Cu	Fe	Mn	Zn
		mg dm^{-3}	g dm^{-3}	$CaCl_2$	------------------------------- mmol$_c$ dm^{-3} -------------------------------							%	----------------------- mg dm^{-3} -----------------------					
Typic Hapludox (TH)																		
0-0.2	OF	6.0	33.8	5.2	3.2	35.0	13.2	35.0	0.7	51.4	86.4	59.4	8.4	0.4	5.2	28.4	53.6	1.9
0-0.2	RF	12.4	25.2	5.0	2.2	25.0	8.2	42.2	1.5	35.4	77.6	46.3	8.2	0.2	4.4	17.0	49.4	1.1
0-0.2	SC	16.4	24.2	4.8	3.8	19.6	6.8	40.6	1.9	30.2	70.8	42.6	38.4	0.2	4.1	13.8	48.6	0.9
0.2-0.4	OF	3.6	25.6	5.0	2.3	26.0	10.4	37.0	1.0	38.7	75.7	50.8	5.8	0.3	4.8	23.6	53.8	1.1
0.2-0.4	RF	6.0	20.8	4.9	0.9	20.8	5.0	41.4	1.6	26.7	68.1	39.5	11.8	0.1	3.6	13.6	38.2	0.6
0.2-0.4	SC	5.0	18.8	5.0	1.3	22.0	6.4	37.6	0.9	29.7	67.3	44.1	27.0	0.1	3.1	10.4	22.2	0.4
Arenic Hapludult (AH)																		
0-0.2	OF	4.3	24.9	4.7	3.8	19.3	9.4	33.9	2.3	32.5	66.4	48.5	9.7	0.7	2.1	63.8	42.3	1.7
0-0.2	RF	5.0	16.3	4.6	3.2	16.6	5.4	35.1	5.6	25.2	60.3	40.9	15.1	0.4	2.1	42.8	20.9	0.5
0-0.2	SC	40.4	20.9	4.6	5.6	23.6	8.6	41.7	3.9	37.8	79.5	47.2	31.1	0.6	2.4	61.2	18.5	0.9
0.2-0.4	OF	1.3	11.1	4.6	1.9	16.3	6.2	33.3	2.7	24.4	57.7	40.7	9.0	0.3	1.5	30.9	34.2	0.5
0.2-0.4	RF	2.5	11.2	4.4	2.0	15.2	5.1	44.4	9.6	22.3	66.7	34.7	18.7	0.5	1.6	30.5	27.1	0.4
0.2-0.4	SC	28.0	15.2	4.7	4.9	24.1	9.0	41.9	2.5	38.0	79.9	47.1	27.6	0.5	2.5	47.9	15.6	0.6

V - level of base saturation

In both soils, OF showed greater accumulation of OM, due to the higher input of biomass. Major changes in OM content were observed in the 0-0.2 m layers, especially in TH. When compared with the SC area, soil under OF showed increase of 10 g/dm^3 and 6 g/dm^3 at depths of 0-0.2 m and 0.2-0.4 m, respectively. Less evident variations were observed in the AH, but in cultivated area and at depth of 0.2-0.4 m was recorded greater accumulation of OM, resulting from the conventional management practices adopted during several years, including the application of vinasse, which reaches depths, especially in soils with low clay content (Maia and Ribeiro 2004). Because of their close dependence of soil organic matter, CEC showed variations similar to those observed for the OM. Samples collected from cultivated area on AH had a higher CTC, due to liming and vinasse addition. However, in the TH, CEC was significantly larger in the forest, with severe decrease in the cultivated system. Clearly, OM content and CEC were considered the chemical attributes that most reproduced the increase of soil quality with the restoration of natural vegetation on the TH.
In cultivated systems, was observed a decrease in the micronutrients contents, usually associated with the decrease of OM contents and with the continuous application of formulated fertilizers without these elements. Levels of micronutrients were higher in OF when compared to the levels of soils under RF and SC, but are still low.

Physical attributes
Generally, main physical changes due to intensive soil management are the reduction of Pt, especially the macroporosity, and the increase in Da (Araújo *et al*. 2004). Values for Da varied within the range expected for mineral soils (1.10-1.60 g/cm^3) and were below those reported as limiting or with potential to cause restrictions to root growth (1.70-1.80 g/cm^3). Results for Da and Pt showed differences between the TH and AH, attributed to the texture. No change of Pt and Da for different soil uses or vegetation cover was observed. Although no statistically significant differences in physical attributes was observed, the input and stabilization of organic material increased Pt and decreased Da of soils under forest, since in these environments there is no soil tillage such as agricultural systems.
Clay content of TH was 565 g/kg, which did not vary along the transects. In AH, clay content ranged from 245 g/kg, in SC, to 140 g/kg, in OF. Probably, the topsoil of AH was removed and transported from SC (higher elevation area) to OF (vicinity of the dam) by erosion due to it sandy topsoil.
Water retention at field capacity (θcc) was 12.9 g/g for AH and 27.4 g/g for TH. Soil moisture was measured in four seasons, with variation along the transects of 18.7% in AH and 24.1% in TH. Higher contents of OM and clay, and more exuberant vegetation on TH were considered factors related to increased water content.

Microbiological attributes
The microbial growth is greatly influenced by climatic variations, especially moisture and temperature, as well as the effects that these variations have on the vegetal cover (Cattelan and Vidor 1990). The annual average temperature was 21.8^o C and precipitation in the period of 1306.6 mm (Figure 2). The water balance characterized 2008 as an atypical year with water deficiency.

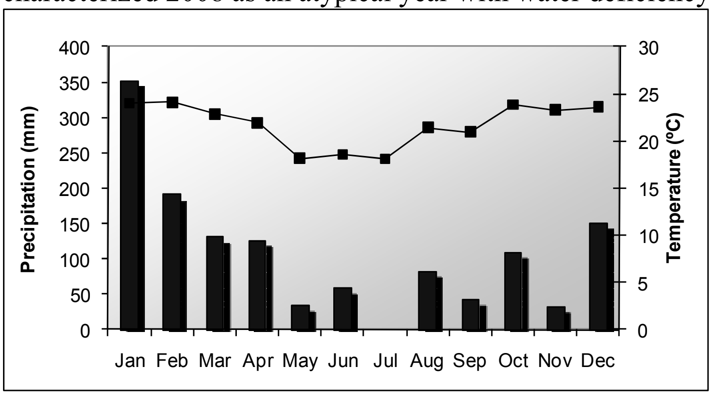

Figure 2. Precipitation and air temperature obtained for the period from jan/08 to Dec/2008.

Old forest on TH showed the highest levels of OM (33.8 g/dm^3 at 0-0.2 m). The OM is an important source of energy and nutrients for heterotrophic microorganisms (Alexander 1977) and increases the storage capacity of water in the soil (Hillel 1982), promoting microbial growth. Comparing the rate of CO_2 released by samples from the two soil types, microbial activity was lower in AH than in TH. Differences were attributed to the lower level of organic matter found in AH, even in OF area (24.9 g/dm^3).
Microbial community showed little fluctuation during the year, due to little climatic changes during the period (Figure 3).

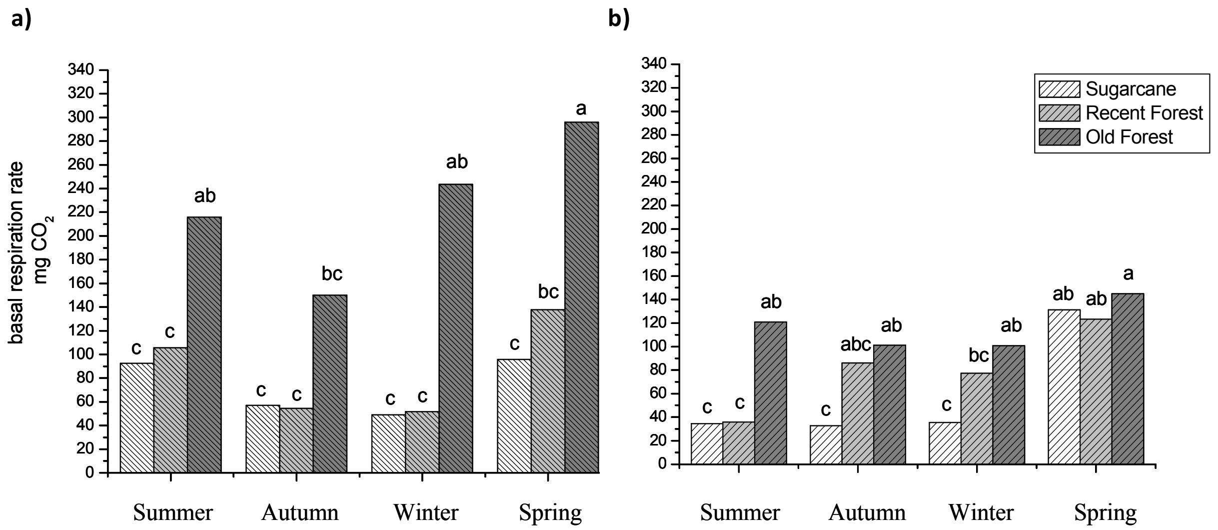

Figure 3. Soil bacteria (CFU/g dry soil) according to the different seasons, in (a) Typic Hapludox and (b) Arenic Hapludult; different letters indicate statistical differences according to Tukey test ($p<0.05$).

Old forest areas showed greater basal respiration rate, while in SC and RF systems, values were significantly lower. For both soils, the time to replace the culture of sugarcane by the most recent native vegetation was not sufficient to cause significant changes in biological properties of soil.

Conclusions

There was an increase of soil quality by reducing the intensity of use and the restoration of natural vegetation. The organic matter content, the cation exchange capacity, and microbial activity were the soil properties most sensitive to changes of soil management and reproduced more variations of soil quality with respect to soil use and vegetal cover.

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