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Potential carbon sequestration in rubber tree plantations in the northwestern region of the Paraná State, Brazil

Selma Regina Maggiotto[1*], Dalziza de Oliveira[2], Celso Jamil Marur[2], Sonia Maria Soares Stivari[3], Monique Leclerc[4] and Claudia Wagner-Riddle[5]

*[1]Universidade de Brasília, s/n, 70910-900, Brasília, Distrito Federal, Brazil. [2]Instituto Agronômico do Paraná, Londrina, Paraná, Brazil. [3]Departamento de Física, Universidade Estadual de Maringá, Maringá, Paraná, Brazil. [4]Laboratory for Environmental Physics, University of Georgia, Athens, United States of Amerca. [5]School of Environmental Sciences, University of Guelph, Guelph, Ontário, Canada. *Author for correspondence. E-mail: srmaggio@unb.br*

ABSTRACT. Rubber tree plantations may improve the soil's physical and chemical properties, and they may sequester atmospheric carbon in the biomass or the soil. However, the potential role of these plantations in sequestering carbon in the soil and plant biomass has not been fully evaluated. This study evaluated rubber tree plantations at Paranapoema, which is located in the northwestern region of the Paraná state of Brazil, to measure the biomass in plantations of different ages and to determine the organic carbon content and $\delta^{13}C$ in the soils. Biomass accumulation was evaluated using the destructive method in plantations of different ages. The total carbon stock in the top 60 cm of the soil was 63.4 Mg C ha^{-1} for the pasture adjacent to the plantations and 66.8 and 79.3 Mg C ha^{-1} for the 4- and 15-year-old rubber tree plantations, respectively. These values are equivalent to an annual increase in soil carbon stocks of 0.85 and 1.06 Mg ha^{-1}, respectively, and they do not include the accumulation of carbon as tree woody biomass. The soil $\delta^{13}C$ indicated a relatively fast conversion from the previous C4-C (pasture; *Brachiaria-Urochloa brizantha*) to C3-C (rubber tree). The results from this study suggest that rubber tree plantations have untapped potential to sequester carbon over a relatively short time period.

Keywords: rubber tree, *Hevea brasiliensis*, soil $\delta^{13}C$, isotopic ratio, soil carbon stocks.

Potencial de sequestro de carbono em seringais no noroeste do Paraná, Brasil

RESUMO. O plantio de seringueiras é uma opção para melhorar as propriedades físicas e químicas do solo e promover o sequestro de carbono atmosférico, seja na biomassa ou no solo. Apesar das vantagens, o potencial de sequestro de carbono dos seringais no solo e na biomassa não foi ainda avaliado. Um estudo foi conduzido em seringais localizados em Paranapoema, na região noroeste do Paraná, com os objetivos de medir a biomassa em seringais de diferentes idades, e determinar o conteúdo de carbono e o $\delta^{13}C$ do solo. O acúmulo de biomassa foi avaliado pelo método destrutivo em seringais de diferentes idades. O estoque total de carbono até 60 cm do solo foi de 63,4 Mg C ha^{-1} na pastagem adjacente aos seringais, 66,8 e 79,3 Mg C ha^{-1} nos seringais de 4 e 15 anos de idade, respectivamente, equivalendo a uma taxa anual de aumento de carbono no solo de 0,85 e 1,06 Mg ha^{-1}, sem considerar o acúmulo de carbono pela biomassa da planta. Os valores de $\delta^{13}C$ do solo indicaram uma conversão relativamente rápida do carbono proveniente de plantas C4 (pastagem, *Brachiaria-Urochloa brizantha*) para carbono de plantas C3 (seringal). Os resultados deste estudo indicam o grande potencial de seringais em sequestrar carbono em um período relativamente curto.

Palavras-chave: seringueira, *Hevea brasiliensis*, $\delta^{13}C$ do solo, razão isotópica, estoque de carbono no solo.

Introduction

The state of Paraná, is the southernmost state in Brazil where the climatic characteristics are adequate to support the growth of rubber tree plantations (CAMARGO et al., 2003). By the year 2000, more than 1000 ha of rubber trees were established and productive in Paraná (PEREIRA et al., 2000). The establishment of rubber tree plantations has been proposed as an option to improve physical and chemical soil properties by protecting the soil from erosion and recycling nutrients through leaf litterfall (PEREIRA et al., 2000). These plantations, as a monoculture or combined with other crops in agroforestry systems, may also sequester carbon from the atmosphere (DEY, 2005; YANG et al., 2005; GUO et al., 2006).

Plant biomass estimates in rubber tree plantations of different ages and grown in potentially dissimilar conditions in southern Brazil (CUNHA et al., 2000; COTTA et al., 2006; WAUTERS et al., 2008) and Asia (DEY, 2005; YANG et al., 2005) have revealed a large range of carbon accumulation rates, from 1.4 to 6.7 Mg C ha^{-1} yr^{-1}. However, fewer studies have investigated changes in the soil carbon accumulation rates beneath rubber tree plantations. For example, when compared to adjacent agricultural areas, an accumulation rate of 0.72 Mg C ha^{-1} yr^{-1} was reported to a depth of 1 m in China (YANG et al., 2005).

Carbon isotopic ratio measurements have been used to gain information regarding changes in soil carbon associated with land use. Because the photosynthetic process discriminates against ^{13}C differently in C3 and C4 plants (FRY, 2006), the $\delta^{13}C$ of the soil organic matter can be used to reflect the long-term source of plant material, and this measure can be used to quantify carbon addition to the soil from the vegetation.

The present study addresses the question of how much carbon can be sequestered by a rubber tree plantation by performing the following two analyses: biomass measurements in rubber tree stands of different ages in adjacent areas to estimate the biomass accumulation rate and soil carbon and isotopic carbon determination in soils to study the carbon storage change that is associated with the conversion from a pasture to a rubber tree plantation.

Material and methods

Study Site

The study site is located at Fazenda Guanabara in Paranapoema (22º43'S, 57º07'W) in the northwestern region of the Paraná state of Brazil. The location is 400 m above sea level, and the climate is classified as humid subtropical (Cfa according to the Köppen classification, LUTGENS; TARBUCK, 2004); the average annual temperature is 22ºC, and the total annual precipitation is 1500 mm. The soil at this site was classified as Oxisol according to the United States Department of Agriculture (USDA) Soil Taxonomy (Latossolo Vermelho in the Brazilian Soil Classification System). The soil has a loamy sand texture (85% sand, 1% silt and 14% clay) and a pH ($CaCl_2$) of 4.0 at a 0-20 cm depth.

Historically, this area was occupied by a seasonal semideciduous forest and contained a large diversity of species, which were predominantly classified in the Caesalpiniaceae, Euphorbiaceae, Myrtaceae and Fabaceae families (SOUZA; BATISTA, 2004). In 1950, the forest was cleared and planted with coffee (*Coffea arabica*). In July 1975, when a severe frost killed all of the coffee plants, the area was planted with pasture grass (*Brachiaria-Urochloa brizantha*) to support extensive cattle grazing. In 1988, 1997 and 1999, nearby areas within the pasture were planted with rubber trees (*Hevea brasiliensis*) in plots that ranged in size from 125 to 250 ha. The study area was planted with the clone PB235 at a density of 500 plants ha^{-1}; in-row trees were spaced at 2.5 m, and the rows were spaced 8 m apart. At the time of sampling, the trees were 4, 6 and 15 years old. Only the oldest stand was being tapped.

Rubber tree biomass sampling and analysis

The quantification of the above- and belowground tree biomass values was completed in February 2003 for each of the three plantations. The diameter at the breast height (dbh) of 80 trees was measured in each stand. Four trees in each area, which were representative of the stand's mean dbh (8.3, 12.5, and 21.9 cm for the 4-, 6- and 15-year-old trees, respectively) were selected for destructive sampling. After felling each tree, the aboveground biomass was separated into leaves, large branches (> 4 cm diameter), small branches (< 4 cm diameter), dry branches, and tree trunks. The belowground biomass was measured by excavating areas of 1, 4 and 6.25 m^2 around each tree stump for the 4-, 6- and 15-year-old trees, respectively, to a depth of 1 m. The roots were separated from the loosened soil by hand picking and sieving. The taproot was removed from the soil using a tractor equipped with a front-end loader. The belowground biomass was separated into the root stump, primary roots, lateral roots and loose roots.

The fresh weight of each component of the above- and belowground tree biomass was determined in the field. For the tree trunk and large branches, sub-samples were taken from the lower, mid and upper one-third regions. Sub-samples (500 g fresh weight) of each component were taken and used for further laboratory analyses. The plant samples were dried at 60ºC until they reached a constant weight, and the fresh biomass water content was determined. The plant material was ground in a Wiley Mill (passed through a 1 mm screen). The total carbon content was determined using the Walkley-Black method. The samples of the plant components were also analyzed using the dry combustion method to calibrate the wet digestion method. The $\delta^{13}C$ of the plant samples was determined using a Tracemass Isotope Ratio Mass Spectrometer (Europa Scientific, Crewe, UK) at the Isotope Analytical Laboratory, University of Saskatchewan, Saskatoon, Canada. In the results section, the means of four samples and the standard errors are presented.

Soil sampling and soil carbon determination

Soil samples for organic carbon determination were taken in April 2003 from the 4- and 15-year-old plantations; they were taken in the area at two positions which were located 2 and 4 m from the tree row. By using an auger, the soil samples were obtained from each sampling position at 0-10, 10-20, 20-40 and 40-60 cm depths from four locations within the area of each plantation (2 positions x 4 layers x 4 tree areas = 32 samples per plantation age). Soils samples were also collected from the adjacent pasture field at 4 locations at the same 4 depths (16 total samples). This area was assumed to represent the original pasture in which the rubber tree plantation was established. In other words, the pasture carbon levels at the time of sampling in 2003 were assumed to have remained unchanged since the rubber tree plantations were established in 1988, 1997, and 1999. Therefore, a comparison of the carbon content in the samples could provide an estimate of the amount of carbon that had accumulated in the soil since the conversion from pasture to rubber tree.

A 500 g sub-sample of the field moist soil was collected using a coning and quartering technique. In the laboratory, these samples were air-dried and passed through a 4 mm sieve to remove the coarse mineral fraction and large plant residue fragments. A sub-sample (25 g) was oven dried at 105°C for 48h for further analysis. The soil was finely ground to < 0.150 mm and analyzed to determine the organic carbon content and $\delta^{13}C$ at the Centre of Nuclear Energy in Agriculture at the University of São Paulo (CENA/USP) in Piracicaba, Brazil. The total soil organic carbon content was calculated assuming a soil bulk density of 1.55 Mg m^{-3} (CUNHA et al., 1999).

The vegetation shift from a *Brachiaria-Urochloa*-dominated pasture, which is a C4 plant, to a rubber tree plantation, which is a C3 plant, allowed the use of $\delta^{13}C$ techniques to measure the amounts of soil organic carbon that were derived from these two sources at each plantation (the 4- and 15-year-old trees). A simple two-pool mixing model was used for the calculation, and it was based on the soil and plant $\delta^{13}C$ and total soil carbon data (BERNOUX et al., 1998) as follows:

$$C_t\,\delta_t = C_{C3}\,\delta_{C3} + C_{C4}\,\delta_{C4} \quad (1)$$

where:

C_t is the total soil organic carbon;

C_{C3} and C_{C4} are the amounts of carbon derived from the rubber tree and pasture grass vegetation, respectively;

δ_t is the $\delta^{13}C$ of the soil organic carbon;

δ_{C3} and δ_{C4} are the $\delta^{13}C$ of the C3 or C4 vegetation, respectively.

For these calculations, the average of the measured $\delta^{13}C$ for the components of the rubber tree biomass (δ_{C3} = -25.91‰ ± 1.16) and the data regarding the $\delta^{13}C$ of the pasture (δ_{C4} = -14.3‰ ± 0.56 for *Brachiaria-Urochloa*, according to MORAES et al., 1996) were used as reported in the literature.

The means and standard errors of all of the samples at each depth (8 samples per depth) or from 4 samples per depth (when the results were divided according to the distance from the tree rows) are presented and were used to estimate the total carbon in the soil and the $\delta^{13}C$ results.

Results and discussion

Rubber tree biomass and carbon stocks

The sum of the trunk and branch biomass values accounted for the majority of the biomass at all of the ages; it increased from 66 % of the total biomass at the 4-year-old plantations to 71 and 81 % at the 6- and 15-year-old plantations, respectively (Table 1). This increase was mostly attributed to an increase in branches biomass rather than in trunk biomass. The biomass accumulation rate of the combination of branches and trunk corresponded to 74 % of the total accumulation rate from 4 to 6 years of age (22.4 kg $plant^{-1}$ yr^{-1}) and 85 % from 6 to 15 years of age (24.9 kg $plant^{-1}$ yr^{-1}). The root biomass accumulation rate decreased from 17 to 11 % of the total for the same age intervals.

Table 1. Rubber tree water content (%), biomass and carbon content (kg $plant^{-1}$), above- and belowground, for each age group of rubber trees in Paranapoema, Brazil.

Variable	Age (yr)	Aboveground					Belowground				Total
		Trunk	Large branches	Small branches	Dry branches	Leaves	Root stump	Main roots	Lateral roots	Loose roots	
Water content (%)	4	51.2	58.6	58.8	-	66.1	47.8	50.1	45.9	54.3	-
	6	50.1	55.7	55.5	-	65.1	43.1	53.1	47.9	59.0	-
	15	48.0	48.6	52.0	19.3	67.0	47.1	56.5	55.6	57.9	-
Biomass (kg $plant^{-1}$)	4	9.03	0.97	5.70	-	2.99	2.32	2.54	0.15	0.14	23.84
	6	23.06	9.29	16.49	-	7.17	4.97	6.53	0.60	0.56	68.67
	15	108.85	79.19	39.83	10.08	10.19	17.33	22.43	1.45	3.15	292.59
Carbon content (kg $plant^{-1}$)	4	3.78	0.41	2.30	-	1.25	1.02	1.15	0.07	0.06	10.04
	6	9.86	3.89	6.81	-	3.01	2.20	2.93	0.26	0.24	29.20
	15	46.21	33.79	16.64	4.33	4.39	7.77	9.93	0.63	1.33	125.00

The carbon content in the biomass ranged from 402.3 ± 10.61 g C kg^{-1} (small branches, 4-year-old plants) to 450.6 ± 1.88 g C kg^{-1} (primary roots, 4-year-old plants). As expected, the amount of carbon in the biomass of the older plantations was relatively higher than of the younger plantations; the carbon level increased from 77 % for the 4-year-old plantation to 81 and 85 % for 6- and 15-year-old trees, respectively. During the first four years, the carbon accumulation rate was 2.51 kg C $plant^{-1}$ yr^{-1}. This rate increased to 9.58 kg C $plant^{-1}$ yr^{-1} from 4 to 6 years old plants and to 10.64 kg C $plant^{-1}$ yr^{-1} from 6 to 15 years old plants (Table 1).

It is a complex task to compare measured biomass production and carbon content with previously published values. Various methods are used to estimate biomass, such as destructive sampling, allometric equations, and geographic information systems; the use of these methods produces results that are expressed in different units (MAGCALE-MACANDOG, 2004). Additionally, the plantation clone, age, soil type, climate conditions and management are important factors that influence tree growth and carbon accumulation (WAUTERS et al., 2008). A summary of some of the published values of total biomass and carbon accumulation rate for the rubber tree is presented in Table 2. These data were derived from different regions of the world and show a large range of results.

Cunha et al. (2000) reported that a 12-year-old rubber tree plantation located in the state of Minas Gerais, Brazil had a total biomass of 349.53 kg $plant^{-1}$. This value is approximately 20 % higher than the individual plant biomass that was measured in the current study for a plantation 3 years younger than the oldest plantation in the current study. In the state of Bahia, Cotta et al. (2006) evaluated a 34-year-old rubber tree plantation associated with cocoa trees and calculated a total rubber tree biomass of approximately 170 Mg ha^{-1}. Low-temperature stress, which occurs during the winter in the northwestern region of the Paraná state, is likely a key explanation for the lower biomass accumulation rates that were measured when compared to other studies that have been performed in regions of Brazil, in which low temperatures occur less frequently.

Because the average biomass accumulation rate varies with age, it is critical that comparisons are made between plantations of the same age. The accumulation rates that were calculated for 6-year-old plantations in India (DEY, 2005) and China (YANG et al., 2005) ranged from 4.1 to 7.4 Mg ha^{-1} yr^{-1}, while we observed a biomass accumulation rate of 5.7 Mg ha^{-1} yr^{-1} in the present study. Although there is a large variation between the total biomass stock in plants, the proportion of aboveground biomass did not vary to the same extent; it ranged from 70 to 85 %. It is also apparent that this proportion increased with age, as observed in this study and by Dey (2005).

Historically, studies have utilized different methods to estimate carbon biomass, using a fixed value of 0.5 kg C kg^{-1} (COTTA et al., 2006, YANG et al., 2005) or measurements (DEY, 2005; WAUTERS et al., 2008), according to Table 2. When comparing plantations of similar ages, the carbon accumulation rates that were determined in the present study were within the range that has been presented in the literature (DEY, 2005, YANG et al., 2005; WAUTERS et al., 2008).

Table 2. Total biomass and carbon stock in rubber tree plantations – data obtained in current study and in the literature.

Source	Location	Age (yr)	Total biomass (Mg ha^{-1})			Carbon accumulation rate (Mg C ha^{-1} yr^{-1})
			Aboveground	Roots	Total	
Current study	Brazil (PR)	4	9.35	2.58	11.93	1.26
	Brazil (PR)	6	28.00	6.33	34.33	2.43
	Brazil (PR)	15	124.12	22.18	146.30	4.17
Cunha et al. (2000)	Brazil (BR)	12 (a)	114.4*	46.4*	160.8*	-
	Brazil (MG)	12 (b)	56.9*	13.9*	70.8*	-
Cotta et al. (2006)	Brazil (BA)	34	136.82	32.4	169.22	2.49
Fernandes et al. (2007)	Brazil (MG)	12	88.67	37.79	126.46	4.72
Wauters et al. (2008)	Brazil (MT)	14	-	-	-	2.97†
	Ghana	14	-	-	-	5.45†
Dey (2005)	India	6	33.9	14.4	44.4	3.58
	India	17	141.1	29.1	170.2	4.48
Yang et al. (2005)	China	4	-	-	9.6†	1.20
	China	6	-	-	24.5†	2.05
	China	16	-	-	132.7†	4.15
	China	38	-	-	340.0†	4.47

*Assuming the average plant density for State of São Paulo, Brazil: 460 trees ha^{-1} (FRANCISCO et al., 2004). †Using allometric equations.

Soil Carbon Dynamics

The position of the soil sample with respect to the rubber tree row and plantation age affected the total soil organic carbon (SOC). Samples that were taken at greater distances from the trees (4 m from the planting row) had lower SOC levels than samples that were taken at a distance of 2 m, and the oldest plantation had the highest SOC (Table 3). The SOC content in the layer that was within the top 20 cm was significantly higher ($p < 0.07$) in the 15-year-old rubber tree plantation, averaging 15.6 ± 0.97 Mg C ha^{-1}, compared to the 4-year-old plantation and the pasture, which had means of 11.4 ± 0.83 and 10.7 ± 0.92 Mg C ha^{-1}, respectively (Figure 1a). However, at the greatest sampled depth, the SOC was similar between all of the sites, ranging from 19.4 ± 1.06 to 21.0 ± 0.68 Mg C ha^{-1}. The intermediate layer (20 to 40 cm) showed large variability in SOC for all of the sampled sites. The total carbon stock in the top 60 cm of the soil was 63.4 Mg C ha^{-1} for the pasture and 66.8 and 79.3 Mg C ha^{-1} for the 4- and 15-year-old rubber tree plantations, respectively. The differences in observed SOC for the two positions with respect to the tree rows were also present in $\delta^{13}C$; the lowest $\delta^{13}C$ values were found at 2 m in the 15-year-old plantation (Figure 1b).

Table 3. Organic carbon (C) levels in soil sampled at 2 and 4 m distance from the tree row in 4- and 15-year-old plantations and from pasture, in Paranapoema, Brazil.

Depth (m)	Rubber tree age / distance from tree row								Pasture	
	15yr / 2m		15yr / 4m		4yr / 2m		4yr / 4m			
	C	SE	C	SE	C	SE	C	SE	C	SE
	g kg^{-1}									
-0.05	9.8	0.10	9.4	0.07	8.8	0.09	6.7	0.08	6.5	0.03
-0.15	11.3	0.11	9.9	0.08	7.6	0.05	6.3	0.03	7.3	0.08
-0.3	9.8	0.16	7.7	0.06	8.0	0.05	7.1	0.03	7.3	0.06
-0.5	6.6	0.05	7.0	0.02	6.7	0.03	6.7	0.03	6.3	0.03

The carbon content in the top soil layer increased as the land transitioned from pasture to young and then to old rubber tree plantations (Figure 1a). The greater SOC in the rubber tree plantations compared to the pasture is likely caused by the greater inputs of organic material in the tree-based system. As a semi-deciduous crop, the rubber tree adds organic matter to the soil surface every year through litter deposition during the wintering period. Because wintering effects usually begin when trees are 4 to 5 years old (GEETHA; JACOB, 2003), the SOC increase through leaf litter deposition becomes more significant as the rubber trees age. The increase in SOC is also observed to a great depth due to the older plantation's well-developed root systems. The larger biomass accumulation rate in the 15-year-old plantation when compared to the 4-year-old plantation corresponded to the higher SOC increase. The growth of the rubber tree from 4- to 15 years old resulted in an SOC carbon sequestration rate of 1.1 Mg C ha^{-1} yr^{-1} to a 60 cm depth. This rate is approximately 20 % of the accumulation rate that was observed in the biomass during the same period (5.2 Mg C ha^{-1} yr^{-1}). When combined with the plant belowground accumulation rate (the roots), this rate increases to 1.9 Mg C ha^{-1} yr^{-1}.

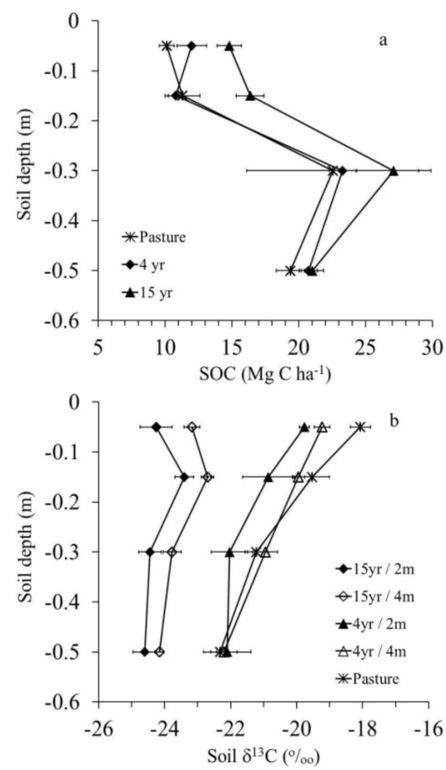

Figure 1. Soil measurements at the pasture, 4- and 15-year-old rubber tree plantations in Paranapoema, Brazil. (a) soil organic carbon (n = 8 at each depth at rubber tree plantations, and n = 4 at each depth at the pasture); (b) $\delta^{13}C$ at different distances from the tree row. Horizontal bars represent ± SE.

An increase in SOC was also observed by Yang et al. (2005), who determined that the annual SOC increase in Chinese rubber tree plantations that were established on formerly arable land was 0.72 Mg C ha^{-1} yr^{-1} to a 100 cm depth. However, Araujo et al. (2004) found no significant differences between the SOC values in areas managed as pasture (9.1 g C kg^{-1}) or rubber tree plantations (8.8 g C kg^{-1}) after approximately 25 years had elapsed since the conversion of the natural forest.

Over the course of fifteen years, the switch from pasture to rubber tree plantation resulted in a significant increase in the proportion of SOC derived from rubber tree vegetation in the 0-60 cm layer. Using equation [1], the SOC in the pasture, which is considered here as being equivalent to the SOC at the time of rubber tree planting, was estimated to contain 48 % *Brachiaria-Urochloa*-derived carbon (C4), while 52

% was derived from the earlier C3 vegetation (i.e., coffee and native forest) (Figure 2). As the rubber trees became established, carbon from the leaves and roots was added to the soil, which increased the contribution of the C3-derived SOC to 57 and 82 % for the 4- and 15-year-old plantations, respectively. The contribution of C4 vegetation to SOC in the pasture varied from 70 % in the 0-10 cm layer to 30 % in the deepest layer sampled; these results reflect the addition of *Brachiaria-Urochloa*-derived carbon to the surface soil layers (data not shown). After 15 years of rubber tree growth, all of the soil layers demonstrated increased levels of C3-derived carbon, ranging from 75 to 86 %.

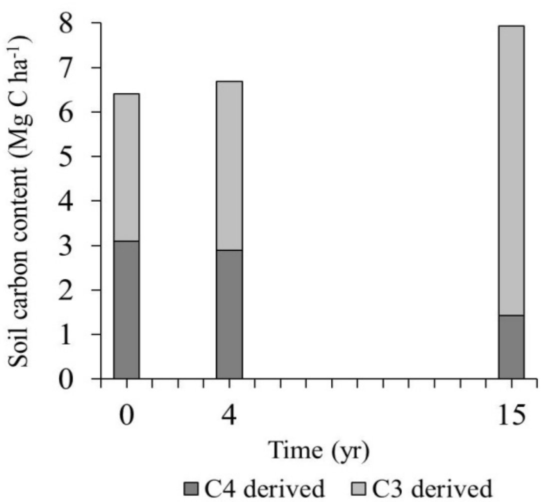

Figure 2. Amount of C3- and C4-derived carbon in the 0-60 cm soil layer of a pasture (0 yr) and rubber tree plantation after 4 and 15 years in Paranapoema, Brazil.

The $\delta^{13}C$ values measured in the current study were within their typical range for C3- or C4- derived SOC values. The site history indicates that the vegetation was predominantly composed of C3 plants, in forest or coffee plantations, until 1975. The introduction of pasture caused a shift to $\delta^{13}C$ values that are typical of C4 plants, and this shift occurred mainly in the 0 - 20 cm layer (Figure 1b - pasture). Following the introduction of rubber trees, a new shift in the soil $\delta^{13}C$ was observed to a depth of 30 cm for the 4-year-old plantation and down to 60 cm for the 15-year-old plantation. This shift reflects the greater input of residues from C3 plants, such as that derived from tree litterfall and fine root turnover, in the rubber tree plantations.

The shift in the soil $\delta^{13}C$ signature 4 years after the rubber trees were established indicates relatively rapid organic carbon dynamics. Similar changes were observed by Martin et al. (1990) in a study that showed losses of C4-derived carbon in the soil in an area in which savanna vegetation (C4) was slowly replaced by woody vegetation, which was composed primarily of C3 plants. The maximum changes in $\delta^{13}C$ occurred in the surface soil layer (0 - 10 cm), and in 16 years, 53 to 71% of the C4-derived carbon was lost. By studying the soil carbon dynamic at 11 different sites, Cerri et al. (2007) evaluated the land use change from forest to pasture and its influence on the SOC $\delta^{13}C$ value. They modeled that in the top soil layer, the shift from forest-derived carbon to approximately 50% pasture-derived carbon occurred within 10 to 30 years after the pasture was introduced, and no significant changes in $\delta^{13}C$ occurred afterwards.

The present study has demonstrated the great potential of rubber tree plantations for carbon sequestration in a relatively short time period in the northwestern region of the Paraná State in Brazil. The study also indicates the significant, untapped potential of rubber trees as a means to sequester carbon in a context of rapidly accelerating climatic change. Furthermore, because the growth of rubber trees occurs primarily in developing nations, it provides the following tangible additional socio-economic benefits: the potential to provide carbon credits to plantation owners, the ability to tap the latex of the rubber trees while the trees are grown, and the possibility to grow additional crops between the rubber tree rows.

Conclusion

The introduction of the rubber tree plantation to a former pasture land resulted in an increase in the soil carbon stock when compared to the pasture, and this increase was attributed to the plantation's root biomass and annual leaf deposition. When comparing plantations of different ages, a biomass accumulation rate that increased over time was observed. The stable isotope technique confirmed that the increased soil carbon was derived from the rubber tree inputs, indicating an increased proportion of C3-derived carbon at the oldest plantation. After 15 years of rubber tree growth, all of the soil layers showed increased levels of C3-derived carbon. This relatively rapid shift from the predominance of C4- to C3-derived carbon is common in tropical regions due to the warm and humid conditions, which lead to a high organic matter decomposition rate.

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