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CENTER OF NUCLEAR ENERGY IN AGRICULTURE

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Carbon sequestration potential of the soil in the restoration of riparian forests of the Corumbataí basin (SP)

Piracicaba

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Thank you very much!!!

Mother's prayer

Our Mother who art underfoot,

hallowed be thy names,

thy seasons come, thy will be done,

within us as around us,

thank you for our daily bread, our water, our air,

and our lives and so much beauty;

Lead us not into selfish craving and the destructions

that are the hungers of the glutted,

but deliver us from wanton consumption

of thy vast but finite bounty,

for thine is the only sphere of life we know,

and the power and the glory, forever and ever.

Amen.

Adapted by Rebecca Solnit

ABSTRACT

GALERA, L. de A. **Carbon sequestration potential of the soil in the restoration of riparian forests of the Corumbataí basin (SP).** 2018. 66 p. Dissertação (Mestrado) – Centro de Energia Nuclear na Agricultura, Universidade de São Paulo, Piracicaba, 2018.

The soil organic matter is the largest carbon reservoir among terrestrial reservoirs and its very important in the regulation of the climate at global scale. Strategies to increase soil organic carbon (SOC) stocks includes afforestation and reforestation and the adoption of recommended management practices (RMPs) like no-till farming and cover crops. The replacement of forestland by agriculture may deplete SOC stocks, by decreasing C input to the soil and increasing the decomposition of organic matter. The Brazilian Forest Code (FC) requires landowners to conserve native vegetation by means of Legal Reserve and Areas of Permanent Preservation (APPs), which includes Hilltop Preservation Areas and Riparian Preservation Areas. It is well known that riparian vegetation provides many ecosystem services, like biodiversity conservation and increasing water availability and quality. Another potential ecosystem service is the mitigation of climate change by accumulating carbon in the vegetation and SOM. The reforestation of riparian zones represents an important opportunity for carbon sequestration and the mitigation of climate change in Brazil, as these restorations are mandatory under the Forest Code. The goal of this study is to contribute with the discussion about the role of riparian forests in the mitigation of climate change. In order to achieve this goal, we compare the SOC stocks of forested riparian areas with the SOC stocks of agricultural areas, namely pasture and sugarcane. Forested soils had an average SOC stock of 44 $Mg.ha^{-1}$ while pasture had 26 $Mg.ha^{-1}$ and sugarcane 27 $Mg.ha^{-1}$. Based on the estimates of the SOC stocks situation after the reforestation of the riparian zones of the 50 sub-watersheds sampled, we could foresee an accretion of 20% of organic carbon in the 0-30 cm soil layer of those areas. We hope that this work contributes to the understanding of the role of the riparian forests in the mitigation of climate change and that the inclusion of the reforestation of those ecosystems in the mitigation strategies options may highlight the urgency in sparing them from devastation.

Keywords: Pasture. Sugarcane. Soil organic carbono. Climate change. Corumbataí basin.

RESUMO

GALERA, L. de A. **Potencial de sequestro de carbono pelo solo na reconstituição de florestas ripárias da Bacia do Corumbataí (SP).** 2018. 66 p. Dissertação (Mestrado) – Centro de Energia Nuclear na Agricultura, Universidade de São Paulo, Piracicaba, 2018.

A matéria orgânica do solo é o maior reservatório de carbono entre os ambientes terrestres e é muito importante na regulação do clima em escala global. As estratégias para o aumento dos estoques de carbono do solo incluem o reflorestamento e a adoção de práticas recomendadas de manejo como o plantio direto e o uso de culturas de cobertura. A substituição de florestas por áreas agrícolas pode reduzir os estoques de carbono do solo ao diminuir a aporte de carbono e aumentar a decomposição da matéria orgânica. O Código Florestal obriga proprietários de terra a conservar a vegetação nativa por meio de Reserva Legal e Áreas de Preservação Permanente, que inclui topos de morro e áreas ripárias. Sabe-se que florestas ripárias provêm diversos serviços ambientais como a conservação da biodiversidade e o aumento na disponibilidade e qualidade da água. Outro possível serviço ambiental é a mitigação das mudanças climáticas pelo acúmulo de carbono na vegetação e no solo. A restauração das zonas ripárias representa uma importante oportunidade para o sequestro de carbono no Brasil, já que são obrigatórias segundo o Código Florestal. O objetivo deste estudo é contribuir com a discussão sobre o papel das florestas ripárias na mitigação das mudanças climáticas. Foram comparados os estoques de carbono de florestas ripárias com os de áreas agrícolas, no caso pastagens e canaviais. O estoque de carbono médio dos solos florestais foi de 44 $Mg.ha^{-1}$, dos de pastagem foi de 26 $Mg.ha^{-1}$ e dos sob canaviais foi de 27 $Mg.ha^{-1}$. Baseado nesses valores, o impacto do reflorestamento das zonas ripárias (30 m) das 50 microbacias amostradas foi estimado, e segundo essa estimativa haveria um acréscimo de 20% de carbono na camada de 0-30 cm destas áreas. Esperamos que este trabalho contribua no entendimento do papel das florestas ripárias na mitigação das mudanças climáticas e que a inclusão da restauração destes ambientes como opção de estratégia de mitigação enfatize a urgência em preservá-los.

Palavras-chave: Pastagem. Cana-de-açúcar. Carbono orgânico do solo. Mudanças climáticas. Bacia do Corumbataí.

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1. INTRODUCTION

The soil organic matter is the largest carbon reservoir among terrestrial reservoirs (Post et al., 1982), and tropical soils represent around 40% of it (Jobbágy and Jackson, 2000), making it especially important in the regulation of the climate at global scale (Fearnside, 2006). The US Environmental Protection Agency, in its most recent Inventory of US GHG Emissions and Sinks, estimated that, in 2015, 6% of the US total emissions were offset by soil C sequestration (US EPA, 2017). Additionally, Sá et al. (2017) estimated that the expansion of the low carbon agriculture in South America could offset 8.2 Pg of C emissions until 2050, by soil C sequestration.

Soil C sequestration occurs when C accumulation rate overcome C emissions (Lal, 2004b), and soil organic matter is formed, either by the biochemical pathway, that occurs early in the decomposition of organic matter by the incorporation of the non-structural compounds of the litter into the microbial biomass, as well as by the physical pathway, that occurs by the transfer of recalcitrant litter fragments into the soil (Cotrufo et al., 2015). Strategies to increase SOC includes afforestation and reforestation and the adoption of recommended management practices (RMPs) like no-till farming, cover crops, nutrient management, manuring, sludge application, improved grazing, water conservation, and agroforestry practices (Lal, 2004b). Any of these methods are considered a win-win strategy because it removes carbon from the atmosphere, while improving soil quality, enhancing agriculture productivity (Lal, 2004a), and while supplying key ecosystem services (Parron et al., 2015).

Land use changes can affect the C balance in the soil. The replacement of forestland by agriculture may deplete SOC stocks, by decreasing C input to the soil; increasing decomposition crop residues due to tillage-induced perturbations; changing soil moisture and temperature regimes (Lal, 2005; Carneiro et al., 2009; Cardoso et al., 2015). In a meta-analysis that investigated near four hundred studies on land-use change in the tropics, the highest SOC losses (32 cm depth in average) were caused by the conversion of primary forest into perennial crops (30%), followed by the conversion of primary forest into cropland (25%), and by the conversion of primary forest into grassland (12%) (Don et al., 2011). On the other hand, there are land use changes that might increase SOC stocks, like the afforestation of agricultural land (29%), or land under fallow (32%), and the conversion of cropland into grassland (26%) (Don et al., 2011). In Brazil, the increase in the arable land led to an increase of emissions caused by such land use changes (LUC). In 2012, approximately half of the total Brazilian emissions were caused by LUC (Brasil, 2014).

The Brazilian Forest Code (FC) is the central piece of legislation that regulates land use and management on private properties. It requires landowners to conserve native vegetation by means of Legal Reserve, that occupies 80% of the property area in the Amazon and 20% in other biomes, and Areas of Permanent Preservation (APPs) that includes Riparian Preservation Areas (RPAs), that intends to conserve water resources by protecting riparian forest buffers, and Hilltop Preservation Areas (HPA), at hilltops and steep slopes. The conservation requirements for LRs and RPAs of the current FC protect 193 ± 5 Mha of native vegetation avoiding emissions to atmosphere of 87 ± 17 GtCO_2e (Soares-Filho et al., 2014).

It is well known that riparian vegetation provides many ecosystem services, like biodiversity conservation, increasing water availability and quality, contributing to stream banks stabilization, retaining pollutant and soil particles (Noble and Dirzo, 1997; Bonnie et al., 2000; Metzger, 2010; Stallard et al., 2010; Ogden et al., 2013; Parron et al., 2015; Vigiak et al., 2016). Another potential ecosystem service is the mitigation of climate change by accumulating carbon in the vegetation and SOM. Mackay et al. (2016) emphasizes that reforestation of riparian zones can help in the mitigation of climate change, suggesting that as soil C sequestration increases with soil moisture and primary productivity (Post et al., 1982), it may be possible that riparian plantings sequester soil C faster than upland ones.

However, carbon sequestration by SOM is very variable, depending on several soil properties such as soil moisture, soil texture, and cation exchange capacity (Pinay et al., 1992; Jobbágy and Jackson, 2000; Freibauer et al., 2004; Moyano et al., 2012). Therefore, there is no simple conclusion about the impacts of land use and land use change on SOC stocks. For instance, the effects of the conversion of forests into pastureland are very debatable, as there are evidences of SOC stocks losses (Hoogmoed et al., 2012; Assad et al., 2013), SOC stocks gains (Brown and Lugo, 1990; Franzluebbers et al., 2000; Tate et al., 2000; Assad et al., 2013), or even no significant change in the SOC stocks (Hoogmoed et al., 2012; Cunningham et al., 2015). In the case of the conversion of forest into pasture, the management system is a strong factor determining losses or gains of carbon (Carvalho et al., 2010), well-managed pastures may increase SOC stocks, while poorly managed pastures may decrease it (Guo and Gifford, 2002; Braz et al., 2013).

The reforestation of riparian zones represents an important opportunity for carbon sequestration and the mitigation of climate change in Brazil, as these restorations are mandatory under the Forest Code. The goal of this study is to contribute with the discussion about the role of riparian forests in the mitigation of climate change. In order to achieve this goal, we compare the SOC stocks of forested riparian areas with the SOC of agricultural areas, mainly pasture and sugarcane. We hypothesized that SOC stocks will be larger in riparian forest soils, compared with pasture and sugarcane.

2. METHODS

2.1. Study area

The study was held in the Corumbataí River basin, located in the central region of the State of São Paulo, in Southeast Brazil (Figure 1). This basin covers an area of approximately 1700 km² and its main land covers and uses are native forests, pastures and sugarcane crops, representing well the predominant land cover/use in the State of São Paulo. Along with that, the main reason for the choice of this study area was that collaborators from the Forest Sciences Department of Escola Superior de Agricultura Luiz de Queiroz had an accurate mapping through geographical information systems (GIS) of several sub-watersheds of the Corumbataí basin, what allowed the estimation of the riparian and land cover/use areas. The climate is classified as Cwa, or subtropical, with dry winter and wet summer, according to the Köppen classification. The annual rainfall varies from 1300 to 1500 mm (Valente, 2001), and the annual mean temperature is of 21.3°C (Schuler et al., 2000).

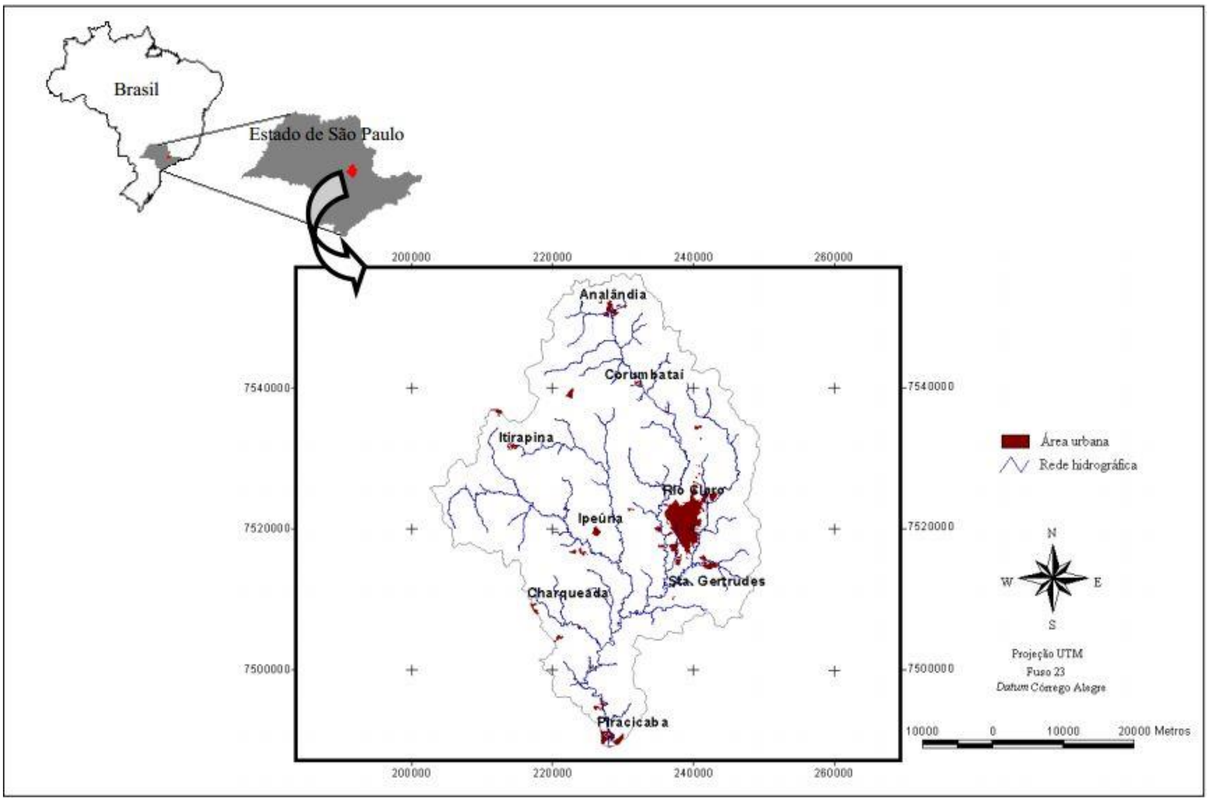
Originally the landscape of the basin was composed by different forestland formations and savannahs (Rodrigues, 1999). The Coffee boom started in the early 19th century and promoted the substitution of the original vegetation of the State of São Paulo by coffee and subsistence crops, with the use of European immigrant workforce (Young, 2001). In 1929, the Great Depression caused enormous international instability and a big decline in coffee prices what induced the substitution of coffee crops by pastureland and cattle raising (Mori et al., 2016). And the most recent trend was the expansion of sugarcane for sugar and ethanol production over those pastures and other crops, in the mid 1950's (Adami et al., 2012).

The high economic growth brought by the agribusiness and its cycles to the State of São Paulo, and more specifically to the Corumbataí basin, was coupled with the devastation of the original vegetation of the region (Del Grande et al., 2003). Nowadays, the remnant forests are restricted to degraded and small fragments isolated in steep-slope terrain and on the margin of waterbodies (Valente, 2005), what in most of the cases, prevent them from providing enough ecosystem services (Cassiano, 2013). However, Cassiano (2013) identified an increment in the forested area of the Corumbataí basin in the last years, and emphasizes that more studies are needed to determine whether the regeneration rates are going to stabilize or increase.

The pastures in the Corumbataí basin are formed with one single grass, generally of the genus Brachiaria and Panicum, as is common in all Brazilian territory (Guarda and Guarda 2014). Managed and degraded pastures were sampled in this study, to represent the average conditions of the pastures of the region. Degraded pastures with small productivity and natural capacity to recover and sustain production were less common, while pastures typically managed with liming, fertilizers and renewal of pastures periodically, were frequently found. The timespans between the application of these inputs and reform of the pastures are virtually unknown for the region, along with the amounts and types of agricultural inputs used.

Sugarcane crops are planted in contour with 1.3 to 1.5 m of row spacing. After the harvest the inter-rows are plowed, and the ratoons are preserved to allow the regrowth of the harvested plants. There is a frequent use of agrochemicals. Limestone and chemical and organic fertilizers are applied annually. The sugarcane harvest in the state of São Paulo has always been done manually, due to the declivity of the relief. This used to cause a great environmental problem as the field was burned to remove the leaves and facilitate the harvest. However, that practice was banned in the state in 2012 and since then the harvest practices have been being converted to mechanical ones, with the use of heavy machinery (Gomes 2017).

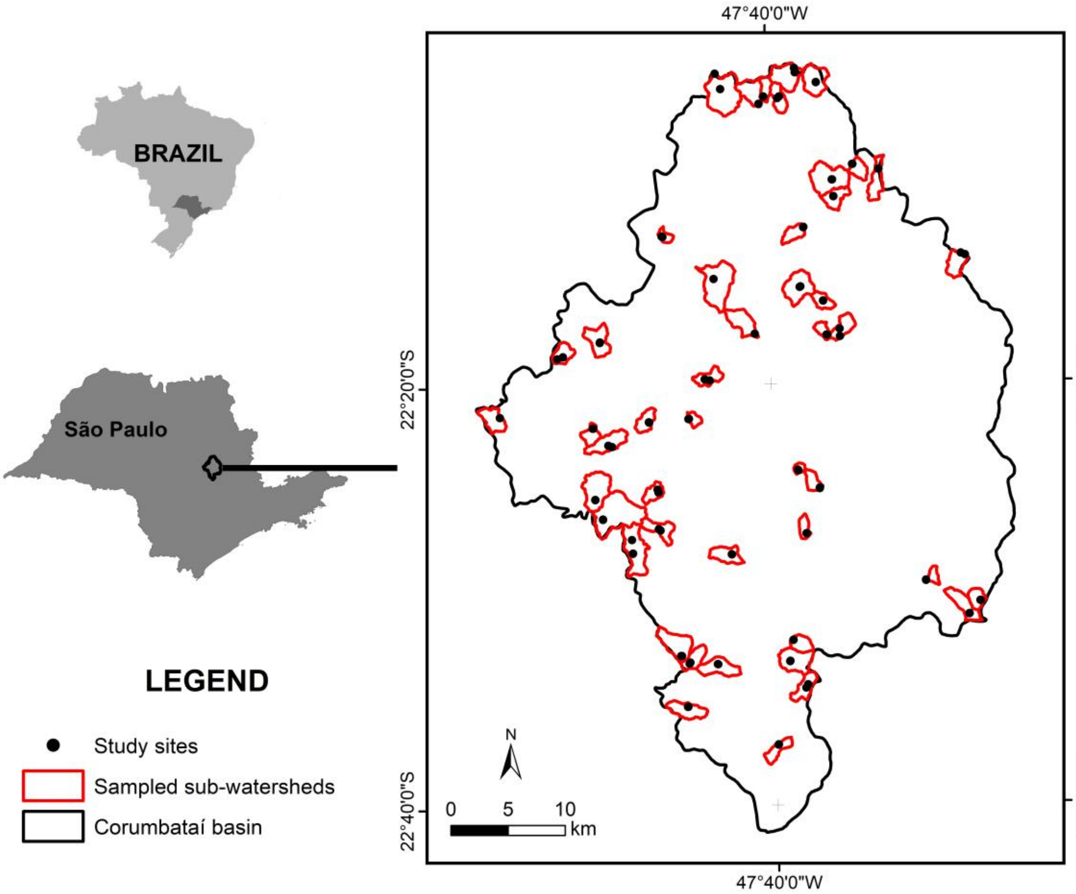
Figure 1 – Corumbataí basin location under São Paulo state's and Brazil's perspective. Adapted from (Valente, 2001)



2.2. Study sites and sampling

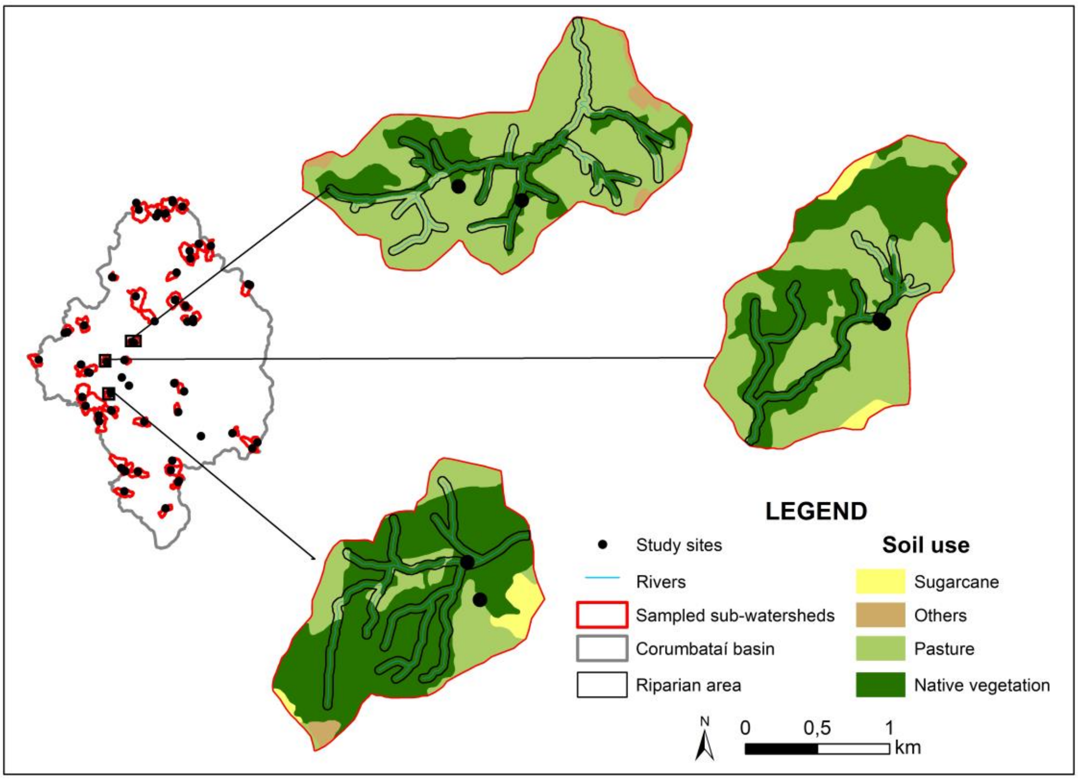
Sixty sub-watersheds with an average area of approximately 20 km^2 were selected as study areas, because they were already mapped by collaborators as already mentioned. We couldn't get the access to all those areas either because we found the gates of the properties locked, and the absence of the landlords, or because we had our entry denied. Therefore, we ended by collecting only 40 of the 60 original sub-watersheds. Hence, we selected more sub-watersheds through satellite imaging to increase our sampling effort and ended with 50 sub-watersheds sampled (Figure 2). The field expeditions started at August 2016 and ended at August 2017.

Figure 2 – Location of the fifty sub-watersheds sampled and the study sites in the context of the Corumbataí basin, the São Paulo state and Brazil



In each of the sub-watersheds, soil from a native forest, and from an agricultural use (pasture or sugarcane) next to it, were collected (Figure 3). Hence, there were 30 sub-watersheds in which we collected soil from a riparian forest and from a pasture next or close to it, and there were 20 sub-watersheds that we collected soil from a riparian forest and from a sugarcane crop next or close to it. We collected two land uses in each sub-watershed, not three. The selection of each study site within the sub-watersheds was based on the GPS coordinates, on the accessibility by car or by foot and on the existence of a riparian forested area. Once at the collection site we walked the furthest we could inside of it (forest, pasture or sugarcane) to avoid the effect of the edges. Firstly, we collected the samples for chemical and isotopic analysis with an auger at the depth of 0-30 cm, as is recommended by the $IPCC_{2006}$ Guidelines, divided in the 0-10 cm, 10-20 cm and 20-30 cm depth intervals. The organic horizons were removed, so just the mineral soil could be collected. The excess soil was removed from the auger with a knife at each collection, and we never touched the samples with bare hands, to avoid contamination. Since there is a higher variability in carbon concentrations in the upper layers of the soil (0-10 cm) (Schöning et al., 2006; Don et al., 2007), four sub-samples were collected at that depth interval to compose one representative sample of it. We chose randomly four spots to get the 0-10 cm samples, and then mixed them inside a plastic bag. In the other two depth intervals only one sample was collected by land cover.

Figure 3 – Example of the land uses of three sampled sub-watersheds in the context of the Corumbataí basin, with the riparian area (30 m buffer) and study sites included



Right beside the first sampling spot we collected soil samples for density determination. We cleaned the litter and grasses to expose the mineral soil, and then pressed a metal ring (104 cm^3) into the soil and determined the bulk density by the weight collected in that known volume, afterwards. In the same spot we opened a hole of 10 cm depth with a post-hole digger and collected the 10-20 cm density sample. The same operation was done for the 20-30 cm sample. Those samples were stored in plastic bags for posterior oven-drying and weighing at the lab. In the moment we arrived with the samples in the lab, the plastic bags were left opened in a counter to lose humidity. After one day all the samples were put into the ovens.

Six hundred samples were collected, among the ones for bulk density and for chemical analysis, considering the two land uses (forest and pasture/sugarcane) for each sub-watershed and three depth intervals (0-10, 10-20, 20-30 cm). The initial plan was to collect at four equidistant spots in each land use of each sub-watershed. Considering the 50 sub-watersheds, the two land uses sampled in each of them and the 6 soil samples collected in each sampling spot (chemical and density; three depths), 2400 samples would have to be collected. Hence this sampling scheme had to be replaced due to time and financial constraints.

2.3. Chemical and isotopic analysis

The soil samples for chemical analysis were dry-out at 60° C for 4 days. After dried, soil samples were crushed to break big aggregates. Then, they were passed through a soil splitter repeatedly, until samples were homogenized, and enough mass was obtained for analysis. The remaining soil was stored for the texture and fertility analysis. The aliquot was sieved (0.25 mm). The “contaminants” like small roots, charcoals and stones were picked up from the material that couldn’t pass by the sieve, and the small aggregates were smashed with a mortar and a pestle. After this, the remnant material was sieved again, and the operation was repeated until samples were free from any “contaminant”. A small amount of this sample was weighed and introduced into a tin capsule to be analyzed by the elemental analyzer (Carlo Erba model 1110, Milan, Italy) and the mass spectrometer (IRMS Delta Plus; Finnigan Mat, San Jose, CA, US), which determined C and N concentrations and the natural isotopic ratio of $^{13}C/^{12}C$, according with the following equation:

$$\delta^{13}C = (R_{sample} / R_{standard} - 1) \times 1000 \quad (1)$$

Where, R is the molar ratio between ^{13}C and ^{12}C in the sample and in the standard (Peedee Belemnite; limestone of the Grand Canyon region, USA).

Based on the isotopic data, the C_3-plants and C_4-plants percent contributions to the soil carbon mass were calculated according to the following mixture model:

$$C_{4p} = \frac{\delta^{13}C_{soil} - \delta^{13}C_{C_3}}{\delta^{13}C_{C_4} - \delta^{13}C_{C_3}} \qquad (2)$$

Where C_{4p} is the proportion of C_4 plants, $\delta^{13}C_{soil}$ is the carbon isotopic composition of the soil's organic matter; $\delta^{13}C_{C_3}$ (-27.2‰) is the carbon isotopic composition of the C_3 source (Martinelli et al., 1996), and the $\delta^{13}C_{C_4}$ (-12‰) is the carbon isotopic composition of the C_4 source (Smith and Epstein, 1971; Assad et al., 2013).

2.4. Bulk density and carbon stocks

The soil collected with the density rings were oven-dried for 24 to 48 hours at 105º C to constant weight and weighed for the determination of the bulk density, based on the volume of the cylinder (104 cm^3), as described by the volumetric ring method (Embrapa, 1997). The soil carbon stocks are expressed in $Mg.ha^{-1}$ and calculated for the 0-10; 10-20; 20-30 cm depth intervals, according to the method described in Ellert et al. (2008), with the following equation:

$$\boldsymbol{SOC_{FD}} = \sum_{o}^{n} \boldsymbol{M_{soil}} \cdot [\boldsymbol{C}] \qquad (3)$$

Where SOC_{FD} is the soil carbon stock for fixed depths, M_{soil} is the mass found in the depth interval, and [C] is the carbon concentration of the soil in the same depth interval.

2.5. Soil organic carbon stocks correction

The total SOC stock (0-30 cm) of the different land uses (forest, pasture or sugarcane) were corrected based on a fixed mass to avoid the effect of different soil bulk densities, caused by the land use, in its comparison. Thus, the lowest soil masses of each depth interval were selected (M_{ref}) and the excess soil masses (M_{ex}) were calculated according to the following equation:

$$M_{ex} = M_{soil} - M_{ref} \tag{4}$$

And for each land use the soil carbon stock for fixed mass was corrected according to the following equation:

$$SOC_{FM} = SOC_{FD} - M_{ex} \cdot [C_s] \tag{5}$$

Where the SOC_{FM} is the cumulative soil carbon stock for a fixed mass, and $[C_s]$ is the soil carbon concentration of the densest soil layer (M_{soil}).

We will call this described correction method as the Equivalent Soil Mass method (ESM). An alternative method was also done to be compared with the first one, we will name it Equivalent Forest Soil Mass (ESM-F). It takes always the mass of the forest layers as reference, according to the following equations:

$$M_{ex} = M_{agriculture} - M_{forest} \tag{6}$$

Where M_{forest} is the mass of the forest soil layer correspondent to $M_{agriculture}$, which is the mass of the agricultural use (pasture or sugarcane) soil layer. M_{ex} is the excess soil mass which will be used in the next equation.

$$SOC_{FM} = SOC_{FD} - M_{ex} \cdot [C_a] \tag{7}$$

Where the SOC_{FM} is the cumulative soil carbon stock for a fixed mass, and $[C_a]$ is the soil carbon concentration of the agricultural use soil layer ($M_{agriculture}$).

2.6. Chemical and granulometric analysis

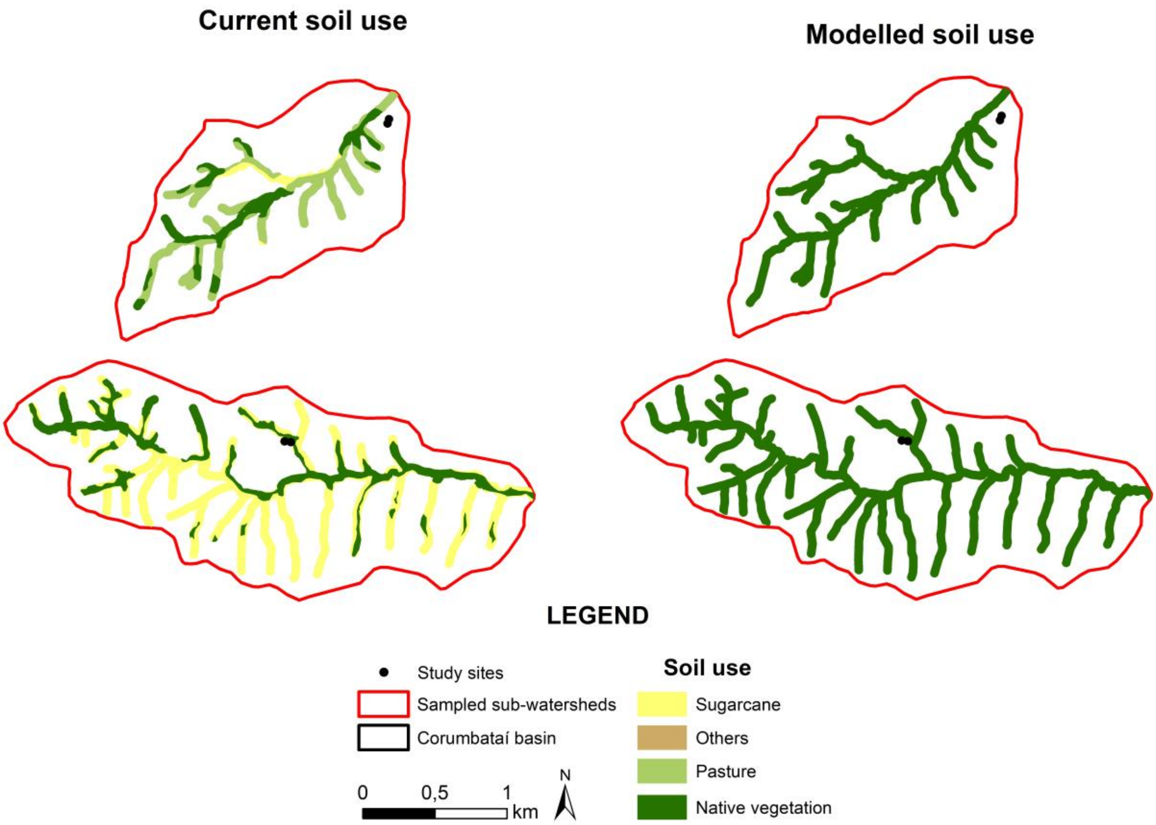
The chemical analysis was done following van Raij et al. (2001). The aluminum was extracted with KCl and determined by titration; phosphorus was extracted with ionic exchange resin and determined by the molybdenum blue method; potassium was determined by photoelectric flame photometry; calcium and magnesium were determined by spectrophotometry; pH in $CaCl_2$ was determined by potentiometry; total acidity (H + Al) was determined by potentiometry, with the use of a SMP buffer solution; organic matter was extracted with sulfuric acid and sodium dichromate and determined by colorimetry; the total exchangeable bases (EB) are the sum of the Ca, Mg, K and Na content; the cation exchange capacity (CEC) is the sum of the exchangeable bases and the total acidity; V% is calculated by the following equation: 100 x (EB/CEC). The soil texture was determined following Camargo et al. (2009) by the pipette method, with 16h of agitation.

All those analyses were made in a private soil analysis laboratory called Pirasolo in the city Piracicaba – Brazil, which is certified by the Agronomical Institute of Campinas (IAC).

2.7. Riparian SOC stock after reforestation estimation

The total riparian area (30 m from stream margin) of the basin was obtained by geographic information system (GIS), with the software ArcGIS version 10.4 (ESRI, 2015), as well as the area of each land use (forest, pasture and sugarcane) in the study area. It was estimated the SOC stock of the total study area, which is the sum of the riparian area (30 m buffer) of all the 50 sub-watersheds, based on the median SOC stock of each land use and their land cover, and the amount of SOC that would be found in the soil if the riparian zones (30 m buffer) of the basin were totally reforested, based on the median SOC stock of the native forest areas and the total study area. The median SOC stocks of the land uses were used because the data haven't showed normality, and in this case the median represents better the stock under different land uses behavior than the mean. The difference between those estimates will indicate if there would be a gain or loss of carbon with the land use change proposed (Figure 4).

Figure 4 – Two sampled subwatersheds were selected to serve as example of the change in the land use of their riparian zones (30 m buffer) that is proposed in this study



2.8. Statistics

The normality of the data was assessed with the Shapiro-Wilk test. The ANOVA variance analysis was performed to identify differences in relation to the variable averages of the three land uses (forest, pasture and sugarcane). The Tukey test was done in order to compare the averages in pairs and determine the statistical differences among land uses.

The controls of the soil carbon stocks were modelled by the adoption of the Generalized Linear Models (GLM) methodology because the soil organic carbon stock data were not normal and followed the step-wise methodology. The GLM ensures the flexibility and modelling capacity required in this study. All tests were taken at a significance level of 5% and executed in the R software version 3.5.0.

3. RESULTS

3.1. Texture, fertility and soil carbon concentration

Overall the soils of the riparian zones of the Corumbataí basin were sandy, with an average sand content of 710 g/kg, and average contents of clay of 213 g/kg, and of silt of 77 g/kg.

Pastures had the highest sand content, forests had intermediate values, while sugarcane showed the lowest sand content ($p<0.05$). As expected, the opposite occurred with clay content with sugarcane soils showing the highest values, forest still being the intermediate and pastures with the lowest clay content ($p<0.05$). Forest and sugarcane soils had no difference in silt content, while pasture showed the lowest average ($p<0.05$) (Table 1 - **Average sand, clay and silt content by depth interval and land use**

Table 1 - Average sand, clay and silt content by depth interval and land use

Land use	Depth interval (cm)	Sand (g/kg)	Clay (g/kg)	Silt (g/kg)
Forest	0-10	703 ±33	213 ±20	85 ±15
	10-20	702 ±34	211 ±21	86 ±15
	20-30	693 ±35	219 ±22	88 ±16
	0-30	699 ±20	214 ±12	86 ±9
Pasture	0-10	786 ±37	157 ±21	56 ±18
	10-20	800 ±37	152 ±22	49 ±16
	20-30	798 ±37	151 ±23	50 ±16
	0-30	795 ±21	154 ±12	52 ±9
Sugarcane	0-10	614 ±52	293 ±35	93 ±23
	10-20	613 ±53	298 ±36	89 ±23
	20-30	609 ±52	303 ±37	88 ±22
	0-30	612 ±30	298 ±21	90 ±13

Sugarcane soils had the highest pH in $CaCl_2$, followed by pastures and forests with the lowest values ($p<0.05$), but overall all of them are considered acidic soils, as is common for weathered tropical soils (Latifah et al., 2018). The average forest soil organic matter content was higher than the pasture and sugarcane ones ($p<0.05$), which haven't had statistical difference ($p<0.05$). There was no P content difference among land uses ($p>0.05$), although the sugarcane soils presented higher values (Table 2).

There was no exchangeable bases difference among land uses ($p>0.05$), but there was cation exchange capacity difference. Forest presented higher values than pasture and sugarcane ($p<0.05$), that haven't had difference between them ($p>0.05$).

Table 2 - Average values and standard error of the fertility variables by depth interval and land use

Land use	Depth interval (cm)	pH $CaCl_2$	Organic matter (g/dm^3)	P (mg/dm^3)	Exchangeable bases (mmolc/dm3)	CEC ($mmol_c/dm^3$)
Forest	0-10	4.5 ±0.1	27 ±2	12 ±1	36 ±5	93 ±6
	10-20	4.4 ±0.1	22 ±2	9 ±1	29 ±5	90 ±6
	20-30	4.3 ±0.1	18 ±2	7 ±1	25 ±4	87 ±6
Pasture	0-10	4.7 ±0.1	18 ±2	12 ±4	26 ±4	63 ±5
	10-20	4.7 ±0.1	14 ±2	11 ±4	25 ±5	63 ±7
	20-30	4.6 ±0.1	12 ±2	9 ±4	24 ±5	66 ±8
Sugarcane	0-10	5.0 ±0.2	15 ±2	15 ±2	33 ±5	70 ±8
	10-20	5.1 ±0.2	14 ±2	13 ±3	34 ±6	69 ±9
	20-30	5.0 ±0.2	12 ±1	10 ±2	32 ±7	66 ±8

The average soil carbon concentration of riparian forests was higher than the averages for pasture and sugarcane ($p<0.05$), which haven't had statistical difference ($p>0.05$).

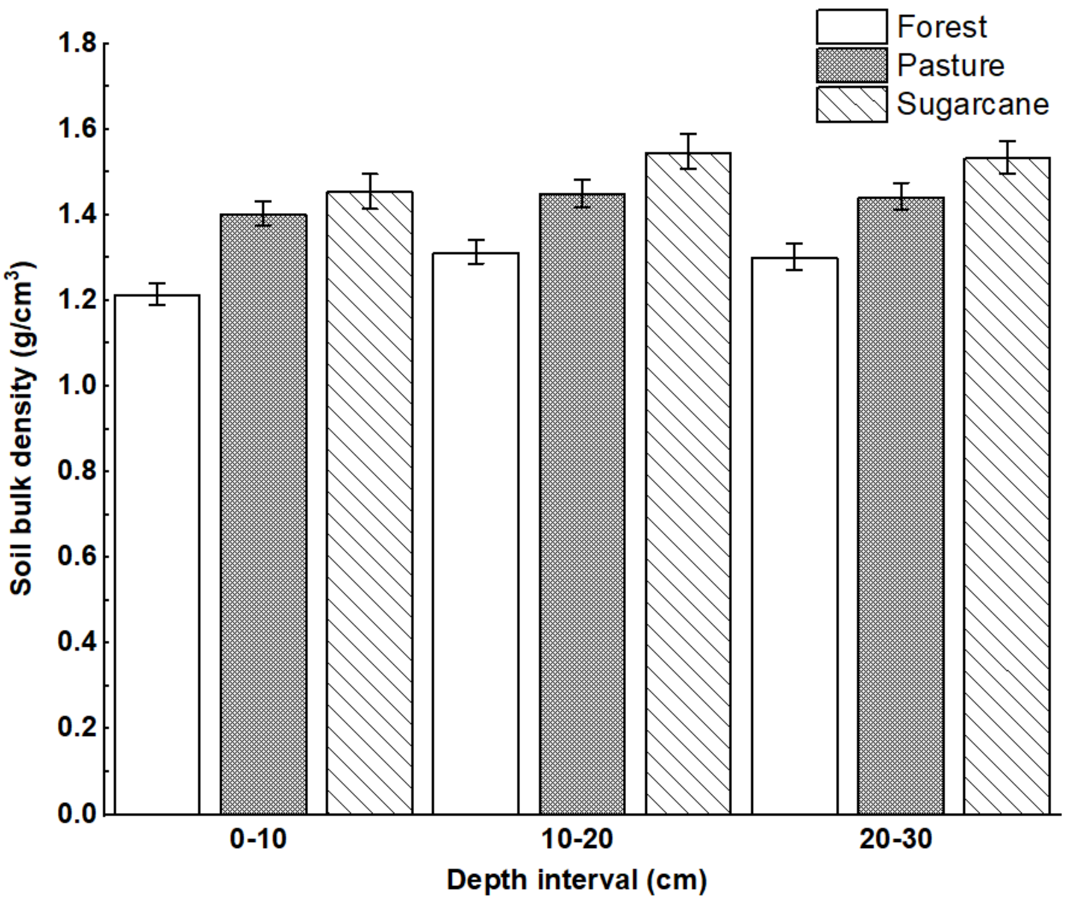
Table 3 - Average soil carbon concentration (%) by depth interval and soil use

Land use	Depth (cm)	Soil carbon concentration (%)
Forest	0-10	1.5 ±0.1
	10-20	1.3 ±0.1
	20-30	1.1 ±0.1
Pasture	0-10	0.9 ±0.2
	10-20	0.7 ±0.2
	20-30	0.7 ±0.2
Sugarcane	0-10	0.8 ±0.1
	10-20	0.8 ±0.1
	20-30	0.7 ±0.1

3.2. Soil bulk density, SOC stock and N stock variation of the different land uses

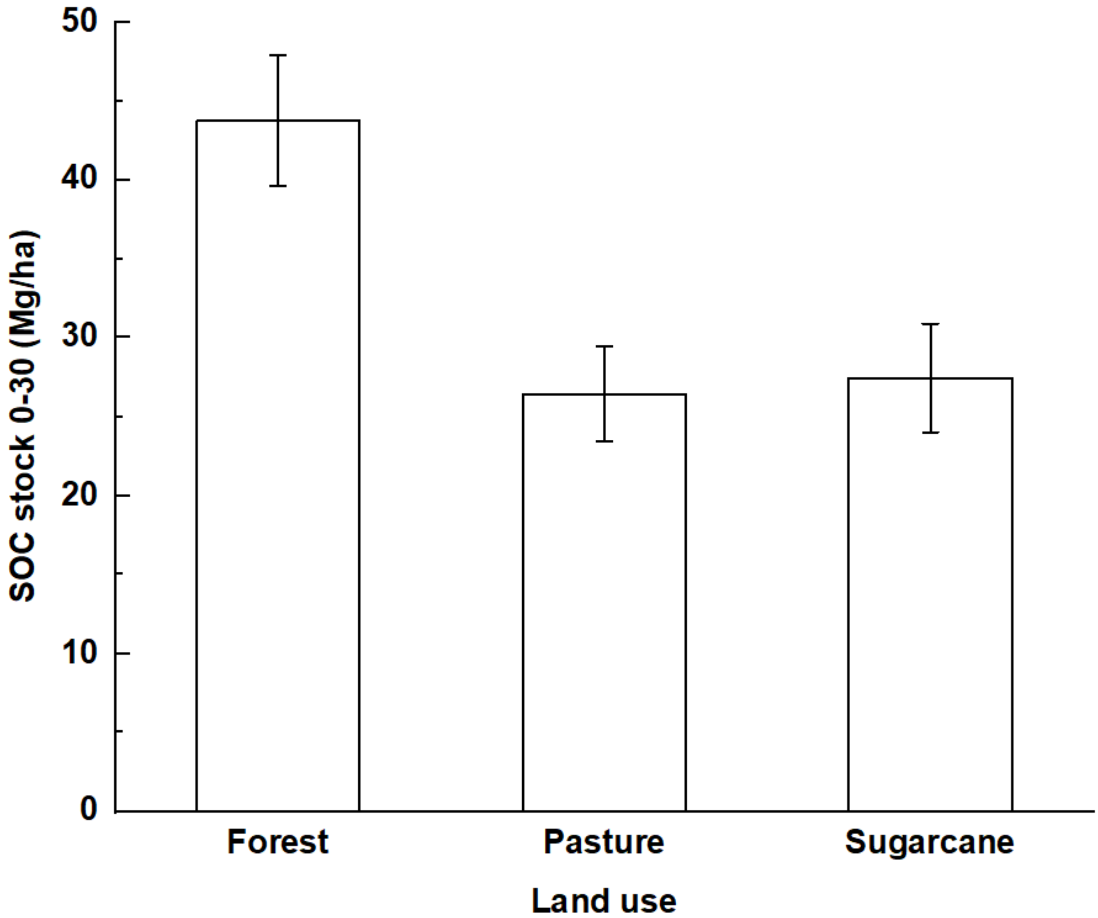
Forest, sugarcane and pasture bulk density averages were different ($p<0.05$), with sugarcane having the highest values, meaning that sugarcane areas were more compacted, as their sand content were the lowest, followed by pasture and finally forests, the least compacted soils (Figure 5).

Figure 5 – Average soil bulk densities and standard error of the three depth intervals (0-10 cm; 10-20 cm; 20-30 cm) for the three land uses (forest, pasture, sugarcane)



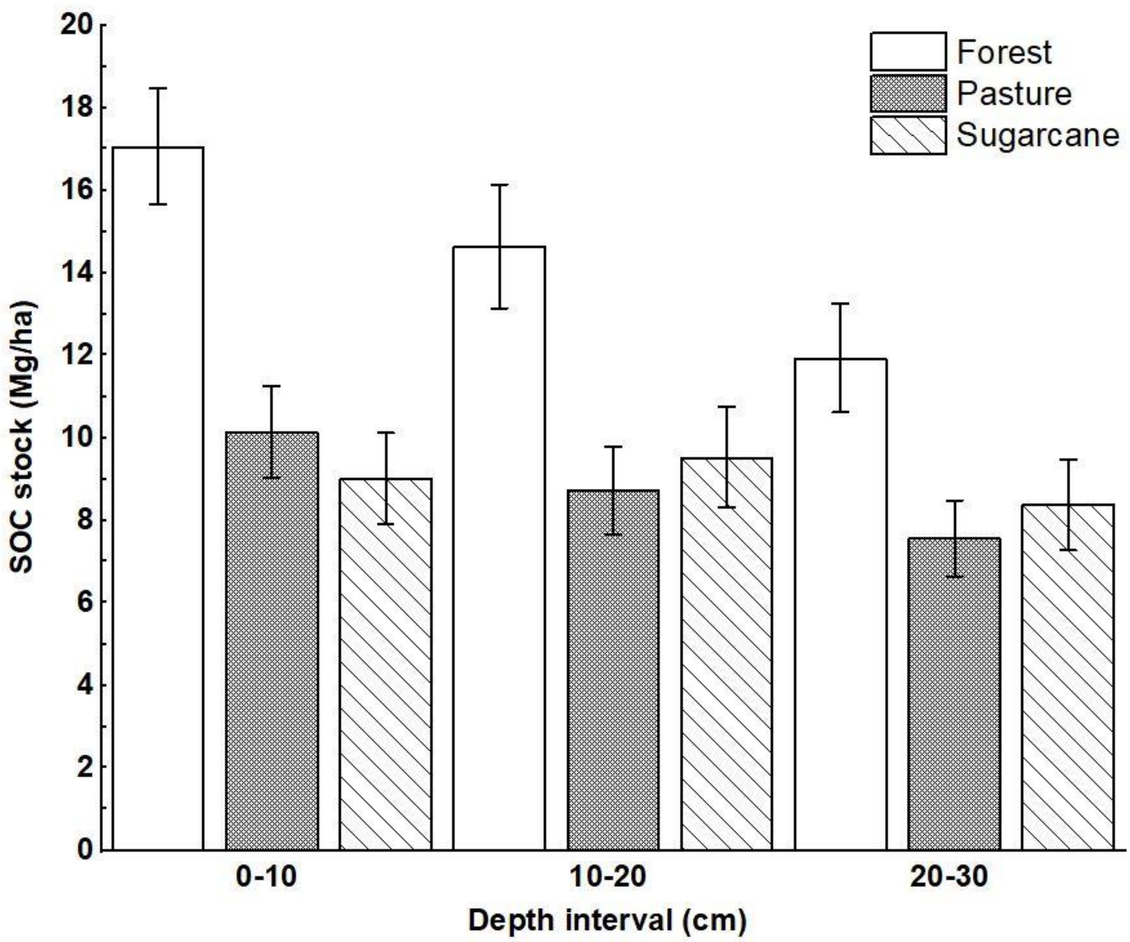
SOC stocks (0-30 cm) were higher in forest areas, reaching in average 44 $Mg.ha^{-1}$, followed by 27 $Mg.ha^{-1}$ in sugarcane and 26 $Mg.ha^{-1}$ in pastures (Figure 6). Pasture and sugarcane had no statistical difference between than ($p>0.05$) but were different than forest soils ($p<0.05$).

Figure 6 – Average soil carbon stocks (0-30 cm) and standard error of riparian forests, pastures and sugarcane



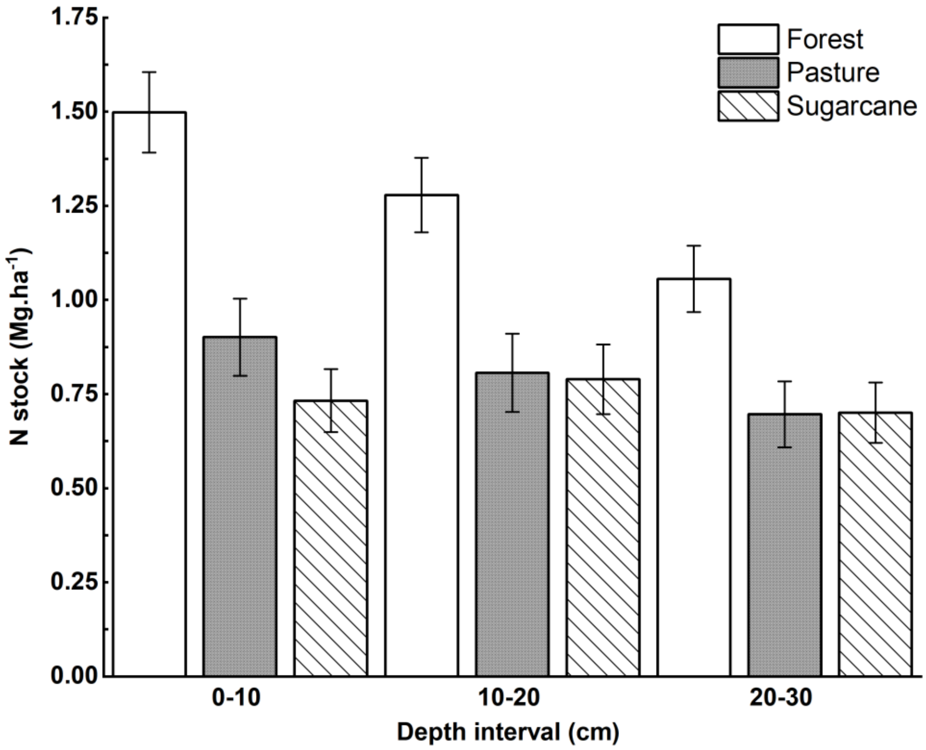
The average SOC stocks for each soil layer of the three land covers area shown in Figure 7. The forest areas had the largest stocks in every depth interval and decreased from 17 $Mg.ha^{-1}$ (0-10 cm) and 15 $Mg.ha^{-1}$ (10-20 cm) to 12 $Mg.ha^{-1}$ (20-30 cm). Pastures also showed this trend of decreasing the SOC stocks along the profile going from 10 Mg.ha-1 (0-10 cm) and 9 $Mg.ha^{-1}$ (10-20 cm) to 8 $Mg.ha^{-1}$ (20-30 cm), but this trend couldn't be observed in sugarcane as its stocks were of 9 $Mg.ha^{-1}$ (0-10 cm), 10 $Mg.ha^{-1}$ (10-20 cm) and 8 $Mg.ha^{-1}$ (20-30 cm).

Figure 7 - Average soil organic carbon (SOC) stocks and standard error of the three depth intervals (0-10 cm; 10-20 cm; 20-30 cm) for the three land uses (forest, pasture, sugarcane)



The average forest N stock was higher than the N stocks of pasture and sugarcane (p<0.05), which haven't had statistical difference between them (p>0.05) (Figure 8).

Figure 8 - Average N stock (%) and standard error of the three depth intervals (0-10 cm; 10-20 cm; 20-30 cm) for the three land uses (forest, pasture, sugarcane)



3.3. Controls of soil carbon stocks

Soil organic carbon stocks are influenced by many variables like temperature, rainfall, soil texture, soil cover and soil density (Sollins et al., 1996; Jobbágy and Jackson, 2000; Eclesia et al., 2012; Saiz et al., 2012; Doetterl et al., 2015). This study was carried out in a drainage basin; therefore, factors like temperature and rainfall haven't varied through the sample sites. So we adjusted an equation with the main soil properties that control soil carbon stocks, based on previous studies (Jobbágy and Jackson, 2000; Saiz et al., 2012; Assad et al., 2013; Doetterl et al., 2015). The soil cover (forest, pasture or sugarcane) and the soil clay content (g/kg) were selected to determine the SOC_{0-30} ($Mg.ha^{-1}$). The adjusted correlation coefficient (r^2) for carbon stocks (0-30 cm) was of 48%, indicating a reasonable capacity to explain the data variability.

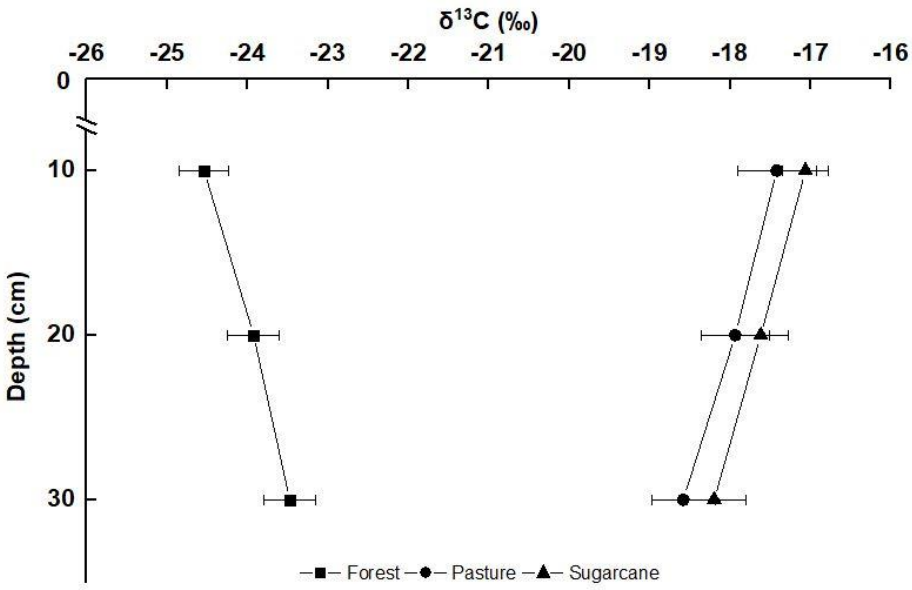
$$SOC_{0\text{-}30} = 20.31 - 11.04*Pasture - 26{,}07*Sugarcane + 0{,}11*Clay \qquad (8)$$

The $SOC_{0\text{-}30}$ decreases in 11.04 if the soil cover is pasture, and in 26.07 if the land cover is sugarcane, in relation to the forest soil cover. The $SOC_{0\text{-}30}$ increases in 0.11 for each extra clay content unit. The residuals were normally distributed, indicating that the adjusted model was appropriate.

3.4. Isotopic analysis

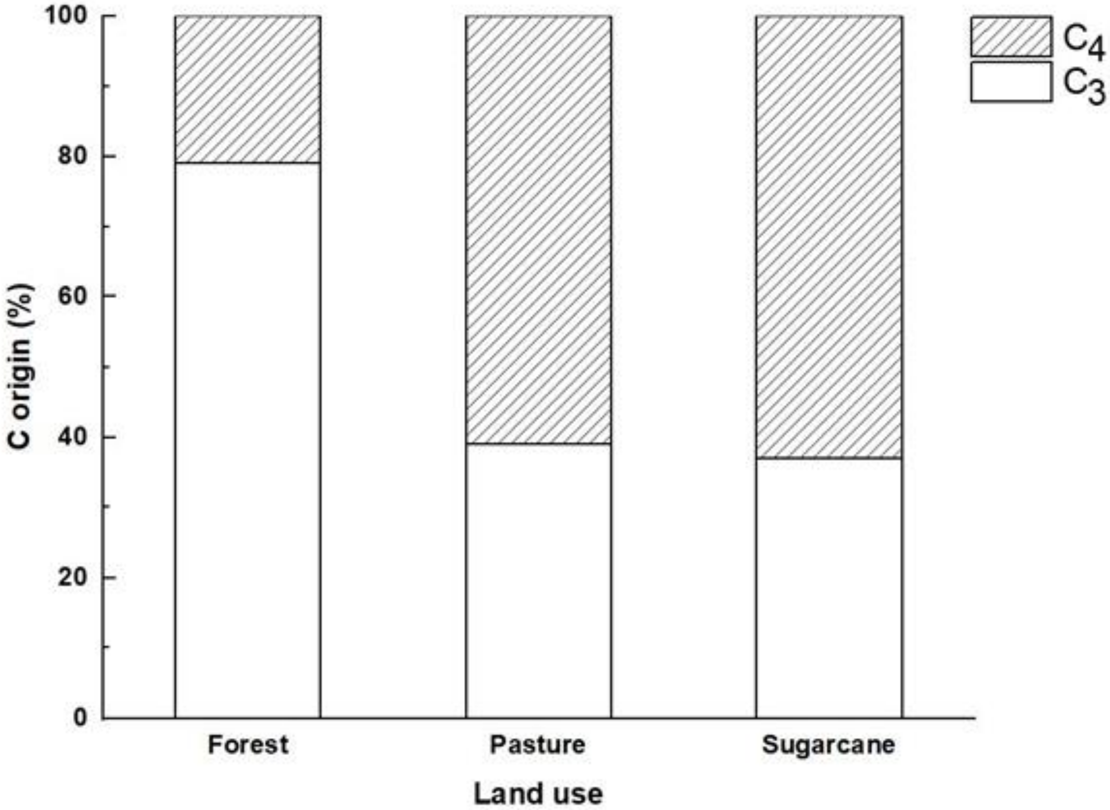
The average $\delta^{13}C$ of the riparian forest soils were of -24.5‰ (0-10 cm), -23.9‰ (10-20 cm) and 23.5‰ (20-30 cm), much smaller than the values for pasture, that were of -17.4‰ (0-10 cm), -18‰ (10-20 cm) and -18.6‰ (20-30 cm), and for sugarcane, that were of -17‰ (0-10 cm), -17.6‰ (10-20 cm) and -18.2‰ (20-30 cm) ($p<0.05$). The average $\delta^{13}C$ of the pasture and sugarcane areas were very similar ($p>0.05$), and decreased at similar rates along the profile, while the forest soils had an enrichment in $\delta^{13}C$ along the profile (Figure 9).

Figure 9 - Average and standard error (bars) of $\delta^{13}C$ of soil organic matter with soil depth of riparian forests, pastures and sugarcane areas collected in fifty small sub-basins of the Corumbataí River basin



For the whole soil profile (0-30 cm) forest areas had an average C_3 carbon contribution in its profiles of 79%, and C_4 carbon contribution of 21%, while pasture and sugarcane areas had 39 and 37% of C_3 carbon, and 61 and 63% of C_4 carbon, respectively. As showed in Figure 9, the $\delta^{13}C$ of the forest areas were lower than pasture and sugarcane, which had very similar values, so the same pattern is observed in the mixture model results (Figure 10).

Figure 10 – Average percent of C_3 and C_4 carbon for each land use for the 0-30 cm depth interval



3.5. Riparian SOC stock after reforestation estimation

We assumed as the total riparian area as the sum of the 30 m riparian buffer established by the Brazilian Forest Code for all the streams of the 50 sub-watersheds sampled here, which gives an area of 2,300 ha. The area covered with forests, pastures and sugarcane crops comprises 97% of the total riparian area, and were equivalent to 1,470, 560 and 200 ha, respectively. The total SOC stock for each land use were calculated by the product of their areas (ha) with their median SOC stocks ($Mg.ha^{-1}$; 0-30 cm), and were equal to 60,300, 11,600 and 4,500 Mg of C for forest, pasture and sugarcane, respectively. The sum of those stocks is the estimate current total SOC stock of the total riparian area, which is equal to 76,500 Mg of C, being 79 % from forests, 15 % from pastures and 6 % from sugarcane crops.

The estimate of the SOC stock that would occur if the total study area were constituted of riparian forests is the product of the median SOC stock of the forests ($Mg.ha^{-1}$) with the total riparian area (ha), being equal to 91,600 Mg of C; therefore 15,100 Mg of C higher than the actual use, representing an SOC stock increase of 20%.

4. DISCUSSION

4.1. Texture and fertility analysis

The soils of the Corumbataí basin are mainly sandy, as was confirmed by the average of sand, silt and clay content. Pasture areas were the ones with the highest sand content, while sugarcane areas had the lowest. This can be due to the decision of farmers in using the best soils for more intensive crops, like sugarcane, that also had the highest clay content among land uses. As expected, the organic matter content results followed the SOC stocks ones. Forest soils showed the highest organic matter content and also the highest SOC stocks, in comparison with pastures and sugarcane that were lower and with no difference between them ($p>0.05$).

Sugarcane soils had the highest pH (in $CaCl_2$), pastures had intermediate values and forest soils had the lowest. The soils of the region are commonly weathered and acidic; thus, farmers need to improve their fertility with lime application. That's a common practice in sugarcane crops, made in an annual base, and in well managed pastures. Exchangeable bases land use averages had no difference as well ($p>0.05$), but there was in the cation exchange capacity (CEC). Pasture and sugarcane haven't had any difference, while forests showed the highest values ($p<0.05$). Liming precipitates Al, taking it off the soil solution and decreasing CEC values while maintaining the exchangeable bases levels. Although sugarcane soils showed the highest P content, as was expected because of the frequent input of phosphate fertilizers and lime, there was no statistical difference of the P content averages among land uses ($p>0.05$).

4.2. SOC stocks correction

The correction for density, generally decreases the SOC stocks in agricultural lands , as those tend to promote soil compaction by cattle grazing, in the case of pastures, and heavy machinery traffic, in the case of sugarcane crops, what causes an overestimation of the SOC stocks of those land uses, when comparing with the native vegetation. Here, we compared the effects of soil density corrections on SOC stocks (Table 4).

The ESM method used the least compacted layer as reference independently of the land use, therefore, stocks of both the native vegetation and the agricultural are simultaneously adjusted, slightly decreasing forest stocks, as in most cases agricultural soils were more compacted. The ESM-F method used always the forest layer as reference, therefore, it kept the SOC stocks of the native vegetation unchanged and adjusted the values for pasture and sugarcane. Regardless the use of one method or the other, or in absence of any correction, the SOC stocks were always higher in the native vegetation (Table 4).

Table 4 - Different SOC stocks corrections for land use comparisons

	Average SOC stocks ($Mg.ha^{-1}$; 0-30 cm)		
	No correction	**ESM**	**ESM-F**
Forest	44	44	44
Pasture	30	26	28
Sugarcane	34	27	28

4.3. SOC stock of the different land uses

As we hypothesized, the SOC stocks of the riparian forest soils were larger than the pasture and sugarcane ones. Forest soils tend to have larger SOC stocks as there are higher litterfall rates, higher moisture, lower soil temperature, better soil aggregation and lower erosion than agricultural soils (Lugo and Brown, 1993; Silver et al., 2000; Lal, 2005). It is important to highlight that sugarcane soils had the highest clay content and the lowest sand content (Table 1), and despite of this, sugarcane soils showed much lower SOC stocks than riparian forests. Taking into account, the model output that considered not only land use, but also soil texture, it seems that the major driver of SOC stocks is land use, and not soil texture.

It is always useful to compare the results obtained in a local scale, with results obtained in a regional scale or from a metanalysis that encompass a large number of studies. In this regard, we compared our results with those of Bernoux et al. (2002), that estimated SOC stocks (0-30 cm) on the basis of a map of different soil-vegetation associations in Brazil and found an average stock of 42 $Mg.ha^{-1}$ for seasonal semi-deciduous forest in non-Latossolos with low activity clay (LAC), which is very similar to the average for riparian forests of this work (44 $Mg.ha^{-1}$). We also compared our results with those of Assad et al. (2013), that found a mean SOC stocks, of 64 $Mg.ha^{-1}$ in soils under native vegetation, and of 52 $Mg.ha^{-1}$, in pasturelands soils. Although these stocks are higher than stocks found here, the same pattern was found, higher stocks in native vegetation than in cultivated land. However, there are cases in which pastureland may have SOC stocks at the same level or even higher than native forests, as the productivity of tropical grasses can be high if well managed (Neill et al., 1996). Besides that, pastures are not cultivated like annual crops, therefore avoiding soil losses by tilling. That could be seen in Assad et al. (2013) that sampled more than 100 pasture soils throughout the main Brazilian biomes, and found SOC stocks , varying from less than 20 $Mg.ha^{-1}$ to more than 100 $Mg.ha^{-1}$.

Finally, it is important to emphasize the fact that as expected, the forest and pasture soils showed a decrease in the average SOC stocks along the profile (Premrov et al., 2017), but this was not the case for the sugarcane areas, probably because those soils are prepared with farming implements periodically, what mixes the layers. There is also the hypothesis that the top soil layers, which contains larger C concentration, had been removed by erosional processes (Youlton et al., 2016), exposing the C depleted sub-soil.

4.4. The origin of the soil organic matter (stable carbon isotope analysis)

The average $\delta^{13}C$ of the forest soils was lower compared to the other land uses (Figure 9). This is an indication that the predominant carbon input in the riparian areas originated from plants that followed the C_3 photosynthetic pathway. There was an average increase of 1‰ in $\delta^{13}C$ along 30 cm of the riparian forest soils. This is probably related to the decomposition of soil organic matter, that causes a discrimination against the heavy isotope (Balesdent et al., 1988), as an evidence of land cover changes in the past would consist in a larger $\delta^{13}C$ increase (Martinelli et al., 1996).

The $\delta^{13}C$ of the pasture and sugarcane soils were similar to each other and denotes a dominance of carbon from plants that follow the C_4 photosynthetic pathway (Figure 9). Nevertheless, there still is a significant presence of C_3-originated carbon in those areas, even in the surface layer. That can be noticed by the average $\delta^{13}C$ of pasture and sugarcane for the 0-10 cm layer, that were of ~-17‰, a value that is lower than the average

$\delta^{13}C$ of C_4-plantas (-12‰) (Smith and Epstein 1971). The $\delta^{13}C$ of pasture and sugarcane keep decreasing until the 30 cm depth (Figure 9), indicating an increasing influence with depth of old carbon with lower $\delta^{13}C$ values originated from the C_3-plants of the forests that were previously present on the areas.

In general, the average contribution of C_3 and C_4-carbon to pasture and sugarcane soils were of ~40% and ~60%, respectively; while in the forest C_3 carbon contributed with more than 80%. As already mentioned, the pasture and sugarcane soils sampled still held remnant carbon from the native forests that were there before, but the forest areas, which are supposed to be remnant riparian forests, had 20% of C_4-carbon contribution (Figure 10). We suggest here that this may be cause by upland erosion that carrier soil particles from pastures and sugarcane crops. Additionally, we also noticed that in some forest areas there was the presence of exotic grasses that are responsible for adding C_4-carbon into these areas.

4.5. Controls of soil carbon stocks

The correlation coefficient of the SOC stocks model explained approximately half of the variance. Interestingly, the coefficient correlation found here was very similar to other studies, although they used different variables than used here (Eclesia et al., 2012). For instance, Assad et al. (2013), also found that half of the soil carbon stocks variance could be explained by mean annual temperature and sand content. However, over larger areas of West Africa, Saiz et al. (2002) found that water availability and sand content explained more than 80% of the SOC variance.

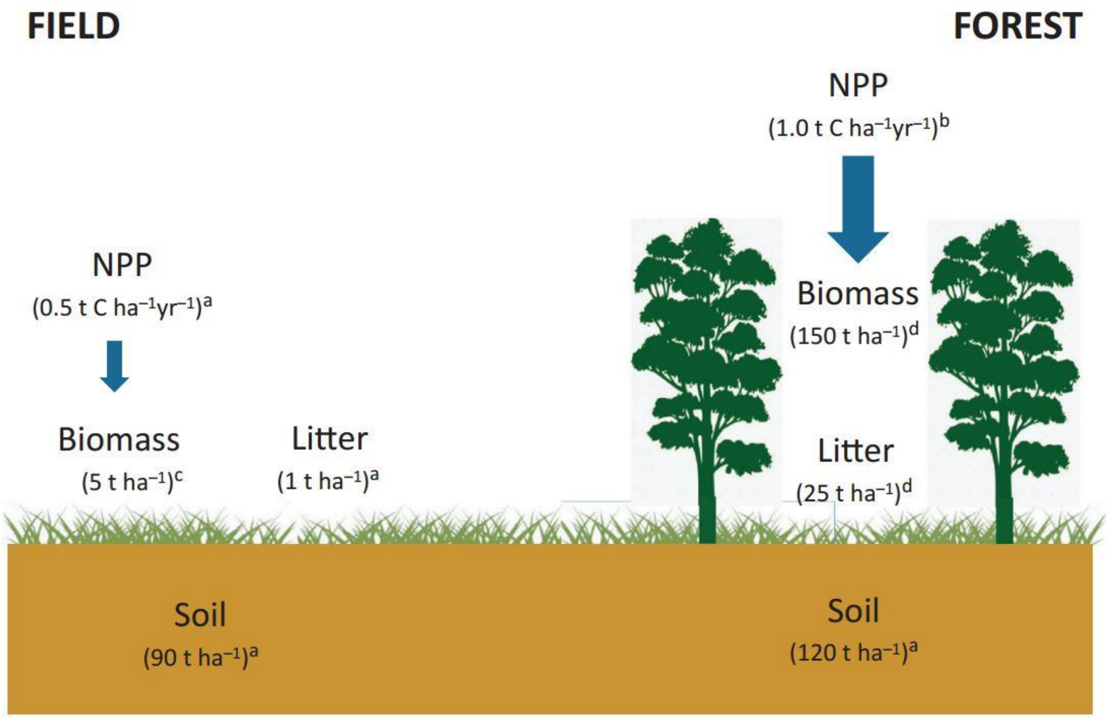
Although only half of the variance was explained in our model, Land use/cover was the most important driver of SOC stocks in our study. Forest soils had larger SOC stocks probably due to greater litterfall rates and lower losses, mainly via soil erosion, than agricultural lands (Lugo and Brown, 1993; Silver et al., 2000; Lal, 2005). The pastureland in riparian zones of the Corumbataí basin are mainly extensive, low-input pastures (Comin, 2013), therefore its lower SOC is probably related to its grass lower productivity (Costa et al., 2009), and higher nutrient export (dos Santos et al., 2015), coupled with soil compaction caused by cattle grazing that increases the chances of erosion (Milne and Haynes, 2004).

Sugarcane sites, on the other hand, that are intensively cultivated showed SOC stocks similar to pastures ones. We hypothesize here that although SOC stocks are similar, the causes that lead to organic matter losses are different. Although sugarcane soils receive all sorts of amendments, sugarcane soils are occasionally prepared by scarification, but are annually prepared by subsoiler and tilling in a cycle of 5 to 7 years (Camilotti et al., 2005), increasing the chances of carbon losses by organic matter oxidation. Additionally, soils are exposed after harvesting, also enhancing decomposition and loss of carbon to the atmosphere, and soil losses by erosion (Pinheiro et al., 2010; Cerri et al., 2011).

4.6. Estimates of SOC stock gains by reforestation of riparian areas according to the Forest Code

The soil carbon gain (20%) with reforestation based on the current median SOC stocks of the remnant riparian forests, demonstrates that by just following the law there would be a considerable increase in ecosystem services in the Corumbataí basin. Figure 11, adapted from Cunningham et al. (2015) shows the estimated net primary production and carbon stocks of the abandoned agricultural land and of the recovered forest, enhancing the notion that reforestation is an important tool for mitigating climate change. The same pattern was observed by Burger et al. (2010) in riparian forests of Northern Victoria, in the Mediterranean region of Australia. They found a carbon content increase of 29% after five years of restoration, and of 45% from the transitional to the remnant forests. Those estimates of soil carbon accumulation in riparian forests restoration are good evidences of their role in the mitigation of climate change.

Figure 11 – Illustration of the potential for carbon sequestration after reforestation of agricultural land based on estimates of the ecosystems carbon sinks. NPP = net primary production. Adapted from: Cunningham et al. (2015)



Organic matter accumulation in soils takes decades ; (Burger et al., 2010; Hoogmoed et al., 2012). Cunningham et al. (2015) found that the increase in the stocks could only be seen after 45 years. A meta-analyses demonstrated that soil C concentration increases only after 30 years (Paul et al., 2002), and another study underscored that there is no significant increase in soil C content in the reforestation of pasture, at all (Laganière et al., 2010).

We propose that soil organic carbon sequestration is, along with the protection of waterbodies and biodiversity, a key ecosystem service provided by riparian forests. Those ecosystems are very important due to all of those benefits they provide to the environment and to mankind, no wonder there is a piece of legislation in Brazil describing how and where they should be protected. Unfortunately the law is not fully fulfilled, what affects the quality and availaility of water in important regions of the country; the protection of species in biodiversity hotspots like the Cerrado and the Atlantic Forest; and the possibility to offset a great part of Brazilian gheenhouse gases emissions.

5. CONCLUSION

The hypothesis made at the introduction was confirmed in this study. Forested soils indeed had higher SOC stocks in comparison with pasture and sugarcane. It is true despite of the soil texture differences between the collection sites, and as all those sites are within the same basin, that cannot be said about the climate influence in the soil carbon accumulation. Based on the estimates of the SOC stocks situation after the reforestation of the riparian zones of the 50 micro-watersheds sampled, we could foresee an accretion of 20% of organic carbon in the 0-30 cm soil layer of those areas. We hypothesized that this would happen, but we knew that is not always the case, as not rarely pastureland and perennial crops presents higher soil carbon content than forestland (Trumbore et al., 1995; Carvalho et al., 2010; Maia et al., 2010; Eclesia et al., 2012; Assad et al., 2013; Braz et al., 2013).

We hope that this work contributes to the understanding of the role of the riparian forests in the mitigation of climate change. These ecosystems are very important for the protection of the watercourses and are protected by law in Brazil. Unfortunately, the law is not sufficient to promote the actual protection of the riparian zones in our country, but as the climate change issue gets greater awareness worldwide, we hope that by including the reforestation of those ecosystems in the mitigation strategies options may highlight the urgency in sparing them from devastation.

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APPENDIXES

Appendix A - Table 5 - Information about the collection sites. Stream order of the riparian zones sampled, which not necessarily is the same zone for the different land uses sampled; agricultural use sampled in each sub-watershed for the comparison with the riparian forest; and the collection sites coordinates

Sub-watershed identification	Forest stream order	Agricultural use stream order	Agricultural use collected	Forest site coordinates	Agricultural use site coordinates
2	2	2	Pasture	22°05'44.968" S 47°37'25.853" W	22°05'44.668" S 47°37'25.653" W
1	1	1	Pasture	22°05'15.767" S 47°38'29.656" W	22°05'15.867" S 47°38'27.856" W
15	2	2	Pasture	22°06'28.569" S 47°39'24.559" W	22°06'28.569" S 47°39'24.559" W
3	4	1	Sugarcane	22°06'43.369" S 47°40'21.961" W	22°06'22.768" S 47°40'07.361" W
8	1	2	Sugarcane	22°05'15.767" S 47°42'34.067" W	22°05'59.868" S 47°42'18.166" W
47	1	1	Pasture	22°09'54.173" S 47°34'19.846" W	22°09'53.373" S 47°34'19.046" W
44	1	1	Pasture	22°09'39.072" S 47°35'38.149" W	22°09'39.372" S 47°35'39.149" W
43	1	1	Sugarcane	22°10'22.773" S 47°36'41.152" W	22°10'22.373" S 47°36'42.152" W
59	2	2	Pasture	22°11'10.374" S 47°36'38.052" W	22°11'010.074" S 47°36'38.152" W
60	3	3	Pasture	22°12'37.175" S 47°38'12.257" W	22°12'36.175" S 47°38'11.857" W
76	1	1	Pasture	22°13'56.6" S 47°30'11.9" W	22°14'01.7"S 47°29'59.4" W
87	3	3	Pasture	22°15'27.0" S 47°38'25.9" W	22°15'25.2" S 47°38'23.8" W
88	3	3	Pasture	22°16'06.5" S 47°37'15.2" W	22°16'07.1" S 47°37'15.3" W
140	1	1	Sugarcane	22°17'27.3" S 47°36'26.4" W	-
139	1	1	Pasture	22°17'44.6" S 47°37'04.8" W	22°17'43.6" S 47°37'06.0" W
318	1	1	Pasture	22°21'37.4" S 47°44'11.7" W	22°21'37.8" S 47°44'13.3" W
188	2	3	Pasture	22°19'48.9" S 47°43'05.9" W	-
120	1	1	Sugarcane	22°21'38" S 47°44'14.4" W	-
137	3	3	Pasture	-	-
173	1	1	Pasture	22°18'35.5" S 47°50'33.3" W	22°18'40.8" S 47°50'51.3" W
171	1	1	Pasture	22°17'55.1" S 47°48'39.8" W	22°17'56.6" S 47°48'40.3" W
323	3	3	Pasture	22°22'00.1" S 47°49'07.1" W	22°22'00.5" S 47°49'05.3" W
315	3	3	Pasture	22°21'45.2" S 47°46'14.6" W	22°21'46.1" S 47°46'13.6" W

Sub-watershed identification	Forest stream order	Agricultural use stream order	Agricultural use collected	Forest site coordinates	Agricultural use site coordinates
403	1	1	Sugarcane	-	-
352	2	1	Pasture	22°22'49.4" S 47°48'19.6" W	22°22'53.3" S 47°48'08.5" W
414	1	1	Sugarcane	22°25'23.2" S 47°49'02.4" W	22°25'23.9" S 47°49'02.4" W
485	1	1	Sugarcane	22°26'19.1" S 47°48'40.2" W	22°26'20.3" S 47°48'40.4" W
409	3	3	Pasture	22°24'57.3" S 47°45'51.4" W	22°25'05.8" S 47°45'48.5" W
547	1	1	Sugarcane	-	-
508	3	3	Sugarcane	22°26'53.5" S 47°45'44.9" W	22°26'49.5" S 47°45'49.9" W
531	1	1	Sugarcane	22°28'04.7" S 47°42'08.0" W	22°28'04.9" S 47°42'07.3" W
561	2	2	Sugarcane	22°29'26.4" S 47°32'14.8" W	22°29'27.4" S 47°32'14.7" W
572	1	1	Sugarcane	22°30'26.5" S 47°29'29" W	22°30'26.5" S 47°29'28.2" W
580	2	2	Sugarcane	22°31'03.5" S 47°30'03.1" W	22°31'04.0" S 47°30'03.6" W
615	4	4	Sugarcane	22°32'11.3" S 47°39'03.6" W	22°32'11.5" S 47°39'04.2" W
620	1	1	Pasture	22°33'11.1" S 47°39'14.3" W	22°33'12.2" S 47°39'14.7" W
634	3	3	Sugarcane	22°34'18.5" S 47°38'21" W	-
619	1	1	Pasture	22°33'14" S 47°44'23" W	22°33'10.8" S 47°44'20.7" W
632	2	2	Sugarcane	22°33'17.1" S 47°42'55.4" W	22°33'16.7" S 47°42'56.4" W
635	1	1	Sugarcane	22°35'17.2" S 47°44'29.3" W	22°35'17" S 47°44'30.8" W
652	2	2	Sugarcane	22°37'08.2" S 47°39'54.2" W	22°37'09.3" S 47°39'54.5" W
A	1	1	Pasture	22°12'58.41" S 47°45'22.70" W	22°12'56.68" S 47°45'25.32" W
B	-	-	Pasture	22°24'17.7" S 47°43'45.2" W	22°24'17.5" S 47°43'45.5" W
C	-	-	Pasture	22°23'25.11"S 47°44'33.03"W	22°23'26.2" S 47°44'32.8" W
D	3	3	Pasture	22°27'57.99"S 47°47'9.97"W	22°27'58.2" S 47°47'10.8" W
E	-	-	Pasture	22°29'41.35"S 47°35'47.13"W	22°29'42.3" S 47°35'46.6" W
F	2	2	Pasture	22°27'09.1" S 47°38'17.8" W	22°27'08.4" S 47°38'17.6" W
G	1	1	Pasture	22°24'08.7" S 47°38'39.7" W	22°24'07.2" S 47°38'40.8" W
H	2	1	Pasture	22°25'00.8" S 47°37'35.2" W	22°24'59" S 47°37'34.8" W
616	2	2	Sugarcane	22°32'52" S 47°44'46.3" W	22°32'51.7" S 47°44'48.3" W

Appendix B - Table 6 - Sub-watersheds land uses. The total area in hectares of the sub-watersheds; The total forestland, sugarcane crop and pastureland area (in ha) of the sub watersheds; The total riparian zone, that's the area of the total 30 meters buffer around all water courses of the sub watershed in hectares; The percentage of forestland in the total riparian zone of the sub-watershed

Sub-watershed identification	Sub-watershed total area (ha)	Sub-watershed forestland cover (ha)	Sub-watershed sugarcane crop cover (ha)	Sub-watershed pastureland cover (ha)	Sub-watershed total riparian zone (30 m buffer) (ha)	Riparian zone forestland cover (%)
2	386.60	39.85	134.46	20.32	21.08	63.8
1	437.53	102.62	11.59	314.75	88.49	24.4
15	247.73	102.49	74.74	39.07	32.04	89.2
3	514.59	128.00	60.54	146.64	57.36	60.4
8	813.70	258.84	362.65	173.40	129.11	62.2
47	282.46	62.67	107.75	110.84	39.12	63.6
44	207.89	170.84	6.64	30.41	26.68	81.2
43	677.80	323.39	142.71	51.97	72.41	78.2
59	281.11	91.10	9.16	116.34	32.88	76.0
60	210.69	34.17	2.67	150.24	43.83	34.9
76	286.29	63.61	128.65	89.82	62.17	56.1
87	524.09	146.26	16.51	357.14	113.53	48.7
88	193.27	31.62	1.29	159.39	50.42	39.4
140	271.22	59.72	30.13	173.96	59.76	51.7
139	132.66	28.13	4.21	97.59	19.08	59.4
318	109.82	54.96	10.34	44.51	20.43	99.4
188	239.02	58.48	0.00	174.63	49.63	55.9
120	825.16	305.52	306.33	169.30	67.61	86.5
137	401.78	176.42	40.06	140.70	61.19	87.5
173	238.51	62.91	59.05	4.53	22.51	84.4
171	402.15	114.97	37.03	147.70	21.55	33.2
323	196.17	112.41	8.29	67.56	29.81	61.6
315	229.72	98.16	6.15	125.41	27.31	81.5

Sub-watershed identification	Sub-watershed total area (ha)	Sub-watershed forestland cover (ha)	Sub-watershed sugarcane crop cover (ha)	Sub-watershed pastureland cover (ha)	Sub-watershed total riparian zone (30 m buffer) (ha)	Riparian zone forestland cover (%)
352	409.25	250.60	49.36	102.14	54.39	81.3
414	606.08	225.25	82.95	187.59	108.43	55.6
485	1055.87	397.91	256.92	281.72	155.01	67.9
409	204.65	148.92	9.02	44.04	39.95	92.0
547	655.78	221.48	236.88	150.97	122.66	74.1
508	303.75	150.56	58.05	80.26	61.86	75.4
531	310.51	24.31	265.78	11.71	19.56	78.3
561	109.98	20.60	89.38	0.00	13.00	85.2
572	203.99	111.26	90.05	0.00	19.32	89.5
580	366.71	64.00	302.71	0.00	25.32	88.2
615	229.65	122.83	106.82	0.00	45.68	94.5
620	484.68	193.68	219.10	71.90	95.04	72.9
634	287.33	79.03	183.43	14.51	45.63	73.1
619	261.09	18.59	171.61	32.48	19.67	54.5
632	395.04	43.85	307.01	32.63	35.15	53.3
635	354.85	55.93	298.19	0.00	100.05	35.6
652	220.60	62.11	118.21	37.49	44.27	55.6
A	99.63	36.09	42.45	0.00	7.76	89.6
B	-	-	-	-	-	-
C	-	-	-	-	-	-
D	-	-	-	-	-	-
E	-	-	-	-	-	-
F	-	-	-	-	-	-
G	69.06	3.76	41.98	11.77	4.83	43.2
H	181.48	27.26	96.66	26.77	5.76	41.3
616	493.00	38.93	266.36	49.73	45.12	51.5

Appendix C - Table 7 - Texture and carbon content information of the samples collected. The sub-watershed identification, land use and depth interval of each sample; Clay, sand and silt content of each sample; Soil bulk density, C concentration and SOC stock, corrected by the Equivalent Soil Mass method, od each sample collected

Sub-watershed identification	Sampled land use	Depth interval (cm)	Clay content (g/kg)	Sand content (g/kg)	Silt content (g/kg)	Soil bulk density (g/cm^3)	Carbon concentration (mg/g)	Corrected SOC stock ($Mg.ha^{-1}$)
2	Forest	0-10	62	930	8	1.30	5.03	6.52
2	Forest	10-20	67	930	3	1.44	4.83	6.97
2	Forest	20-30	66	930	4	1.24	4.59	5.70
2	Pasture	0-10	85	910	5	1.39	4.12	5.34
2	Pasture	10-20	88	910	2	1.74	3.23	4.66
2	Pasture	20-30	87	910	3	1.69	3.00	3.72
1	Forest	0-10	62	930	8	1.51	4.31	6.50
1	Forest	10-20	65	930	5	1.50	3.21	4.80
1	Forest	20-30	73	920	7	1.43	4.09	5.79
1	Pasture	0-10	75	920	5	1.58	4.44	6.69
1	Pasture	10-20	75	920	5	1.63	3.86	5.79
1	Pasture	20-30	82	910	8	1.41	3.87	5.48
15	Forest	0-10	82	910	8	1.28	5.72	7.33
15	Forest	10-20	65	930	5	1.30	4.93	6.39
15	Forest	20-30	74	920	6	1.36	3.87	5.24
15	Pasture	0-10	56	940	4	1.43	4.04	5.17
15	Pasture	10-20	58	940	2	1.55	3.66	4.74
15	Pasture	20-30	64	930	6	1.39	2.85	3.87
3	Forest	0-10	114	870	16	1.11	7.24	8.02
3	Forest	10-20	89	900	11	1.29	5.12	6.59
3	Forest	20-30	85	910	5	1.27	5.00	6.35
3	Sugarcane	0-10	354	570	76	1.75	9.50	10.52
3	Sugarcane	10-20	400	550	50	1.71	9.90	12.75

Sub-watershed identification	Sampled land use	Depth interval (cm)	Clay content (g/kg)	Sand content (g/kg)	Silt content (g/kg)	Soil bulk density (g/cm^3)	Carbon concentration (mg/g)	Corrected SOC stock ($Mg.ha^{-1}$)
3	Sugarcane	20-30	373	590	37	1.56	8.77	11.14
8	Forest	0-10	499	390	111	1.19	13.02	15.54
8	Forest	10-20	475	390	135	1.25	13.59	16.93
8	Forest	20-30	502	350	148	1.09	13.07	14.28
8	Sugarcane	0-10	513	400	87	1.28	19.84	23.69
8	Sugarcane	10-20	525	400	75	1.35	20.37	25.39
8	Sugarcane	20-30	525	420	55	1.39	21.39	23.38
47	Forest	0-10	547	160	293	1.13	23.72	25.55
47	Forest	10-20	570	170	260	1.19	18.65	19.56
47	Forest	20-30	590	190	220	1.67	18.28	19.47
47	Pasture	0-10	431	340	229	1.08	26.35	28.38
47	Pasture	10-20	415	350	235	1.05	24.52	25.72
47	Pasture	20-30	415	320	265	1.07	19.95	21.25
44	Forest	0-10	479	320	201	1.28	23.00	29.47
44	Forest	10-20	521	310	169	1.33	21.01	27.99
44	Forest	20-30	543	280	177	1.14	17.49	19.85
44	Pasture	0-10	441	450	109	1.47	15.48	19.84
44	Pasture	10-20	437	460	103	1.36	16.02	21.34
44	Pasture	20-30	398	460	142	1.22	14.85	16.86
43	Forest	0-10	64	930	6	1.38	6.27	8.68
43	Forest	10-20	75	920	5	1.49	3.94	5.88
43	Forest	20-30	84	910	6	1.52	2.56	3.90
43	Sugarcane	0-10	101	890	9	1.59	4.23	5.85
43	Sugarcane	10-20	75	920	5	1.64	3.78	5.64
43	Sugarcane	20-30	70	920	10	1.65	2.63	4.00
59	Forest	0-10	92	900	8	1.27	9.54	12.11
59	Forest	10-20	79	910	11	1.44	8.56	10.04

Sub-watershed identification	Sampled land use	Depth interval (cm)	Clay content (g/kg)	Sand content (g/kg)	Silt content (g/kg)	Soil bulk density (g/cm^3)	Carbon concentration (mg/g)	Corrected SOC stock ($Mg.ha^{-1}$)
59	Forest	20-30	82	910	8	1.12	3.92	4.39
59	Pasture	0-10	145	850	5	1.47	10.78	13.69
59	Pasture	10-20	125	830	45	1.17	7.45	8.73
59	Pasture	20-30	122	850	28	1.29	5.22	5.85
60	Forest	0-10	169	680	151	1.14	18.19	20.67
60	Forest	10-20	170	720	110	1.39	9.81	11.74
60	Forest	20-30	205	650	145	1.39	8.16	9.34
60	Pasture	0-10	361	270	369	1.40	13.34	15.16
60	Pasture	10-20	364	280	356	1.20	8.70	10.41
60	Pasture	20-30	349	330	321	1.14	7.89	9.03
76	Forest	0-10	154	830	16	1.36	12.39	16.81
76	Forest	10-20	144	840	16	1.44	8.95	12.90
76	Forest	20-30	143	830	27	1.55	7.76	12.00
76	Pasture	0-10	178	810	12	1.57	3.47	4.71
76	Pasture	10-20	151	840	9	1.75	4.02	5.79
76	Pasture	20-30	151	840	9	1.76	2.67	4.13
87	Forest	0-10	92	880	28	1.46	6.47	8.97
87	Forest	10-20	97	880	23	1.52	4.96	7.54
87	Forest	20-30	156	790	54	1.33	2.97	3.96
87	Pasture	0-10	267	510	223	1.39	10.56	14.63
87	Pasture	10-20	306	490	204	1.58	7.95	12.08
87	Pasture	20-30	320	460	220	1.55	5.40	7.19
88	Forest	0-10	134	820	46	1.49	15.70	23.35
88	Forest	10-20	133	830	37	1.38	13.16	18.12
88	Forest	20-30	112	860	28	1.41	9.04	12.71
88	Pasture	0-10	90	890	20	1.57	4.69	6.98
88	Pasture	10-20	76	920	4	1.62	2.65	3.66

Sub-watershed identification	Sampled land use	Depth interval (cm)	Clay content (g/kg)	Sand content (g/kg)	Silt content (g/kg)	Soil bulk density (g/cm³)	Carbon concentration (mg/g)	Corrected SOC stock ($Mg.ha^{-1}$)
88	Pasture	20-30	45	950	5	1.59	1.85	2.60
140	Forest	0-10	143	800	57	1.41	16.45	23.23
140	Forest	10-20	137	810	53	1.47	11.07	16.24
140	Forest	20-30	127	860	13	1.35	7.97	10.73
140	Sugarcane	0-10	97	890	13	1.70	4.05	5.72
140	Sugarcane	10-20	88	910	2	1.72	4.05	5.94
140	Sugarcane	20-30	74	920	6	1.71	2.67	3.59
139	Forest	0-10	29	970	1	1.37	5.35	7.30
139	Forest	10-20	67	930	3	1.39	5.31	7.41
139	Forest	20-30	60	930	10	1.48	4.90	7.25
139	Pasture	0-10	77	910	13	1.53	4.14	5.65
139	Pasture	10-20	84	910	6	1.64	2.51	3.50
139	Pasture	20-30	97	890	13	1.67	2.28	3.37
318	Forest	0-10	56	940	4	1.43	6.84	9.76
318	Forest	10-20	65	930	5	1.47	4.13	6.06
318	Forest	20-30	67	930	3	1.53	3.20	4.68
318	Pasture	0-10	67	930	3	1.59	3.92	5.59
318	Pasture	10-20	65	930	5	1.48	3.07	4.50
318	Pasture	20-30	76	920	4	1.46	2.40	3.52
188	Forest	0-10	146	820	34	1.43	11.99	17.16
188	Forest	10-20	147	840	13	1.44	9.40	13.58
188	Forest	20-30	132	840	28	1.48	8.04	11.91
188	Pasture	0-10	147	840	13	1.50	6.29	9.00
188	Pasture	10-20	170	820	10	1.52	5.84	8.43
188	Pasture	20-30	164	820	16	1.52	5.27	7.81
120	Forest	0-10	200	700	100	1.26	14.66	18.43
120	Forest	10-20	182	750	68	1.14	11.39	12.96

Sub-watershed identification	Sampled land use	Depth interval (cm)	Clay content (g/kg)	Sand content (g/kg)	Silt content (g/kg)	Soil bulk density (g/cm³)	Carbon concentration (mg/g)	Corrected SOC stock (Mg.ha^{-1})
120	Forest	20-30	158	810	32	1.35	7.06	9.55
120	Sugarcane	0-10	131	860	9	1.53	5.12	6.44
120	Sugarcane	10-20	137	850	13	1.71	5.54	6.30
120	Sugarcane	20-30	161	830	9	1.67	4.67	6.32
137	Forest	0-10	114	880	6	1.24	7.90	9.76
137	Forest	10-20	98	900	2	1.39	5.28	7.32
137	Forest	20-30	85	910	5	1.28	3.38	4.33
137	Pasture	0-10	90	900	10	1.57	3.41	4.22
137	Pasture	10-20	54	940	6	1.44	1.66	2.30
137	Pasture	20-30	75	920	5	1.47	2.21	2.84
173	Forest	0-10	95	900	5	1.33	10.29	13.72
173	Forest	10-20	107	890	3	1.50	5.53	7.95
173	Forest	20-30	69	930	1	1.56	4.04	6.31
173	Pasture	0-10	54	940	6	1.37	4.62	6.16
173	Pasture	10-20	65	930	5	1.44	2.07	2.98
173	Pasture	20-30	64	930	6	1.68	2.15	3.35
171	Forest	0-10	76	920	4	1.50	4.62	6.13
171	Forest	10-20	81	910	9	1.53	4.14	6.23
171	Forest	20-30	95	900	5	1.55	3.69	5.28
171	Pasture	0-10	106	890	4	1.33	10.63	14.11
171	Pasture	10-20	84	910	6	1.51	4.46	6.72
171	Pasture	20-30	75	920	5	1.43	4.04	5.79
323	Forest	0-10	109	890	1	1.23	7.21	8.89
323	Forest	10-20	135	860	5	1.35	7.28	9.85
323	Forest	20-30	140	840	20	1.47	5.29	7.77
323	Pasture	0-10	74	920	6	1.46	4.95	6.10
323	Pasture	10-20	73	920	7	1.61	4.71	6.37

Sub-watershed identification	Sampled land use	Depth interval (cm)	Clay content (g/kg)	Sand content (g/kg)	Silt content (g/kg)	Soil bulk density (g/cm³)	Carbon concentration (mg/g)	Corrected SOC stock (Mg.ha^{-1})
323	Pasture	20-30	58	940	2	1.48	3.10	4.55
315	Forest	0-10	132	860	8	1.39	7.45	10.33
315	Forest	10-20	121	870	9	1.44	7.40	10.63
315	Forest	20-30	144	850	6	1.34	6.10	8.16
315	Pasture	0-10	107	890	3	1.44	6.96	9.66
315	Pasture	10-20	93	900	7	1.45	5.43	7.81
315	Pasture	20-30	111	870	19	1.46	6.48	8.67
403	Forest	0-10	279	720	1	1.24	12.40	15.40
403	Forest	10-20	245	730	25	1.31	13.37	17.49
403	Forest	20-30	236	750	14	1.29	8.11	10.44
403	Sugarcane	0-10	288	690	22	1.68	4.70	5.84
403	Sugarcane	10-20	305	690	5	1.70	5.28	6.91
403	Sugarcane	20-30	319	670	11	1.63	4.21	5.43
352	Forest	0-10	64	930	6	1.28	6.24	7.99
352	Forest	10-20	64	930	6	1.50	2.50	3.72
352	Forest	20-30	59	940	1	1.38	2.35	3.24
352	Pasture	0-10	75	920	5	1.58	5.68	7.28
352	Pasture	10-20	83	910	7	1.49	3.95	5.89
352	Pasture	20-30	92	900	8	1.56	3.48	4.79
414	Forest	0-10	292	650	58	1.01	23.94	24.27
414	Forest	10-20	304	620	76	1.32	15.39	20.37
414	Forest	20-30	337	580	83	1.25	11.46	14.35
414	Sugarcane	0-10	301	630	69	1.35	8.82	8.94
414	Sugarcane	10-20	347	610	43	1.58	10.16	13.45
414	Sugarcane	20-30	344	590	66	1.60	8.68	10.87
485	Forest	0-10	370	590	40	1.05	36.90	38.85
485	Forest	10-20	287	630	83	1.22	19.65	24.04

Sub-watershed identification	Sampled land use	Depth interval (cm)	Clay content (g/kg)	Sand content (g/kg)	Silt content (g/kg)	Soil bulk density (g/cm^3)	Carbon concentration (mg/g)	Corrected SOC stock ($Mg.ha^{-1}$)
485	Forest	20-30	291	660	49	1.16	18.04	21.00
485	Sugarcane	0-10	283	670	47	1.43	10.76	11.32
485	Sugarcane	10-20	267	680	53	1.68	11.13	13.61
485	Sugarcane	20-30	285	660	55	1.65	8.90	10.36
409	Forest	0-10	151	830	19	1.27	15.21	19.24
409	Forest	10-20	114	880	6	1.38	9.95	13.69
409	Forest	20-30	134	860	6	1.46	6.86	10.02
409	Pasture	0-10	66	930	4	1.58	3.08	3.90
409	Pasture	10-20	56	940	4	1.51	2.87	3.94
409	Pasture	20-30	62	930	8	1.60	2.59	3.78
547	Forest	0-10	106	890	4	1.30	5.27	6.86
547	Forest	10-20	101	890	9	1.43	4.62	6.07
547	Forest	20-30	122	870	8	1.20	4.65	5.58
547	Sugarcane	0-10	124	870	6	1.39	3.58	4.67
547	Sugarcane	10-20	138	850	12	1.31	3.86	5.07
547	Sugarcane	20-30	163	830	7	1.57	3.98	4.78
508	Forest	0-10	85	910	5	1.18	6.82	8.02
508	Forest	10-20	74	920	6	1.30	5.48	7.13
508	Forest	20-30	85	910	5	1.29	4.52	5.83
508	Sugarcane	0-10	89	900	11	1.54	3.78	4.44
508	Sugarcane	10-20	83	910	7	1.57	3.17	4.13
508	Sugarcane	20-30	68	930	2	1.57	2.89	3.73
531	Forest	0-10	389	460	151	1.29	20.19	26.10
531	Forest	10-20	383	470	147	1.29	16.01	20.61
531	Forest	20-30	385	440	175	1.10	16.39	18.11
531	Sugarcane	0-10	489	390	121	1.45	14.25	18.42
531	Sugarcane	10-20	520	400	80	1.49	15.02	19.34

Sub-watershed identification	Sampled land use	Depth interval (cm)	Clay content (g/kg)	Sand content (g/kg)	Silt content (g/kg)	Soil bulk density (g/cm³)	Carbon concentration (mg/g)	Corrected SOC stock ($Mg.ha^{-1}$)
531	Sugarcane	20-30	565	340	95	1.38	12.33	13.62
561	Forest	0-10	129	810	61	1.44	5.03	7.27
561	Forest	10-20	127	830	43	1.60	3.42	5.46
561	Forest	20-30	115	870	15	1.60	2.07	3.32
561	Sugarcane	0-10	202	770	28	1.46	6.22	8.98
561	Sugarcane	10-20	198	760	42	1.66	4.84	7.73
561	Sugarcane	20-30	205	740	55	1.73	3.73	5.96
572	Forest	0-10	400	500	100	1.14	23.94	26.50
572	Forest	10-20	405	510	85	1.25	20.59	25.64
572	Forest	20-30	402	510	88	1.34	21.00	28.15
572	Sugarcane	0-10	486	420	94	1.11	9.79	10.83
572	Sugarcane	10-20	486	430	84	1.54	9.90	12.33
572	Sugarcane	20-30	466	420	114	1.42	8.43	11.31
580	Forest	0-10	437	390	173	0.97	36.99	35.91
580	Forest	10-20	463	350	187	1.00	23.94	23.98
580	Forest	20-30	495	360	145	0.89	20.30	17.98
580	Sugarcane	0-10	563	290	147	1.29	15.09	14.65
580	Sugarcane	10-20	528	300	172	1.36	14.17	14.20
580	Sugarcane	20-30	563	320	117	1.40	14.78	13.10
615	Forest	0-10	231	570	199	1.11	13.59	15.03
615	Forest	10-20	263	500	237	1.37	12.16	16.66
615	Forest	20-30	259	490	251	1.29	11.88	15.38
615	Sugarcane	0-10	209	670	121	1.52	5.38	5.95
615	Sugarcane	10-20	244	650	106	1.70	4.22	5.78
615	Sugarcane	20-30	228	630	142	1.76	3.77	4.88
620	Forest	0-10	230	580	190	1.03	20.83	21.51
620	Forest	10-20	154	700	146	1.35	7.99	10.59

Sub-watershed identification	Sampled land use	Depth interval (cm)	Clay content (g/kg)	Sand content (g/kg)	Silt content (g/kg)	Soil bulk density (g/cm³)	Carbon concentration (mg/g)	Corrected SOC stock (Mg.ha^{-1})
620	Forest	20-30	237	550	213	1.54	10.00	14.50
620	Pasture	0-10	118	770	112	1.19	8.30	8.57
620	Pasture	10-20	104	820	76	1.33	5.20	6.88
620	Pasture	20-30	74	880	46	1.45	2.64	3.82
634	Forest	0-10	165	790	45	1.11	14.17	15.66
634	Forest	10-20	148	800	52	1.10	9.00	9.87
634	Forest	20-30	130	830	40	-	4.99	-
634	Sugarcane	0-10	161	830	9	1.48	3.90	4.30
634	Sugarcane	10-20	152	840	8	1.60	3.60	3.95
634	Sugarcane	20-30	151	840	9	1.74	3.91	-
619	Forest	0-10	159	790	51	1.10	12.51	13.72
619	Forest	10-20	175	740	85	1.30	9.54	12.36
619	Forest	20-30	213	710	77	1.35	6.77	9.14
619	Pasture	0-10	131	830	39	1.33	6.24	6.83
619	Pasture	10-20	146	810	44	1.56	5.59	7.25
619	Pasture	20-30	176	760	64	1.62	5.12	6.92
632	Forest	0-10	494	200	306	1.06	13.92	14.78
632	Forest	10-20	542	150	308	0.91	7.73	7.02
632	Forest	20-30	519	180	301	0.88	8.27	7.28
632	Sugarcane	0-10	521	180	299	1.23	9.74	10.35
632	Sugarcane	10-20	506	170	324	1.18	9.51	8.63
632	Sugarcane	20-30	551	160	289	1.31	10.09	8.88
635	Forest	0-10	379	190	431	1.04	23.31	24.28
635	Forest	10-20	336	180	484	1.00	28.80	28.81
635	Forest	20-30	370	170	460	1.13	13.55	14.51
635	Sugarcane	0-10	404	240	356	1.09	3.72	3.88
635	Sugarcane	10-20	442	230	328	1.12	4.08	4.09

Sub-watershed identification	Sampled land use	Depth interval (cm)	Clay content (g/kg)	Sand content (g/kg)	Silt content (g/kg)	Soil bulk density (g/cm^3)	Carbon concentration (mg/g)	Corrected SOC stock ($Mg.ha^{-1}$)
635	Sugarcane	20-30	386	290	324	1.07	3.08	3.29
652	Forest	0-10	327	330	343	1.18	28.57	33.65
652	Forest	10-20	348	330	322	1.12	19.93	22.42
652	Forest	20-30	381	330	289	1.25	19.77	24.67
652	Sugarcane	0-10	248	500	252	1.67	7.60	8.95
652	Sugarcane	10-20	258	500	242	1.67	6.41	7.21
652	Sugarcane	20-30	255	500	245	1.64	6.10	7.61
A	Forest	0-10	112	880	8	1.06	20.00	21.14
A	Forest	10-20	101	890	9	1.40	8.20	11.51
A	Forest	20-30	101	890	9	1.42	8.46	11.98
A	Pasture	0-10	67	930	3	1.58	3.19	3.37
A	Pasture	10-20	56	940	4	1.55	2.50	3.50
A	Pasture	20-30	55	940	5	1.60	3.05	4.32
B	Forest	0-10	447	220	333	0.89	21.77	19.29
B	Forest	10-20	478	210	312	1.07	22.97	24.65
B	Forest	20-30	437	220	343	0.98	12.79	12.49
B	Pasture	0-10	365	460	175	1.11	22.70	20.11
B	Pasture	10-20	435	390	175	1.19	18.34	19.68
B	Pasture	20-30	467	360	173	1.23	14.58	14.23
C	Forest	0-10	161	830	9	1.21	13.05	15.79
C	Forest	10-20	173	780	47	1.36	13.37	18.22
C	Forest	20-30	196	770	34	1.37	11.15	14.48
C	Pasture	0-10	93	900	7	1.41	6.33	7.65
C	Pasture	10-20	84	910	6	1.46	4.20	5.71
C	Pasture	20-30	83	910	7	1.30	5.29	6.88
D	Forest	0-10	124	870	6	1.16	7.28	8.36
D	Forest	10-20	131	860	9	1.34	8.10	10.87

Sub-watershed identification	Sampled land use	Depth interval (cm)	Clay content (g/kg)	Sand content (g/kg)	Silt content (g/kg)	Soil bulk density (g/cm³)	Carbon concentration (mg/g)	Corrected SOC stock (Mg.ha^{-1})
D	Forest	20-30	134	860	6	1.39	5.68	7.70
D	Pasture	0-10	126	870	4	1.15	8.54	9.80
D	Pasture	10-20	141	850	9	1.42	7.11	9.55
D	Pasture	20-30	123	870	7	1.36	6.21	8.42
E	Forest	0-10	350	400	250	1.00	10.27	10.23
E	Forest	10-20	353	410	237	1.26	9.78	10.81
E	Forest	20-30	328	380	292	1.14	10.92	12.47
E	Pasture	0-10	346	400	254	1.07	23.30	23.21
E	Pasture	10-20	-	-	-	1.11	18.02	19.92
E	Pasture	20-30	-	-	-	1.16	18.99	21.68
F	Forest	0-10	408	480	112	0.55	74.25	40.81
F	Forest	10-20	460	370	170	0.55	70.40	38.73
F	Forest	20-30	506	280	214	0.61	59.65	36.66
F	Pasture	0-10	227	730	43	1.25	19.44	10.69
F	Pasture	10-20	228	720	52	1.41	17.15	9.44
F	Pasture	20-30	279	670	51	1.38	15.71	9.66
G	Forest	0-10	234	700	66	1.42	7.63	9.51
G	Forest	10-20	191	730	79	1.62	7.98	11.29
G	Forest	20-30	244	650	106	1.58	3.87	5.35
G	Pasture	0-10	137	860	3	1.42	7.57	10.74
G	Pasture	10-20	163	830	7	1.41	7.87	11.07
G	Pasture	20-30	133	860	7	1.41	6.57	9.28
H	Forest	0-10	273	680	47	1.03	47.32	48.65
H	Forest	10-20	289	600	111	0.90	74.62	67.29
H	Forest	20-30	282	610	108	0.74	74.66	55.01
H	Pasture	0-10	114	880	6	1.32	10.72	11.02
H	Pasture	10-20	122	870	8	1.35	14.56	13.13

Sub-watershed identification	Sampled land use	Depth interval (cm)	Clay content (g/kg)	Sand content (g/kg)	Silt content (g/kg)	Soil bulk density (g/cm³)	Carbon concentration (mg/g)	Corrected SOC stock ($Mg.ha^{-1}$)
H	Pasture	20-30	96	900	4	1.32	17.67	13.02
616	Forest	0-10	181	720	99	1.16	8.29	9.61
616	Forest	10-20	170	750	80	1.37	6.38	8.75
616	Forest	20-30	167	740	93	1.24	4.67	5.81
616	Sugarcane	0-10	297	610	93	1.56	5.64	6.53
616	Sugarcane	10-20	266	610	124	1.67	5.85	8.03
616	Sugarcane	20-30	315	580	105	1.44	5.50	6.83