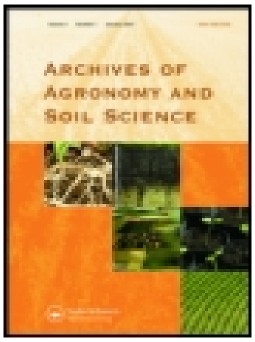

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REVIEW ARTICLE

Soil quality analysis in riparian areas for soil and water resource management

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ABSTRACT

Cultivating areas adjoining watercourses can cause serious changes in the soil attributes, promoting negative environmental processes. The aim of this study was to assess the changes in the properties of soil and use comparative diagrams to compare soil quality in response to land use in riparian areas in Brazil. Based on the obtained data, a soil quality index was calculated for each type of land use, and comparative diagrams were drawn and compared to assess soil quality. Agricultural land use alongside rivers (riparian areas) has caused negative changes to the main properties of soil. Comparing diagram areas, land under banana cultivation, degraded pastures and silvopastoral land had values that were 40%, 36% and 29%, respectively, of diagram areas for the native forest. While banana cultivation caused the greatest negative changes to the physical and mechanical properties, silvopastoral land and degraded pastures caused the greatest negative changes to the chemical properties. The polygons formed, which were used to compare the reference areas to the areas for the three different agricultural land uses, differed in shape and area compared to reference values, proving that these comparative diagrams are a useful tool in the assessment of soil quality in riparian areas.

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Comparative diagrams; environmental impact; land adjoining watercourses; soil degradation

Introduction

The agricultural use of land along river courses (riparian zones) is a common practice in many regions of Brazil. Normally, federal environmental laws protect areas adjacent to streams and rivers because any exposure of these soils can promote erosion and siltation in a short time. Elmore and Beschta (1987) consider riparian areas the most important part of a watershed for a wide range of values and resources. Healthy riparian zones may help control the transport of sediments and chemicals to stream channels (Lowrance et al. 1984; Tanaka et al. 2016).

Vegetation cover by native forests in riparian zones has the environmental function of preserving water resources by acting as a sediment trap upslope of rivers (Connolly et al. 2015; Rodrigues-Filho et al. 2015). Although riparian areas may occupy only a small area of a watershed, they represent an extremely important component of the overall landscape, because the resiliency that plants (native forest) provide allows riparian systems to withstand a variety of environmental conditions (Elmore and Beschta 1987; Fernandes et al. 2014). When protected areas

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are left untouched, i.e. native forests, the soil has adequate soil properties; however, from the moment the land starts to be used for farming and is exposed to inappropriate soil practices, the original soil properties are changed (Islam and Weil 2000). In an agricultural landscape, management of riparian zones changes soil properties, plant and soil biodiversity, nutrient cycling, and erosion potential (Neher et al. 2005; Lovell and Sullivan 2006; Young-Mathews et al. 2010).

Understanding and quantifying the impact of land use and soil management on the physical, mechanical and chemical qualities of the soil in agricultural areas, mainly in riparian areas, is fundamental to the development of sustainable agricultural systems and integrity of waterbodies (Clapcott et al. 2012; Iori et al. 2014). Consequently, there has been strong interest in the evaluation of soil quality under different types of land use in order to define appropriate soil management systems (Raiesi 2007; Paz-Kagan et al. 2014). Tohidyan Far and Rezaei-Moghaddam (2015) stated that today sustainable development, as the main goal in the agricultural sector, will be achieved if water and soil resources are conserved within the framework of technical rules and operations in principle.

Soil quality assessments can be used to evaluate and monitor sustainable land management practices in agroecosystems. Soil quality is determined by several properties and soil processes and can be understood in terms of the interactions among the physical, chemical and biological attributes of soil. In addition, these indicators can be used to check the effects that land use of varying intensity has on soil; in general, land use intensity presents an inverse relationship with soil quality (Andrews et al. 2004).

Most riparian zones have long been negatively influenced by human activities and numerous approaches have been adopted for mitigating the adverse impacts of agriculture practices (Marquez et al. 1998; Aguiar et al. 2015), but in Brazil, there is little information when these areas adjacent to rivers are degraded and should undergo immediate recovery.

Thus, the aim of this work was to present a case study where we performed to identify and to compare soil quality under different land-use types used for agriculture and native forest in riparian areas in Brazil.

Materials and methods

The study was conducted in the sub-basin of the Ribeira River (Ribeira de Iguape River), in Registro, a county in the south of São Paulo State, Brazil (24° 26′ S; 47° 49′ W′; 905 m asl). According to the Köppen classification system, the climate is Cfa, without a distinct dry season and with an annual average temperature of approximately 21 °C. The average annual rainfall is 1,700 mm, with the most rain falling between December and March. The soil types in the study areas included Dystric and Eutric Cambisol, according to the World Reference Base for Soil Resources (IUSS 2015).

This paper presents a case study performed to identify and study soil quality in riparian areas adjacent to the Ribeira de Iguape River (protected area according to Brazilian Law Nº 4771/1965) used for agriculture and livestock farming, very common in Brazil. We identified and selected four kinds of land use in the investigated area: banana cultivation without agricultural machinery traffic, with annual NPK fertilization by farmer, under Eutric Cambisol; degraded pasture with extensive Brachiaria decumbens L. coverage, with extensive grazing and many livestock, under Dystric Cambisol; silvopastoral land with free transit for animals inside, under Dystric Cambisol; and native forest land as reference area, under Eutric Cambisol. Soil evaluation and sampling were performed in irregular grids (20 points) for each land use type. Soil samples were collected from the surface of the most representative zone in the topsoil at a depth of 0.00 to 0.05 m. Effects on soil quality are more pronounced in this layer (Auler et al. 2014) because the mechanical compression of the soil is more intense.

Undisturbed soil samples were collected using sampling rings measuring 2.5 cm in height and 7 cm in diameter. The rings were gently pushed into the soil with Uhland soil samplers. The collected samples were wrapped in waterproof plastic wrap and sealed with paraffin wax to maintain the natural moisture content and preserve the structure of the collected samples during transport to the laboratory. Analyses were performed at the Soil Science Laboratory of the Registro Campus, Universidade Estadual Paulista (UNESP) and Soil Physics Laboratory of the Department of Soil Science, Federal University of Lavras (UFLA).

Physical, mechanical, and chemical soil analyses were carried out to assess soil quality (bulk density, volumetric total porosity, macroporosity, microporosity, water-dispersible clay, clay flocculation index, precompression stress, shear strength, penetration resistance and soil fertility). The physical and chemical characteristics of the soil samples from each type of land were evaluated (Table 1).

After air drying, the soil was sieved (2 mm), and physical and chemical analyses were carried out. Particle density was determined by the pycnometer method. The texture was determined by the pipette method. Organic matter (OM) was analyzed using the wet combustion method. Bulk density was calculated as follows:

$$\mathrm{Bd} = \frac{\mathrm{W}}{\mathrm{V}} \quad (1)$$

where Bd is bulk density (Mg m^{-3}), W the dry soil weight (Mg) and V the dry soil volume (m^3).

The volumetric total porosity (VTP) was estimated using the relationship between bulk density and particle density as follows:

$$\mathrm{VTP} = \left[1 - \left(\frac{\mathrm{Bd}}{\mathrm{Pd}}\right)\right] \quad (2)$$

where VTP is volumetric total porosity (m^3 m^{-3}), Bd is bulk density (Mg m^{-3}) and Pd is particle density (Mg m^{-3}).

Microporosity (Mi) was determined from samples equilibrated at –6 kPa based on the following equation:

$$\mathrm{Mi} = \frac{a - b}{c} \quad (3)$$

where Mi is microporosity (m^3 m^{-3}), a is soil sample weight at –6 kPa (g), b is dry soil weight (g) and c is dry soil volume (m^3).

Macroporosity (Ma) was calculated as follows:

$$\mathrm{Ma} = \mathrm{VTP} - \mathrm{Mi} \quad (4)$$

where Ma is macroporosity (m^3 m^{-3}), VTP is volume total porosity (m^3 m^{-3}) and Mi is microporosity (m^3 m^{-3}).

The water-dispersible clay (WDC) content was determined by the pipette method following the same procedure used to test soil texture but without adding NaOH. The clay flocculation index (CFI) was calculated using the following equation:

Table 1. Main physical and chemical characteristics of the dystric cambisol for native forest (NF), silvopastoral land (SL), degraded pasture (DP) and land under banana cultivation (BC) in the Ribeira Valley region, Brazil.

	Land uses			
Soil characteristics	NF	SL	DP	BC
Clay (g kg^{-1})	155	237	216	294
Silt (g kg^{-1})	343	122	146	317
Fine sand (g kg^{-1})	6	186	212	232
Coarse sand (g kg^{-1})	495	455	426	157
Total sand (g kg^{-1})	502	641	638	389
Soil organic matter (g kg^{-1})	25	33	45	36

$$\mathrm{CFI} = \left[\frac{(\mathrm{C} - \mathrm{WDC})}{\mathrm{C}}\right] * 100 \quad (5)$$

where CFI is the clay flocculation index (%), C is clay content (g kg^{-1}) and WDC is water-dispersible clay content (g kg^{-1}).

To determine the precompression stress of the samples, undisturbed soil samples were equilibrated at –6 kPa and submitted to an uniaxial compression test (Dias Junior and Pierce 1995). Loads were applied using an automatic consolidometer (model CNTA-IHM/BR-001/07), with pressure generated by compressed air. The pressures applied to the soil samples were 25, 50, 100, 200, 400, 800 and 1600 kPa, with the assumption that maximum deflection was defined as compression up to 90% of the soil sample for each pressure level. The soil compression curve was obtained by plotting the deformation values for the samples (void ratio or bulk density) against the logarithm of the pressure applied. The soil precompression stress (SPS) of samples was estimated using either method 1 or 3, according to Dias Junior and Pierce (1995), which partition soil precompression stress as a function of soil moisture tension.

Soil shear strength (SSS) was measured with a vane-test apparatus (vane shear tests) at depths of 0.00 to 0.05 m. The vane was turned slowly at a constant angular velocity. The point at which soil flow would begin was defined as when the applied torque reached the maximum value and resulted in the shearing of the soil in the area around the vane. This test followed the standardized methodology described by NBR 10,905/89. Soil penetration resistance (SPR) was performed with a model PLG1020 electronic penetrometer (Falker Agricultural Automation) at 0.00 to 0.40 m with a steel cone 12.83 mm in diameter.

Soil susceptibility (soil erodibility), the K factor from the Universal Soil Loss Equation (USLE), was calculated using the following equation (Denardin 1990):

$$K = (0.6084\,P) + (0.834286\,SOM) - (0.116162Al) - (0.377756\,TS) \quad (6)$$

where K is soil erodibility (t ha h ha^{-1} Mj^{-1} mm), P is the permeability coefficient (very fast = 0.01, fast = 0.02, moderate = 0.03, slow = 0.04, very slow = 0.05 and imperfectly drained = 0.06), SOM is soil OM (%) multiplied by a factor of 0.01, Al is Al_2O_3 content (%) multiplied by a factor of 0.01 and TS is the total sand content (%) multiplied by a factor of 0.001.

Phosphorus (P) (Mehlich extraction), potassium (K) (Mehlich 1 extraction), magnesium (Mg), and calcium (Ca) contents and the sum of bases (SB), base saturation (V%), cation exchange capacity (t), cation exchange capacity at pH 7.0 (T), pH, and hydrogen plus aluminum (Al+H) values were evaluated. For a better understanding on this subject matter, the chemical properties (soil fertility) were ranking in different categories, in very low, low, medium, higher every higher for soil pH, and very low, low, medium, good and very good for others chemical properties.

IBM SPSS Statistics 20.0 (demo version) was used to determine which variables (soil properties) discriminated between the four previously defined land uses. Soil property data were then subjected to an analysis of variance (ANOVA). If the F-test identified significant differences at $p < 0.05$, the averages were grouped by Scott-Knott criteria using SISVAR software (Ferreira 2011).

To construct comparative diagrams, soil quality index for each soil attribute (physical, mechanical and chemical properties) was calculated, with a t value between 0 and 1. Values of soil quality index for each soil attribute found for the samples from agricultural land were divided by the values for soil samples from the native forest (soil quality index = soil attributes values from agricultural land/soil attributes values from the native forest). Higher values for some soil attributes indicate better soil sustainability; this includes values for volumetric total porosity, macroporosity, microporosity, the clay flocculation index, phosphorus, potassium, calcium, magnesium, sum of bases, cation exchange capacity, cation exchange capacity at pH 7.0 and base saturation. For these variables, we calculated the ratio between the value for each type of land use and the soil reference value (native forest). Example to macroporosity (Ma): Ma score = BC Ma Value/NF Ma Value → 0.07 m^3 m^{-3}/0.11 m^3 m^{-3} = 0.64 (Ma score to BC of 64% in relation to NF). Since higher values for other soil attributes may indicate problems or factors that limit sustainability, such as bulk density, soil penetration resistance, soil shear strength, soil precompression stress, soil erodibility, hydrogen plus aluminum and pH, the ratios of the inverse values for these attributes were analyzed. Example to soil penetration resistance (SPR): SPR score = BC SPR Value/NF SPR Value → 493 kPa/1509 kPa = 0.33 (SPR score to BC of 33% in relation to NF). The value obtained close to 1 (score of 100%) of soil attributes means as an ideal or sustainable value, in other words, represents soil attributes for agricultural land use similar to the native forest area.

Data for each soil attribute were plotted along an axis of a comparative diagram (or radar graph type), where each axis represents each soil attributes. To compare the soil quality between land uses, we compare the areas of each polygon formed (radar graph type or comparative diagrams) for each type of land use. We utilized GeoGebra software to calculate the areas of each polygon formed.

Results

Discriminant function analyze

Discriminant function analysis uses linear combinations of variables to best separate the mean vectors of two or more groups of multivariate observations relative to the within-group variance. Figure 1 provides results of a discriminant function analysis of soil attributes of analyzed Cambisol samples from each type of land (degraded pasture, land under banana cultivation, silvopastoral land and native forest). The variables (soil attributes) were associated with each predetermined group, making it possible to examine each soil attribute separately. This type of analysis provides further insight into and allows for an objective assessment of different land use groups in relation to a set of variables, allowing a deeper and clearer understanding of the variables that characterize those land use groups.

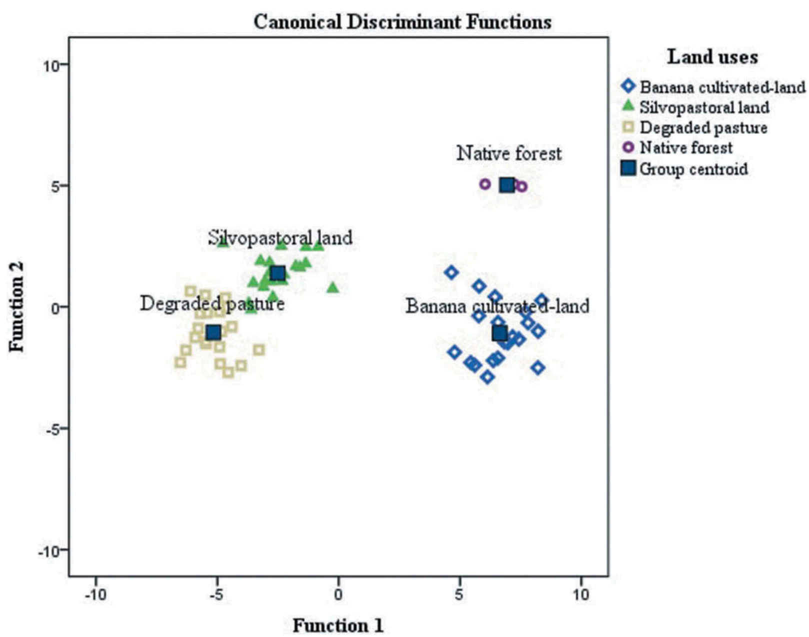

Figure 1. Discriminant functions separating different soil management practices (degraded pasture, land under banana cultivation, silvopastoral land and native forest) in a dystric cambisol.

Table 2. Mean values of physical (WDC, CFI, Bd, VTP, Ma and Mi) and mechanical properties (SPS, SPR and SSS), and soil erodibility (K) for native forest (NF), silvopastoral land (SL), degraded pasture (DP) and land under banana cultivation (BC) in a dystric cambisol in the Ribeira Valley region, Brazil.

	Land uses			
Soil attributes investigated	NF	SL	DP	BC
WDC (g kg^{-1})	51 b (4)	27 b (22)	22 b (12)	121 a (43)
CFI (%)	67 b (2)	88 a (8)	91 a (4)	59 b (11)
Bd (Mg m^{-3})	1.14 c (0.027)	1.47 a (0.103)	1.39 a (0.107)	1.28 b (0.12)
VTP (m^3 m^{-3})	0.57 a (0.01)	0.43 c (0.04)	0.46 c (0.04)	0.52 b (0.05)
Ma (m^3 m^{-3})	0.11 a (0.01)	0.05 b (0.02)	0.09 a (0.05)	0.07 b (0.03)
Mi (m^3 m^{-3})	0.46 a (0.02)	0.38 b (0.05)	0.37 b (0.02)	0.45 a (0.04)
SPS (kPa)	154 a (10)	191 c (27)	173 b (32)	192 c (72)
SPR (kPa)	493 a (64)	1320 c (470)	695 b (117)	1509 c (390)
SSS (kPa)	66 a (4.2)	95 b (14)	110 c (18)	79 b (22)
K (t ha h ha^{-1} Mj^{-1} mm)	0.004 a (0.001)	0.015 b (0.004)	0.018 c (0.009)	0.023 d (0.010)

WDC: water-dispersible clay; CFI: clay flocculation index; Bd: bulk density; VTP: volumetric total porosity; Ma: macroporosity; Mi: microporosity; SPS: soil precompression stress; SPR: soil penetration resistance; SSS: soil shear strength; K: soil erodibility. Values followed by different letters in each row are significantly different by the Scott-Knott test at $p < 0.05$. Values in parentheses represent the standard deviation.

Physical and mechanical soil properties

Table 2 presents the mean values of the physical and mechanical attributes of a Brazilian Cambisol from different land use types. Water-dispersible clay contents were higher in soils under banana cultivation than in the other types of land (native forest, silvopastoral land, and degraded pasture). No significant difference was found between native forest, silvopastoral land, and degraded pastures, indicating that these land types did not differ from each other. Land under banana cultivation was the only area where additional nutrients were supplied to the soil, causing water-dispersible clay values to increase. Higher water-dispersible clay content in riparian zones can cause major problems for streams and rivers due to the increased risk of soil erosion, silting and water pollution.

The comparative diagram in Figure 2 summarizes the physical attributes that reflect soil quality in the layer from 0.00 to 0.05 m in depth for different agricultural land types relative to values for the native forest. Banana cultivation was the type of land use that caused the most damage to the physical properties of soils in riparian areas adjacent to the Ribeira de Iguape River. The diagram indicates that degraded pastures, silvopastoral land and land under banana cultivation had areas for physical attributes of soil that were 75%, 63% and 57%, respectively, of the value for the native forest.

In banana cultivation and silvopastoral land use systems, precompression stress and penetration resistance were higher, indicating higher internal soil strength. Soil precompression stress and penetration resistance were lower in native forest, followed by the values for degraded pastures (Figure 3). The greater impacts on precompression stress and penetration resistance in the areas under banana cultivation are due to management and harvesting operations because these areas undergo extensive manipulation, and ideal soil moisture conditions are not maintained, which further alters these soil properties and results in the soil having a low load-bearing capacity.

The area diagram for some mechanical properties and for soil erodibility indicate a high degree of soil degradation in riparian areas adjacent to the Ribeira de Iguape River. Banana cultivation and silvopastoral use resulted in the greatest degradation of soil mechanical properties and increase in soil erodibility, as shown by the fact that the areas for soil mechanical properties in the diagrams are only 29% and 28% for land under banana cultivation and silvopastoral land, respectively, relative the area for native forest (Figure 3). The impact on soil is further compounded by banana harvesting due to traffic from the agricultural workers carrying heavy bunches of bananas, which increases ground contact pressure and causes more soil compaction. The damage to soil structure in silvopastoral land (Table 2 and Figure 3) can be attributed to animal trampling; however, this was not observed in degraded pastures, even with grazing animals, due to the positive aspects of the root systems of grasses in degraded pasture areas. Comparing diagram areas (polygon for each

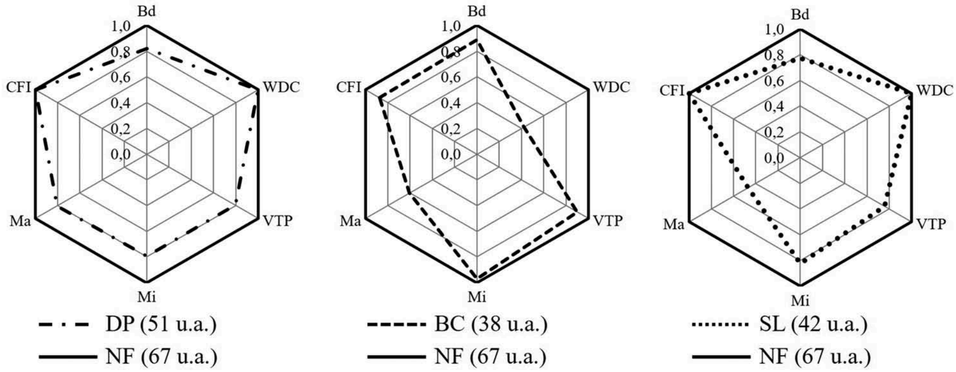

Figure 2. Comparative diagrams for the physical properties of the dystric cambisol for degraded pasture (DP), land under banana cultivated-land (BC) and silvopastoral land (SL) in relation to native forest (NF). u.a.: unit of area of the diagram.

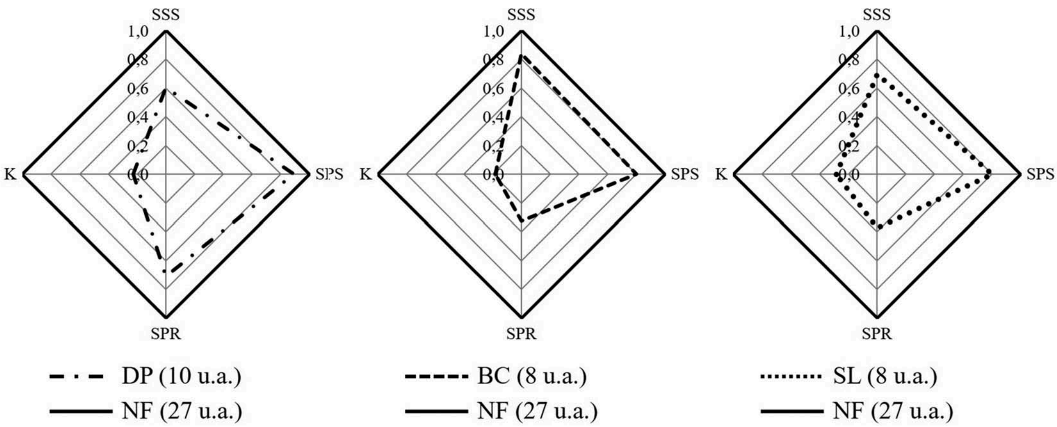

Figure 3. Comparative diagrams for soil precompression stress (SPS), soil penetration resistance (SPR), soil shear strength (SSS) and soil erodibility (K) of the dystric cambisol from degraded pasture (DP), land under banana cultivated-land (BC) and silvopastoral land (SL) in relation to native forest (NF). u.a.: unit of area of the diagram.

type of land use), degraded pastures had better results for mechanical properties and soil erodibility (10 units of area) than land under banana cultivation (8 units of area) and silvopastoral land (8 units of area). The diagram area for degraded pastures is 36% that of the area for native forest.

Chemical soil properties

The type of land use in riparian zones showed large variations to the soil chemical properties studied (Table 3). Following the criteria of for interpreting soil analyses to evaluate soil fertility and active soil acidity, the most fertile areas were in the land under banana cultivation, followed by the native forest, silvopastoral land and degraded pastures. We investigated ten chemical attributes in this study to evaluate soil fertility (Table 3), and the native forest had eight attributes ranked as 'good' or 'very good'. This result confirms that for studies of soil quality, the designation of preserved areas as reference areas is appropriate, especially for aspects of soil chemistry.

Among the soil chemical attributes investigated, only base saturation and hydrogen plus aluminum were statistically similar between banana cultivation and native forest areas (Table 3). The other soil chemical attributes differed significantly. Silvopastoral land and degraded pastures were the worst in terms of soil fertility. However, for comparisons of the average values for phosphorus, potassium and

Table 3. Mean values of chemical properties (soil fertility) of the dystric cambisol for native forest (NF), silvopastoral land (SL), degraded pasture (DP) and land under banana cultivation (BC) in the Ribeira Valley region, Brazil.

Soil attributes investigated	Land uses			
	NF	SL	DP	BC
P (mg dm^{-3})	28 b [4] (2.3)	5 b [1] (2.8)	5 b [1] (2.4)	321 a [5] (218.2)
K (mg dm^{-3})	49 b [3] (1.4)	47 b [3] (23.2)	36 b [2] (20.1)	142 a [5] (61.6)
Mg ($cmol_c$ dm^{-3})	2 b [5] (0.1)	3 b [5] (0.8)	1 c [4] (1.1)	5 a [5] (1.0)
Ca ($cmol_c$ dm^{-3})	8 b [5] (0.1)	2 c [3] (1.2)	2 c [3] (1.0)	10 a [5] (2.2)
SB ($cmol_c$ dm^{-3})	11 b [5] (0.2)	5 c [4] (1.8)	3 c [3] (2.1)	16 a [5] (3.1)
V (%)	86 a [5] (0.2)	38 b [2] (18)	36 b [2] (16)	92 a [5] (3)
t ($cmol_c$ dm^{-3})	11 b [5] (0.2)	5 c [4] (1.5)	4 c [3] (1.7)	16 a [5] (3.1)
T ($cmol_c$ dm^{-3})	13 b [4] (0.2)	13 b [4] (2.7)	10 b [4] (2.3)	17 a [5] (3.1)
pH	7 b [4] (0.1)	5 c [3] (0.3)	5 c [3] (0.3)	7 a [5] (0.3)
H+ Al ($cmol_c$ dm^{-3})	2 b [2] (0.1)	8 a [4] (0.3)	7 a [4] (2.7)	1 b [2] (0.3)

P: phosphorus; K: potassium; Mg: magnesium; Ca: calcium; SB: sum of bases; V%: base saturation; t: cation exchange capacity; T: cation exchange capacity at pH 7.0; pH: potential of hydrogen; H+ Al: hydrogen plus aluminum. Categories for soil fertility: [1] very low, [2] low, [3] medium, [4] good and [5] very good. Categories for soil pH: [1] very low, [2] low, [3] medium, [4] higher e [5] very higher. Values followed by different letters in each row are significantly different by the Scott-Knott test at $p < 0.05$. Values in parentheses represent the standard deviation.

cation exchange capacity at pH 7.0, these land types were statistically similar to native forest. The soil potassium is more susceptible to leaching, so the similarity between the potassium values in these land use types (native forest, silvopastoral land and degraded pastures) can be attributed to leaching because rainfall levels are very high in this region. Very low soil phosphorus levels were observed for silvopastoral land and degraded pastures areas, due mainly because Brazilian soils are lacking in this element because of the nature of the parent material and the high demand for soil phosphorus. Lower levels of elements observed in some areas (except in land under banana cultivation due to constant replenishment via fertilization) were due to the initial stages of laminar erosion, which carries nutrients out of the soil surface, as well as loss from seepage or leaching, which 'washes' the soil in a vertical direction.

Agricultural areas generally tend to need additional nutrients, which are added to the soil in the form of special fertilizers. In this study, only land under banana cultivation had additional nutrients supplied. When comparing the diagrams for the chemical attributes of different land use types to diagrams for native forest (Figure 4), land under banana cultivation was the closest of the agricultural land use types to native forest, mainly as a result of chemical soil management (Figure 3). Comparing diagram areas, land under banana cultivation had an area 99% that of native forest. This fact is related to the large supply of nutrients supplied during fertilization. On the other hand, degraded pastures and silvopastoral land had reduced soil fertility.

Comparing diagram areas

Results show the effects of different types of land use on soil properties; deforestation and the effects of land use influence the physical, mechanical, erosion-resistant and chemical attributes of soil (Figure 5). Comparing diagram areas, land under banana cultivation, degraded pastures and silvopastoral land had values that were 40%, 36% and 29%, respectively, of diagram areas for the native forest. In studying different environmental characteristics, researchers often neglect soil structure even though it has a strong impact on water and nutrient access and uptake by crops. Analyses of areas adjacent to water bodies show that covering the land with grass crops helps protect against soil erosion. Soil structure influences water infiltration rates and degrading this structure results in slower infiltration rates. Thus, the degradation of soil structure leads to increased runoff and possibly greater soil loss. Therefore, the replacement of native forests with bananas can cause serious problems for soil conservation and increase the silting up of rivers.

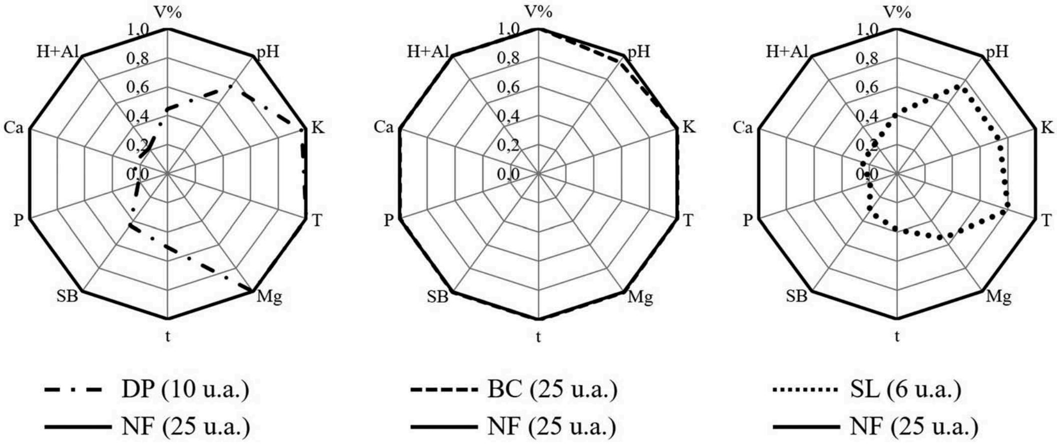

Figure 4. Comparative diagrams for chemical properties of the dystric cambisol from degraded pasture (DP), land under banana cultivated-land (BC) and silvopastoral land (SL) in relation to native forest (NF). u.a.: unit of area of the diagram.

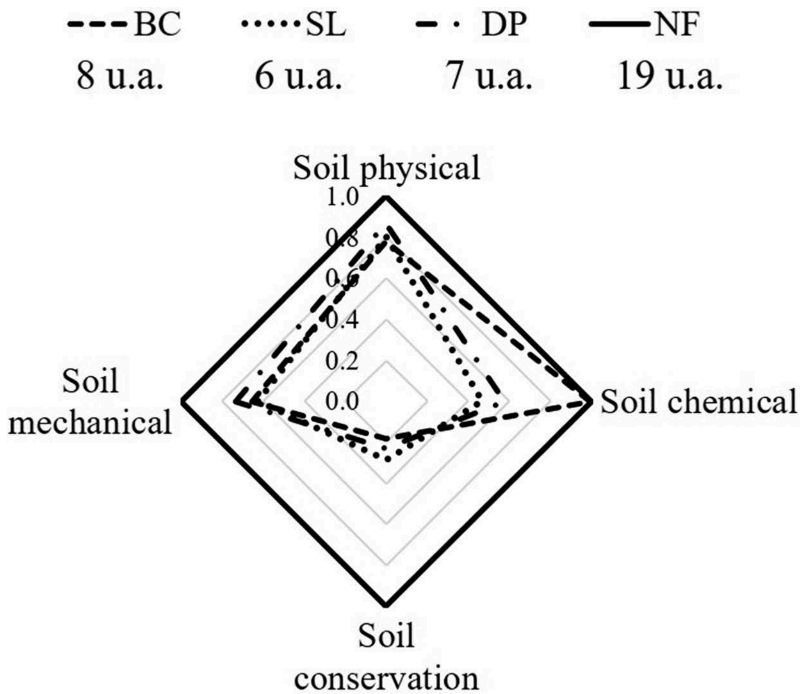

Figure 5. Comparative diagrams for soil attributes of the dystric cambisol from degraded pasture (DP), land under banana cultivated-land (BC) and silvopastoral land (SL) in relation to native forest (NF). u.a.: units of area of the diagram.

Discussion

Discriminant function analyze

According to Baretta et al. (2014), a discriminant function analysis is more appropriate for discriminating among factors related to land use and to determine which soil attributes best distinguish different types of land use. In this study, bulk density, volumetric total porosity, macroporosity, microporosity, soil penetration resistance, magnesium, pH and base saturation were the variables that contributed most to the separation of land use types. Igwe and Udegbunam (2008) noted that soil erosion was directly linked to rate and the volume of water-dispersible clay in soil.

Physical and mechanical soil properties

The clay flocculation index is directly inverse to the water-dispersible clay content and is another index that indicates the ability of soils to resist dispersion in water. Therefore, it is a very good index for predicting soil erodibility and a good microaggregate index. We found the highest clay flocculation indices in degraded pastures and silvopastoral land, with no significant difference between these land types (Table 2). On the other hand, native forest and land under banana cultivation presented the lowest clay flocculation indices and did not differ significantly from each other, indicating a poor capacity for aggregation and that these soils will easily disperse in water. By contrast, degraded pastures and silvopastoral land showed a low potential for soil loss. In some soils of southeastern Nigeria, Igwe et al. (1995) showed that the clay flocculation index ranked as the highest among micro- and macroaggregate indices in predicting potential soil loss.

We found the highest and lowest values for bulk density and volumetric total porosity, respectively, in agricultural areas. Native forest (reference area) presented lower bulk density values and higher volumetric total porosity values (Table 2). Islam and Weil (2000) also found similar results, wherein agricultural areas had higher bulk densities than reference areas and more extensive changes in soil structure were observed in agricultural areas when compared to references areas. The higher bulk density and, consequently, lower volumetric total porosity in degraded pastures and silvopastoral land were due to animal trampling, mainly because soil sampling was performed from a zone in the topsoil, which is more susceptible to the effects of animal trampling. Similar results were found by Chaichi et al. (2005).

Soil macroporosity in agricultural areas (silvopastoral land, degraded pastures and land under banana cultivation) was approximately 0.10 m^3 m^{-3} (Table 2). A soil macroporosity of 0.10 m^3 m^{-3} is the minimum value for adequate liquid and gas exchange between the external environment and soil and is considered critical for root growth of most crops (Baver et al. 1972). These findings indicate that most of the plants on silvopastoral land, degraded pastures and land under banana cultivation may encounter problems related to soil aeration and greater resistance to penetration, as plants do not grow satisfactorily when macroporosity exceeds this critical value (Gupta and Allmaras 1987). The proportions of soil micropores ranged from 0.37 to 0.46 m^3 m^{-3}. Soil microporosity was the highest in native forest and land under banana cultivation and the lowest in degraded pastures and silvopastoral land (Table 2). High and low values for microporosity and macroporosity in the soil, respectively, can indicate problem-related to soil compaction. Normally, compacted soils have an increase in the number of soil micropores along with a reduction in porosity.

The changes in soil attributes, relative to those of native forest, in degraded pastures, resulted in less damage related to soil physics than the changes that occurred in land used as silvopastures or for banana cultivation. These observed results were due to the improved efficiency of the root systems of grasses in preserving soil structure. Recent works have also observed improved efficiency of grasses in preserving soil structure (Ajayi and Horn 2016).

In many degraded areas, grasses are a way to stabilize soil, mainly due to increases in soil OM, which improves the physical properties of the soil. Soil stabilization by grasses improves soil strength, especially through the bonding of soil particles. Grasses, due to their higher root density (Wang and Gong 1998) and better root distribution relative to other plant types, improve bonding between mineral particles and aggregates, which improves the soil structure and overall profile (Ajayi and Horn 2016).

Soil shear strength showed a pattern similar to that of other mechanical soil properties (soil precompression stress and soil penetration resistance), with the highest values found in agricultural areas (land under banana cultivation, degraded pastures and silvopastoral land) and the lowest values found in the native forest (Table 2). Similar to the observations in several previous studies (Servadio et al. 2001), soil shear strength increased with an increase in bulk density and a decrease in volumetric total porosity (Table 2), indicating that internal strength and the void ratio can favor an increase in soil shear strength.

Our results confirm the presence of intense soil compaction in agricultural areas along riparian zones, particularly in degraded pastures and land under banana cultivation owing to increased contact pressure from animal trampling and agricultural workers (banana shippers), respectively. Furthermore, areas with mechanical soil degradation had an increased susceptibility to erosion (Bertol et al. 2005). According to Römkens et al. (1997), soil erodibility (the K factor from the USLE) is a complex property that can be thought of as the ease with which soil is detached by splashing water during rainfall, surface flow or both. The effects of land use on soil erodibility differed significantly among the land types studied here in the following order: land under banana cultivation > degraded pastures > silvopastoral land > native forest. Except native forest, all land uses here investigated had visible signs of soil erosion. This is worrying since it is clearly an issue that attention should be paid to soil quality of the land uses and management in these unstable areas, as streambank erosion is identified as one of the main nonpoint sources of sediment pollution of natural streams (Khanal et al. 2016; Al-Madhhachi and Hasan 2018). The lower susceptibility to erosion found in areas of native forest is associated with better physical and mechanical soil properties (Table 2), mainly macroporosity, total porosity, bulk density, soil precompression stress and soil penetration resistance. On the other hand, areas of banana cultivation presented the highest soil erodibility, indicating that the concentration of eroded sediment may be larger, which would promote greater siltation of rivers situated below areas of banana cultivation.

Silvopastoral land and degraded pastures presented intermediate results in soil erodibility (Table 2). Trampling by animals had a strong effect in both areas, but vegetation cover and associated root systems reduced the effects on the soil. Degraded pasture areas were cultivated with Brachiaria decumbens L., while silvopastoral land was a forested area that allowed the free transit of animals. Both areas showed resistance to damage, mainly in the soil structure. This protection occurred because of root systems, which help to protect the soil structure and promote an increase in soil OM. Soil uses involving grasses (C4 plants) promote greater accumulation of soil OM, because these plants have a relatively higher C:N ratio. Römkens et al. (1997) explain that there are interactions between soil erodibility (K factor) and cover-management (C factor from the USLE), primarily due to the effect of OM or organic carbon on soil loss. These authors indicate that the organic carbon content of soils depends on the annual additions of surface and subsurface crop residues and manure and on their decomposition rate.

Chemical soil properties

The replacement of native forests by agricultural land causes widespread soil degradation, which commonly involves reductions in calcium, magnesium, potassium, sodium and carbon content (Likens et al. 1970; Ekholm and Lehtoranta 2012; Rodrigues-Filho et al. 2015). Suleiman et al. (2017) indicate land use change is one of the major factors related to soil degradation and alterations. Comparing diagram areas, silvopastoral land and degraded pastures had areas that were 25% and 40%, respectively, of the area for native forest (Figure 5). In addition, widespread impoverishment has resulted in a loss of biodiversity and a reduced capacity of ecosystems to recover from disturbances. The degradation of pastures promotes the loss of OM proportional to its concentration in the soil, as well as the loss of nutrients such as phosphorus, potassium, calcium and magnesium. Because exploitation of these areas is continuous and performed in a disorganized manner and without nutrient replacement, pasture productivity and soil nutrient contents both decrease. Extensive animal management does not include the growth and development of forage plants, which hampers dry matter production and results in the chemical degradation of soil.

The replacement of preserved areas in agricultural areas can accelerate soil erosion (Likens et al. 1970; Ekholm and Lehtoranta 2012). Furthermore, according to these authors, the conservation of native vegetation helps to protect the soil from the rainfall impact and consequently against soil particle detachment.

Unlike for its chemical attributes, land under banana cultivation had the greatest degree of negative changes in physical and mechanical properties and in soil erodibility relative to the properties of native forest. The constant replacement of nutrients through fertilization in areas of banana cultivation led to chemical properties of the soil that were better than in native forest. Banana cultivation proved to be very harmful to the soil and water bodies, especially because of parameters that influence soil erosion and siltation and contamination of river (Gunningham and Sinclair 2005). This study was performed in areas adjacent to the Ribeira de Iguape River, which is a sensitive area, making the observed results very worrisome, mainly because of the risk of contaminating the river. Ghaderi et al. (2012) explain that poorly managed agricultural operations can lead to contamination of groundwater and river water by nutrients.

Riparian lands are important in this studied region of Brazil, mainly because it has deeper and better-quality soils. Lovett and Price (2007) also noted that riparian land is important because it is often the most fertile and productive part of the landscape in terms of both agricultural production and natural ecosystems. However, even though it is productive area (riparian lands), the results summarized here indicate that riparian land is often a vulnerable area that is at risk of damage from cultivation or over-grazing. The definitions of riparian zones based on land use are of limited use for management purposes, mainly because of the complex interactions between land and water in riparian areas (Lovett and Price 2007). Moreover, farmers in riparian areas who cultivate crops along riverbanks in this region of Brazil often pay little attention to protecting the natural processes that are fundamental to riparian land. Even in agricultural areas, native forest have an important role in soil and river protection of the riparian zones. Fernandes et al. (2014) found effects of riparian forest structure on stream water quality in agricultural landscapes. Therefore, the federal environmental laws become an important tool for the preservation of riparian zones, both for soils and rivers.

Conclusions

The effects of agricultural use on the soil in areas under long-term preservation parallel to a river are evident when investigated soil properties are compared to a reference area (native forest).

The replacement of native forests by areas of banana cultivation in areas adjacent to rivers causes a greater environmental impact than replacing native forest with degraded pastures or silvopastoral land. Physical and mechanical properties of the soil best reflected the differences in soil quality between te evaluated land uses alongside rivers (riparian areas). The adoption of comparative diagrams for soil assessment helped to elucidate the relationships between agricultural land uses and the physical, mechanical and chemical aspects of soil quality in riparian areas, proving are a useful tool in the assessment of soil quality in riparian areas.

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No potential conflict of interest was reported by the authors.

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