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Potential of Rubber Plantations for Environmental Conservation in Amazon Region

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ABSTRACT

The Amazon is the largest tropical rainforest in the world. Its conservation is important to avoid world climate changes, especially rising atmospheric temperature, release of greenhouse gases and control of the water cycle. The objective of this review is to discuss the potential of planting rubber trees as a source of income and C storage and to demonstrate the advantages of their introduction in a sustainable form to reduce the concentration of CO_2 in the atmosphere. In the humid tropical Amazon, in upland soil areas, rubber monoculture plantations present the lowest estimated evapotranspiration compared with a natural forest. The potential carbon sequestration in total dry weight of adult rubber plantations is estimated in 275.1 ton ha^{-1}. In the latter case this is comparable with the average values found for primary forests (240 ton ha^{-1}) and tropical agroforestry systems (95 ton ha^{-1}), respectively. Another advantage is the carbon accumulation in soil cultivated with rubber trees in monoculture and polyculture plantations. The cultivation of rubber trees by small farmers will have less impact on fauna because these farmers will maintain more extensive forest plots. Furthermore, if smallholdings can have at least one perennial crop as a main source of income, communities in the Amazon will reduce the rate of deforestation in comparison with that necessary for short-cycle annual crops.

Keywords: *Hevea* spp., carbon sequestration, greenhouse effect, smallholdings, edaphoclimatic conditions

CONTENTS

INTRODUCTION

The genus *Hevea* has a native range covering the Brazilian Amazon region along with the contiguous areas of Bolivia, Colombia, Peru, Venezuela, Ecuador, Suriname and Guiana - 7.5 million km^2, three-fourths of South America. Of the eleven species of the genus, the one originating in Brazil, *Hevea brasiliensis*, has the greatest productive capacity (99% of the natural rubber produced in the world), quality and genetic variability (Goldthorpe and Tan 1996).

The natural rubber obtained by tapping these trees in the wild became extremely valuable in the latter part of the 19th and start of the 20th centuries, causing a "rubber boom" in the Amazon. But after 1912, this cycle entered in decline, mainly due to the entrance in the market of rubber from commercial plantations in Asia, particularly Malaya (then a British colony and now the independent country Malaysia) (Weinstein 1983; Gasparotto *et al*. 1997).

This cultivation, starting only in the early 19th century, made the trees the last important plant species domesticated by humans. Worldwide rubber cultivation today covers an area of around 10 million ha, 92% of which is located in Southeast Asia (7.2 million ton, representing 78% of worldwide production), where rubber growing is the main source of support for 20 million rural producers, in most cases smallholders with 0.5 to 3.0 ha - 85% of area (IRSG 1999). Among the factors behind this successful Asian expansion are the absence of South American leaf blight, caused by the fungus *Microcyclus ulei*, and the greater suitability of perennial tree crops to the humid tropics, because they conserve a great part of the structure that determines the matter and energy exchange relations of tropical rainforests. Another factor is their stability in the face of extreme weather conditions, determined by the levels of solar radiation and rainfall. Other agroecosystems, such as pasture and annual crops (such as rice), which have structures and growth patterns very different from primary forest, have proved to be less sustainable in humid tropical regions (Moreira and Fageria 2008).

The conversion of tropical primary forest, such as the Central Amazon, into farms planted with cash crops has for the most part had significant negative impacts on this ecosystem, but there are some alternatives. In Brazil the degraded area with pastures is, approximately, of 17.5 million ha the rubber tree is a viable option. Reports of up to three successive cultivation cycles in a single area (± 90 years) without loss of productivity, show that the system can function sustainably, as the result of the performance of dif-

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ferent components of its dynamic, the most relevant examples of which are discussed below.

WATER CYCLE

Cabral (1991) studied the water balance for two consecutive years (1985 and 1986) of a plantation of adult rubber trees in comparison with the adjacent primary forest, under edaphoclimatic conditions (Dystrophic Yellow Latosol – Embrapa 1998 or Xanthic Ferralsol – FAO 1990), average air temperature of 26°C and atmospheric humidity around 85% –Schroth *et al*. 1999) of the Western Brazilian Amazon (40-50 m a.s.l.). The driest months are July to September, and the wettest months are February to April (Schroth *et al.* 1999).

The differences found were related to the greater leaf area index (LAI) of the forest, due to its great diversity of species, associated with the low density of deciduous trees. In the rubber plantation, the LAI was smaller, falling nearly to zero for a period longer than a month because of the species' annual leaf exchange. As a consequence, the rain interception by the forest canopy was greater and resulted in an average daily evapotranspiration rate of 3.4 ± 0.4 mm day^{-1}. In the rubber plantation this rate was 2.5 ± 0.6 mm day^{-1}, corresponding on average to 73.5% of the forest's evapotranspiration. Because of the greater interception, the forest returned 50% of the rainfall to the atmosphere, while the rubber plantation returned 35% to the system. In similar conditions, pasture returned 65% to the atmosphere (**Table 1**).

In contrast, the levels of water stored in the soil under the rubber trees were higher than in the primary forest and in mixed areas of the Western Amazon (**Table 1**), remaining near the field capacity in the rainy season and always above 70% in the dry season. Under the forest the water in the soil was below field capacity during brief dry spells of the rainy season, falling to levels around 60% in the dry season. In both the rubber plantation and forest the surface runoff was nearly zero due to retention by the vegetation and litter and also the good soil drainage (Teixeira 2001). In plantations of *H. brasiliensis* in Malaysia, grown on rolling terrain under higher rainfall than in the Brazilian Central Amazon, Haridas and Subramaniam (1985) recorded 0.5% surface runoff. This result was certainly due to the 18 to 24% rainfall interception, caused by the lower leaf area of the rubber trees and plant population per area.

According to the type of topography, these results show that depending on the extension of the area planted with rubber trees, the nearby water sources can be more plentiful, with the evapotranspiration rate demonstrated by Cabral (1991). In continuous plantations it would be necessary to cover a very wide area, which would not be currently feasible in the conditions of the humid tropical Western Amazon, faced with the cost of inputs and soil correctives and deficient marketing infrastructure. Only this kind of management with rubber tree monoculture could significantly reduce the convection rains, which are responsible for 50% of the total precipitation of the Amazon region (Salati 1987).

Rain interception and evapotranspiration values nearer those of the primary forest should be registered in rubber trees plantations with crowns budded with *Hevea pauciflora*, hybrids of *H. pauciflora* with *H. brasiliensis* and hybrids of *H. pauciflora* with *H. benthamiana* or *H. guianensis* resistant to South American leaf blight (*Microcyclus ulei*) (Pinheiro *et al*. 1988). These are evergreen species with LAI nearly 50% higher than clones of *H. brasiliensis* (Moraes and Moreira 2003). Even among the clones of this species there are substantial differences in rain interception in function of the crown volume and density (Haridas and Subramaniam 1985).

Table 1 Annual balance in a mixed area (annual crops, polyculture and moculture plantation, fallow, cities and primary forest), rubber monoculture and primary forest contiguous in a upland soil of Western Amazon - Amazonas State, Brazil (Cabral 1991).

	Rainfall (mm)	**Evapotranspiration**	**Balance[1]**
Mixed area	2243	1787 (80%)	456 (20%)
Primary forest	2434	1217 (50%)	1217 (50%)
Rubber plantation	2532	894 (35%)	1638 (65%)
Pasture	1978	1281 (65%)	697 (35%)

[1] Balance – Water storage and drainage (Rainfall – Evapotranspiration).

PHYTOMASS ACCUMULATION

The phytomass accumulated by rubber trees is highly variable according to the plant age, species, clone, density, health and nutritional state, along with environmental conditions and management techniques. Polinière and Brandt (1967) found, in the Yangambi Biosphere Reserve (Democratic Republic of Congo, Africa), that the shoot dry weight (DW) per plant was 0.52 ton for 20-year-old clones of *H. brasiliensis* PR107. Dyck (1939) found, in the edaphoclimatic conditions of Singapore, dry weight output of 3.56 ton from a seed-propagated rubber tree with an age of about 35 years in an isolated area, while Shorrocks (1965a) reported production of 4.59 ton of DW per plant in 33-year-old Tjir 1 clones for untapped trees and 2.12 ton of DW in the same stand for tapped trees.

The phase of maximum phytomass accumulation starts after the closing of the canopy, which can occur starting in the fifth year with vigorous clones under good growing conditions. Under these conditions, with the LAI equal to 5.8, the primary productivity was 35.8 ton ha^{-1} of dry matter per year (Templenton 1968).

The shoot DW production figures reported by Shorrocks (1965a) and Shorrocks *et al*. (1965) were obtained by determining the fresh and DW of the leaves, stems, branches, trunks and roots. The root DW was determined in eight-year-old plants, in which it corresponded to 15% of the aerial parts' DW. If this proportion is maintained, the data from Shorrocks (1965a) coincide with the findings of Templenton (1969), who recorded average production of 0.24 ton $plant^{-1}$ of DW from PR107 clones up to 10 years old at the start of the tapping phase.

To estimate the shoot DW of *H. brasiliensis*, based on direct measurement, Shorrocks *et al.* (1965) proposed the following formula:

$$\text{Log}A = 2.7826\log B - 2.5843 \text{ or } A = 0.002604B^{2.7826},$$

where:
A = Shoot dry weight (kg)
B = Trunk girth of 1.3 m from the graft point (cm).

Although there are equations with fixed constants for many clones, Shorrocks *et al.* (1965) stated that the general use of a single equation is more coherent, since the errors caused by variations from the type of management and local edaphoclimatic conditions are of the same order of magnitude as those caused by variations among clones. In the case of budded crowns with *H. pauciflora* or hybrids (Pinheiro *et al*. 1988; Moraes 2000), an extra 10 to 20% should be added to the output of dry weight due to the greater crown volume compared with *H. brasiliensis*.

In view of the amplitude of variation of dry weight and the possibility of its estimation based on the girth of the trunk, it is possible to determine the quantity of carbon contained in the phytomass, which is therefore no longer an important theme for research with this objective.

As mentioned previously, the total dry weight accumulated depends on the number of plants per hectare. With an assumed density of 250 plants ha^{-1} for cultivation in Malaysia (Dijckman 1951) with phytomass yields estimated at 2.12 ton $plant^{-1}$ of DW at the end of exploitation (33 years) in Malaysia (Shorrocks 1965a), the DW outputs can reach 529.5 ton ha^{-1}. In the former case this is comparable with the values of 504 ton ha^{-1} (Klinge 1976) and 562 ton ha^{-1} (Bernard-Resersat 1978) obtained in native tropical forests in the Brazilian Amazon and Ivory Coast, respectively.

With a conversion factor of 0.45, as proposed by Botkin *et al.* (1993) to estimate the potential storage of organic carbon (OC) existing in the total dry weight biomass, carbon fixation in the two examples, without accumulation of litter, was 238.3 (Malaysia) and 74.3 ton ha^{-1} (Brazil) in total dry weight. A further 36.8 and 11.2 ton, respectively, should be added, corresponding to the production of 46 and 14 ton of dry rubber obtained during the commercial exploitation phase.

In tropical agroforestry systems, the potential carbon sequestration is estimated at between 12 and 228 ton ha^{-1}, with average values of 95 ton ha^{-1} (Albrech and Kandji 2003), while abandoned pasture and 20-year-old secondary forest have potential of 81 and 110 ton ha^{-1}, respectively (Uhl *et al*. 1988; Salomão *et al*. 1996). In Rondônia State, Brazil, the C storage in pasture (stock raising is the main activity in the Brazilian Amazon) with a mean age of about 10 years was 28.3 ton ha^{-1}, with almost 20 ton ha^{-1} (69%) in the form of OC (Fujisaka *et al*. 1998). Edaphoclimatic conditions, forage and soil management resulted in differences observed between pastures.

The use of rubber wood to make furniture and the other purposes extends the longevity of the carbon storage, keeping it from returning to the system. Consumption of regenerated rubber, and more recently the use of shredded rubber from old tires mixed with asphalt to pave roads, also have the same effect. Therefore, based on the Earth's area that is suitable for the rubber monoculture cultivation (10×10^6 ha), an average value of 5,295 million ton C could be stored in the terrestrial ecosystems over 33 years.

CYCLING OF NUTRIENTS

The return of nutrients to the soil from falling leaves, stems, flowers and fruits also varies depending on the species, edaphoclimatic conditions, clone, management and plant health. This must also be taken into account in calculating the C storage in the system.

The annual deposition of total litter under adult rubber trees ranges from 5 to 7 ton ha^{-1} of DW (Watson 1964; Shorrocks 1965a; Bi and Omont 1987). In the humid tropical Amazon, where South American leaf blight is endemic, the cultivation of rubber trees is actuality viable with the use of crowns budded with *H. pauciflora* or with hybrids of this species (Pinheiro *et al*. 1988). Through this technique, the average annual accumulation in monoculture was 5.1 ton ha^{-1} of only dry leaves in rubber trees cultivated in the Western Brazilian Amazon, which corresponds to over 6 ton ha^{-1} with the inclusion of branches and fruits (Moraes and Moreira 2003). This figure is 82.2% of that recorded in the primary forest in the same edaphoclimatic conditions (Klinge and Rodrigues 1968). An average value of 6 ton ha^{-1} of accumulated litter also was reported by Brown (1980) in different tropical forests around the world.

To introduce the cultivation of rubber trees or any other crops in a humid tropical ecosystem, it is generally necessary to cut down trees with high economic value and remove and burn off the remaining material (Andreux and Cerri 1989). Even though the natural dynamic of the organic matter had been broken by these anthropic activities, Bi and Omont (1987) found that in rubber plantations after 20 years, even though the organic matter content was 30% lower than in primary forest, there was cation exchange capacity (CEC) restitution, water retention and the ratio between fulvic acids (low stability) and humic acids (high stability) was restored.

In India, in soil cultivated with two cycles of rubber trees (60 years), the organic C content was near that of primary forest, but there was an increase of available P derived from litter and a small decrease of total N and exchangeable K (Karthikakuttyama *et al*. 1998). These numbers make sense, because after the first cycle it is almost unnecessary to use phosphate fertilizers to promote the accumulation of phytomass until the new trees are ready to be tapped. Moreira (2007), studying the accumulation of organic matter and the dynamic of soil microbial activity in the Western Amazonian, found that under 17-year-old rubber trees, with crowns budded with *H. pauciflora*, in the layer from 0-10 cm in depth, that the organic C (26.8 g kg^{-1}) was 65% and microbial biomass (179.1 mg kg^{-1}) were 68% of the levels found in the soil of the adjacent primary forest (41.3 g kg^{-1} and 265.3 mg kg^{-1}). These figures are representative, because the area for planting had been cleared with a bulldozer and the entire organic layer removed. The same author also measured the C storage in samples from depths of 0-60 cm, removed from the same rubber plantation, finding approximately 517 ton ha^{-1} of C, compared with 656 ton ha^{-1} in the primary forest soil.

An important characteristic of the production of natural rubber is that the product extracted from cultivated areas has a hydrocarbon composition of 91 to 96% (Morton 1989),

Table 2 Nutrients exportation of in perennial and annual tropical and subtropical crops with yield of 50 t ha^{-1} of product.

Tropical crops	Yield	N	P	K	Ca	Mg	Area	Authors
				(kg)			(ha)	
Oil palm	Oil	2040 (102)[1]	600 (30)	4140 (207)	720 (36)	760 (38)	20	Mengel and Kirkby 2001
Sugarcane	Cane	162 (324)	16 (36)	122 (244)	140 (280)	22 (44)	0.5	Nogueira *et al*. 2007
Banana	Fruit	189 (189)	29 (29)	778 (778)	101 (101)	49 (49)	1	Lahav 1995
Rubber tree	Dry rubber	307 (6.8)	27 (0.6)	9 (0.2)	2 (0.04)	37 (0.8)	45	Haag *et al*. 1987
Corn	Grain	1069 (213.8)	207 (41.4)	773 (154.6)	158 (31.6)	163 (32.6)	5	Coelho 2006
Soybeans	Grain	2925 (265.9)	300 (27.3)	895 (81.4)	95 (8.6)	120 (10.9)	11	Bundy and Oplinger 1984
Coconuts	Dry copra	2214 (61.5)	893 (24.8)	2000 (55.6)	214 (5.9)	429 (11.9)	36	Mengel and Kirkby 2001
Citrus	Fruit	220 (61.1)	45 (12.5)	251 (69.7)	64 (17.8)	13 (3.6)	3.6	Boaretto *et al*. 2007
Cotton	Seed + Lint	1323 (45.6)	323 (11.1)	412 (14.2)	59 (2.0)	118 (4.1)	29	Mengel and Kirkby 2001
Cupuassu	Pulp	-	150 (6.0)	175 (7.0)	20 (0.8)	15 (0.6)	25	Gondin *et al*. 2000
Tea	Dried leaves	2370 (62.4)	192 (5.1)	1154 (30.4)	231 (6.1)	-	38	Mengel and Kirkby 2001
Coffee	Grain	855 (22.5)	50 (1.3)	765 (20.1)	135 (3.5)	75 (2.0)	38	Malavolta *et al*. 1963

[(1)] Between parenthesis is nutrient exportation per hectare.

Table 3 Nutrient cycling in an adult rubber tree monoculture and input of nutrients with the rain and later nutrients leaching in the tropical primary forest in Amazon upland soil (Watson 1964; Shorrocks 1965a; Shorrocks 1965b; RRIM 1972; Jordan 1982; Haag 1985).

Occurrence form	N	P	K	Ca	Mg
			(kg ha^{-1})		
Storage - phythomass	1431	203	938	1604	289
Annual restitution - leaf fall	131	7	41	68	12
Storage - litter	64	9	42	-	17
Storage - soil	118	32	396	275	116
Input of nutrients - rain(1)	-	8	13	10	4
Nutrients leaching(1)	-	9	5	3	1

(1) Relativity quantity of pluviometer precipitation - 3372 mm (average of 1976-1979), in a humid tropical Amazon forest, Venezuela.

Table 5 The Worldwide and Brazil production and consumption of natural and synthetic rubber - 2005 to 2006 (IRSG 2006; IRSG 2007).

	2005		2006	
	World	**Brazil**	**World**	**Brazil(1)**
Natural rubber				
Production (million ton^{-1})	8,920	105	9,700	110
Participation of Brazil (%)		1.2		1.2
Consumption (million ton^{-1})	9,100	395	9,200	310
Participation of Brazil (%)		3.3		3.5
Synthetic rubber				
Production (million ton^{-1})	12,060	385	12,500	445
Participation of Brazil (%)		3.2		3.5
Consumption (million ton^{-1})	11,900	395	12,800	400
Participation of Brazil (%)		3.3		3.2

(1) Estimation - 2006.

so the exportation of N, P, K, Ca and Mg is very low when compared with other tropical crops (**Table 2**). Another important point is that to produce 50 ton ha^{-1} of dry rubber on 45 ha, the rubber trees need proportionally lower amounts of fertilizers than sugarcane, oil palms, soybeans, cotton and banana plants, in crops of 0.5, 20, 11, 29 and 1.0 ha, respectively (**Table 2**).

A further advantage of rubber planting in this ecosystem is the sum of factors, which favors the nutrient cycling dynamic in adult rubber tree plantations and primary forests (**Table 3**). As already mentioned, the levels of annual return of nutrients to replace those exported by the production of rubber are small when compared with other crops (**Table 2**).

Despite this small nutritional requirement, most soils of the Amazon region are characterized by low nutrient availability (90% of soils) with predominance of clays kaolinite and sand washed in from the Brazilian and Guiana Shields (Stark 1970; Moreira and Gonçalves 2006). The soil has been subject to intensive weathering and leaching throughout much of geological history. Their fertility is maintained by cycling of nutrients, mainly due to geochemical, biochemical and biogoechemical processes (Moreira and Fageria 2008). So, to introduce rubber trees in a new area, it is necessary to use fertilizers and pH correctives during the immature phase to speed growth until the canopy closes or tapping can begin.

CARBON GAS EMISSION

The small demand for nutrients and low fossil fuel consumption for manufacture makes natural rubber environmentally compensating. While it takes between 108 and 174 GJ to produce 1 ton of synthetic rubber (finite product), the same amount of natural rubber only takes 13 GJ to make (IRRDB 1998). Each metric ton of natural rubber produced instead of synthetic rubber corresponds to a reduction of 4.8 ton of carbon into the atmosphere. This, added to the total C fixed in shoot dry weight and that of the rubber produced, corresponds to 1019.2 ton ha^{-1} of CO_2, in plantations with 33-year-old trees (Shorrocks 1965a; Apabor 2003), but this value is lower than the primary forest with trapping nearly 4000 ton ha^{-1} of CO_2 per year.

Products such as condoms, surgical gloves and airplane tires can only be made with natural rubber. With the increase in world consumption and price (**Table 4** - IRSG 2007), due to the higher demand of Asian countries, particularly China, demand tends to outstrip supply of rubber (synthetic and natural). Despite of Brazil has been the center of origin, participates with only 1.2% of worldwide production of natural rubber and 3.3% of synthetic rubber, while the consumption was 3.5 and 3.2%, respectively (**Table 5**).

CONCLUSIONS

This manuscript provides a description of the potential of the rubber tree (*Hevea* sp.) for environmental conservation and C sequestration capacity in humid tropical Amazon forest. The Brazilian Amazon region has over 65.2 million ha^{-1} of anthropized areas where monoculture and polyculture rubber plantations can be introduced. The many smallholdings in the region can be appropriate locations for establishment of rubber culture and this can contribute significantly to more sustainable Amazon development.

Monoculture rubber projects in the humid tropical Amazon in degraded areas, mostly with pastures and grains, with the use of budded crown and annual crops during the period while the trees are maturing, are a viable option to sustain smallholders, with less impact on the region's fauna and flora.

Other advantages of rubber growing are the presence of regular monthly income once the trees are mature enough to be tapped, because rubber trees are not subject to biotic and abiotic stresses that can affect production of annual crops, and reduced use of chemical fertilizers and other substances. This latter is a significant factor because of the high costs and difficulty of acquiring agricultural inputs in the region. Besides the fact that rubber tapping is traditional in the region (albeit from native instead of cultivated trees), the introduction of rubber growing along with annual and semi-annual crops in small farming communities in the Amazon will reduce the rate of deforestation by subsistence farmers.

In these communities, rubber growing can also act as an efficient instrument for income distribution, as occurs in the main natural rubber producing countries, where the largest percentage of output comes from smallholdings. For this to be feasible in Brazil, it will be necessary to train small farmers, with government support, to disseminate the existing technologies, and more importantly, to subsidize the acqui-

Table 4 Worldwide natural and synthetic rubber production, consumption and price - 2002 to 2007 (IRSG 2007).

Years	Production		Consumption		Price	
	Natural	Synthetic	Natural	Synthetic	Natural	Synthetic
			(million ton^{-1})			(US$ ton^{-1})
2002	7.3	10.9	7.6	10.9	856	1092
2003	8.0	11.4	7.2	11.3	1120	1263
2004	8.7	12.1	8.0	11.7	1350	1339
2005	8.9	11.9	9.1	12.2	1535	1607
2006	9.7	12.5	9.2	12.8	2113	1710
2007(1)	6.9	10.0	7.2	9.9	2200	1921

(1) Σ(first, second and third trimester).

sition of seedlings, budded onto clones and budded crowns, and the fertilizers necessary for re-introduction of the rubber culture in sustainable commercial form in its region of origin.

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