Review

Reforestation: the dynamics of safe, efficient CO_2 storage

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The Brazilian Ministry of Science and Technology (MCT) / National Council for Science and Technological Development (CNPq) financed the research project "Identification and Quantification of the Main Chemical Components of *Mimosa scabrella* Benthan, related to Forest Management Parameters". One of the objectives of the study was to determine the dynamics and structure of carbon fixation in reforestation, quantitatively and qualitatively. It examined permanent carbon storage in living trees using conventional reforestation practices aimed at producing diverse traditional products. The carbon density decreased with the diameter class of the stands : the carbon density in non-dominant trees was 310 kg/m^3, while it was 280 kg/m^3 in dominant trees. The production function for carbon assimilation C (ton/ha) was given by the model :

$$C = I^2 / (0.154397 - 0.011314 \times I + 0.026268 \times I^2),$$

where I is stand age (years). This permitted calculation of the productive structure. For continuous production, in the optimized regime, the forest in 30 rural farms should be divided into four age classes, each with the same area of production (167.84 ha) ; this would maintain a permanent stock of 13,131 tons of carbon in the living population of *Mimosa scabrella*.

Keywords : carbon structure in forest stands, dynamic assimilation of CO_2 molecules in a forest, structure and dynamics carbon storage with reforestation, greenhouse effect, climatic changes

Introduction

The polemics surrounding the greenhouse effect on the Earth have increased in recent years. Some researchers are warning of the dangers of human activities, while others consider it no more than a natural cycle of the solar system. Regardless, we have been faced with undeniable alterations in the biosphere since the advent of the industrial era.

According to Rifkin (1990), the biosphere has a deficit in its vegetation mass equivalent to the area of Australia. The scientific basis for the mechanisms for clean development, expressed by the law of the accelerated effects of entropy (Hosokawa *et al.* 2001a), determines the necessity for an energetic balance among different components of the universe to maintain the species in the biosphere. This means that a balanced relationship between the masses of the lithosphere, hydrosphere, atmosphere, phytosphere, and anthroposphere is essential when analyzing the convertibil-

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ity of mass to energy articulated by Dr. Albert Einstein.

In the last decade, the governments of many countries suffering from severe environmental deterioration, worsened by extreme climatic events, have started to worry about declines in their gross national products. The options these countries face include: a) reducing the emissions of greenhouse gases, b) using energy in flux primarily, and c) building CO_2 sinks, since CO_2 is the main greenhouse gas.

The use of energy in flux, instead of diked energy, depends on the economic viability of the processes. Classic examples are replacing petroleum, natural gas, and uranium with wind and hydroelectric power, sustained phytomass production, etc. The potential to produce wind and hydroelectric power and arc-voltaic energy depends on geographic location, and is not easily altered. By contrast, it is feasible to produce energy from phytomass, as firewood, charcoal, alcohol, and vegetable oils, on a large scale. Moreover, phytomass plantations and their use are aimed at producing zero CO_2 emissions, although they are not a permanent CO_2 stock. Reforestation is one safe, efficient option for building permanent CO_2 sinks. This subject is considered in this paper.

The Brazilian Ministry of Science and Technology (MCT) financed the project "The Identification and Quantification of the Main Chemical Components of *Mimosa scabrella* Benthan, related to Forest Management Parameters". The objectives of this study were:

a) To conduct basic research into the quantitative and qualitative dynamics and structure of carbon fixation in reforestation.
b) To study the structure of permanent carbon storage in living trees without modifying the conventional reforestation practices used to produce diverse traditional products in order to develop a practical application.

Mimosa scabrella was studied because it is an energetic species (there is a high correlation between carbon presence and energy) that grows on short rotation (enabling calculation of the maximum mean productivity and maximum marginal production in carbon fixation (ton/ha), without resorting to prognostic methods, which always involve projection errors). Moreover, it is a native species, demonstrating that autochthon species can be used for carbon assimilation.

In addition, the investigation was conducted carefully so that the variables and parameters considered could be universally applied when considering reforestation, *i.e.*, to all types of soil, climate, species, etc.

Background to the study

In 1993, the Forestry Engineering Course at the Federal University of Parana, started a multidisciplinary research group to develop studies of the quality and productivity of primary forest, in three research areas: 1) Quality and productivity in the utilization of productive site capacity, which was realized in a case study of *Pinus elliottii* (Hosokawa *et al.* 2001b); 2) A production model for superior quality wood, developed in a case study of *Eucalyptus grandis* (Hosokawa *et al.* 1998); and 3) The identification and quantification of the major chemical components of wood and bark, within the parameters of forest management, using *Mimosa scabrella* as a case study. The latter research produced a great deal of new information, including papers on: a) the dynamic assimilation of CO_2 molecules in reforestation (Hosokawa 2000); b) the structure of the carbon molecules fixed in reforestation (Rochadelli and Hosokawa 2001); c) hemicelluloses in the xylem and phloem of *Mimosa scabrella* (Rochadelli *et al.* 2001); d) determining the bias in the basic specific mass and lignin in the *Mimosa scabrella* trunk (Hosokawa *et al.* 1996); e) qualitative and productive analysis through modeling the biochemistry parameters of *Mimosa scabrella* wood in plywood, energy, and pulp production (Hosokawa *et al.* 1997a); f) the evolution of polysaccharide research in *Mimosa scabrella* (Ganter *et al.* 1993) ; and g) determining the *Mimosa scabrella* rotation based on biomass and gross income criteria (Hosokawa *et al.* 1997b).

In 1995, a model of a sustainable forest focusing on mega-reforestation and the greenhouse effect, as well as quality and productivity, was presented at the VIIIth Brazilian Meeting of Forest Engineers - Brasilia-DF. That study stimulated the Brazilian Science and Technology Ministry to establish a Search Group Directory for the Scientific and National Council for Technological Development. The model was published in *Introducao ao Manejo e Economia de Florestas* (Introduction to the management and forest economics), pp. 115-128, published by UFPR Editors, in 1998 (Hosokawa 1998).

Mimosa scabrella Benthan

Mimosa scabrella belongs to the family Mimosaceae. It is a perennial tree that reaches heights exceeding 20 m with diameters at breast height (DBH) that rarely exceed 40 cm (Carpanezzi *et al.* 1988). It has a tall, elegant trunk when it grows in groups, but isolated trees are short and ramified. With sympodial, dense ramification, a clear to gray green umbrella-type crown grows. The young branches are pilose and reddish to brown in color.

Mimosa scabrella occurs naturally in the states of Sao Paulo, Parana, Santa Catarina, and Rio Grande do Sul (Fig. 1), at altitudes between 500 and 1500 m, where the Cfi climate type predominates. This area extends from latitude 23°50'S to 29°40'S and from longitude 48°30'W to 53°50'W.

The most important contemporary use of *Mimosa scabrella* wood is to produce energy, as firewood, to supply the demands of the lime, ceramics, and food industries. It is also used as charcoal. The wood is also used for braces in construction, and thin pieces are used in olericulture. Sawed or turned, it is used in furniture,

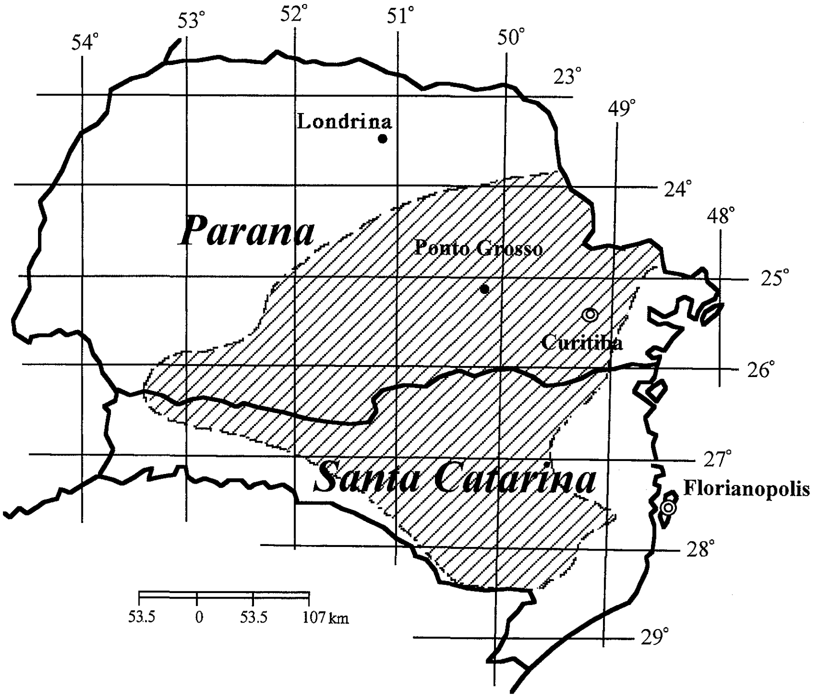

Fig. 1. *Mimosa scabrella* natural occurrence area in Parana and Santa Catarina States, Brazil. (Source: Soares and Hosokawa (1982))

some for export, after adequate drying and refining. It can be used to make veneer for general application. *Mimosa scabrella* wood is used to make toilet paper, through a mechanical pulp process, in a 20 to 80 mixture with *Pinus* spp. wood. The pulp can also be used to manufacture printing and writing paper. In addition, the species has potential for apiarists, as cattle food, and for the revegetation of degraded areas.

Agrisilviculture practices developed by colonists since the 19th Century

Mimosa scabrella agrisilviculture, widely practiced in the northern Curitiba region, secures a regular income for producers and is important in rural areas. It allows acceleration of the traditional culture rotations, without increasing input levels or capital. Its growth is adequate for the realities of rural producers, although it is labor intensive at specific times of the year. *Mimosa scabrella* is usually grown in association with maize and beans. Producers generally subdivide their workable land into a number of similar areas equal to the rotation period of the forest species (7 years), a basic pre-requisite of the Normal Forest model.

The social and economic importance of *Mimosa scabrella* agrisilviculture necessitates studies of aspects of its silviculture and the management of disposable resources, to allow permanent settlements in rural areas, while optimizing the income and quality of life of farmers (Hosokawa *et al*. 1997).

Permanent storage of CO_2 in living trees

To answer questions related to permanent storage of CO_2 in living trees, it is necessary to consider the concept of sustained yield. Physicists have proven that events in our Universe are not sustainable, because energy is not renewable. However, recent studies have demonstrated that relative sustainability is possible (Hosokawa 2000b) and this is the fundamental basis of the continuity of life in the biosphere.

Temporal sustainability is formal and neutral, and means projected duration of stability, return, solid basement, continuity and uniform effect (Baader 1942 ; Richter 1963 ; Speidel 1972). Sustainability necessitates the maintenance of forest areas, wood volume and value, corporate income, capital, work force, and so forth.

From a dynamic perspective, conservation of the volume increment, wood, finances, income, generation of values, capital, work yield, and infrastructure are necessary, since static sustainability is a pre-requisite of dynamic sustainability. Sustainability only results when these parameters are matched within a predetermined physical state with a dynamic flux. For this reason, Speidel (1972) defines sustainability as the capacity of a forest business to optimize the use of the wood, infrastructure yield, and other products to the benefit of current and future generations for a prolonged period. The Normal Forest is only a theoretical and explicative model of sustained yield, which can be considered in real models only when the static and dynamic attributes of the forest are qualified and quantified. This can be done for production units (forest areas) for which the functions of production and productivity can be determined.

In order to construct permanent stocks of CO_2 in living trees, it is necessary to determine mechanisms of the process of carbon atom fixation and maintenance over time to determine the dynamic assimilation of CO_2 molecules by a forest.

Applications of the new knowledge

As evidence of our knowledge of CO_2 storage in reforestation, a practical example of the procedure is presented here.

Formation of a forest based on continuous production

Thirty farms were grouped to form a forest, as

Table 1. Distribution of forest populations from *Mimosa scabrella* Benthan in the rural estates for the case study.

	Estates/area/age (ha)							Area with *M. scabrella*	Total area of estate
Ages	1 year	2 years	3 years	4 years	5 years	6 years	7 years	(ha)	(ha)
Estates									
1		2.50	2.50				2.50	7.50	15.00
2		5.63					1.88	7.51	8.75
3		1.25		0.63			0.63	2.51	7.50
4	1.25		2.50	2.50	5.00	1.88		13.13	37.50
5						5.00	1.88	6.88	12.50
6	5.00		1.25					6.25	7.50
7				2.50				2.50	7.50
8			5.00					5.00	12.50
9				1.25		1.25	1.25	3.75	17.50
10							6.25	6.25	12.50
11				5.00			2.50	7.50	10.00
12			10.00					10.00	21.25
13			1.25				0.63	1.88	12.50
14	1.25	1.88	2.50	2.50	2.50	1.88	1.25	13.76	25.00
15	1.88	2.50			2.50	1.25		8.13	20.00
16		1.25						1.25	6.25
17	3.75	5.00	1.88	1.88	2.50		3.75	18.76	25.00
18							5.00	5.00	12.50
19					2.50	2.50		5.00	7.50
20		2.50		1.88			3.75	8.13	17.50
21	1.25	1.25	1.25	1.25	1.25	1.25	1.25	8.75	15.00
22	0.63		0.63				1.25	2.51	30.00
23		5.00					3.75	8.75	17.50
24	7.50	5.00	7.50	7.50	5.00	7.50	7.50	47.50	55.00
25	5.00	5.00	7.50	5.00	7.50	12.50	10.00	52.50	93.75
26		5.00	5.00	7.50	2.50	5.00	5.00	30.00	42.50
27	3.75	2.50		12.50	5.00		2.50	26.25	75.00
28	6.25	16.25	15.00	3.75	6.25	11.25	15.00	73.75	150.00
29	10.00	7.50	7.50	7.50	10.00	7.50	13.50	63.50	150.00
30	35.00	48.75	56.25	62.50	60.00	52.50	80.00	395.00	600.00
Total	82.51	118.76	127.51	125.64	112.50	111.26	171.02	849.20	1,525.00

Source: Rochadelli (1997)

shown in Table 1.

Structure and dynamic fixation of carbon in reforestation

To quantify the carbon stored in the 30 farms, we determined carbon production data for sites of medium productivity in 27 experimental areas and obtained data on the age class distribution.

To determine the structure of carbon fixation in reforestation, data were collected for stands of each age class (1, 2, 3, 4, 5, 6 and 7 years). Within each stand, four quadrats were established, to monitor natural regeneration and determine the average productivity. The CBH (circumference at breast height) of all the trees of each quadrat was measured. Following the method of Hohenadl, the volumes of seven representative trees in each quadrat were determined. The trees were of size x-3S, x-2S, x-1S, x, x+1S, x+2S, x+3S, where x is the average size and S is the standard deviation.

Trees on the right end of the scale were dominant trees, and those on the left were non-dominant. In all, 28 trees were examined for each age class studied. In addition to determining the volume, the thickness of the bark of the representative trees was determined.

For chemical analyses to determine the carbon biomass, samples were taken from the representative trees. The trees were cut into logs between 30 and 50 cm in length, from the middle of each tree section, resulting in a total of five logs per tree.

Sawdust was prepared from these logs for chemical analysis. The logs were cut into disks, which were used to produce shavings. The shavings were broken in a mill, to produce sawdust of different sizes, which was sorted by straining (TAPPI - T 264om - 88).

The biomass was estimated from the trunk volume and specific mass. It was then multiplied by the basic specific mass for the volumes of each tree of each age and size class, using the formula :

$$P_S = \mathrm{Meb} \times V_V$$

where P_S is the dry weight of the bark, Meb is the basic specific mass, and V_V is the volume of wet bark.

The samples used for the chemical analyses were obtained from the sections of each tree, and the chemical composition of the trunk was determined from the values for each section and the relative size of the section in proportion to the total weight of the trunk. This method was used due to the variation in the properties and chemical composition of the wood with the trunk of a tree, as Hosokawa *et al.* (1996) demonstrated.

Chemical analyses were used to quantify the basic constituents of the trunk, *i.e.*, lignins and holocellulose, and the trace constituents, extracts, and ash, for both the wood and the bark. The concentrations of the extracts obtained in benzene-alcohol, cold water, and hot water were determined (TAPPI - T222om - 88 ; TAPPI - T204OM - 88 ; TAPPI - T207OM - 93 ; TAPPI - T207OM - 93).

From the basic specific mass and volume of each tree, we determined the dry weight of the wood and bark, allowing us to determine the dry weights of the basic and trace constituents.

The amount of carbon in each tree was determined from the lignin concentrations in the wood and bark, assuming that lignin is 60% carbon (IPT 1988). In the same manner, we determined the amount of carbon in holocellulose, which consists of cellulose and hemicellulose. The percentage of carbon in these two compounds is 71.56 and 28.44%, respectively (Romanowski 1986).

The amount of carbon was determined from the cellulose concentration using the dry weight of individual trees and the percentage of carbon in each glucose molecule, after considering the weight of water molecules lost during the linkage of glucose units in long cellulose chains. To evaluate the carbon concentrations in hemicellulose, acid hydrolysis of wood and bark samples from average trees of each age was performed to determine the relative amounts of various monosaccharides, which are the primary constituents of hemicelluloses, such as rhamnose, arabinose, xylose, mannose, and galactose. Determinations were made for wood and bark, starting with the hydrolysis of dry materials, separated with a 100 mesh, after Seaman (1954) as described by Bochicchio (1999).

In absolute terms, the total carbon biomass of individual trees varied from 0.2626 to 111.2642 kg. The oldest trees contained a greater carbon biomass, due to their greater diameters and the presence of many branches. Consequently, carbon biomass tended to increase geometrically with diameter.

In relative terms, the carbon biomass in each tree varied between 40% and 45%, which is close to reported values, indicating, *a priori*, non-homogeneity in the concentration of carbon in the biomass of the trees in the same stand and, ultimately, of the trees in different diameter classes. In general, the carbon biomass relative to the total biomass of the trees was larger in non-dominant trees and smaller in dominant trees. The density of carbon (kg/m^3) tended to decrease as the diameter class of the stand increased. The non-dominant trees were more efficient at fixing carbon ; the density of carbon ranged from 310 kg/m^3 in non-dominant trees, to around 280 kg/m^3 in dominant trees.

Related to the dynamics of carbon fixation in reforestation, we determined the production function for carbon assimilation, as shown in Table 2 and the respective equations.

$$C = I^2/(b_0 + b_1 * I + b_2 * I^2)$$

$$C = I^2/(0.154397 - 0.011314 * I + 0.026268 * I^2)$$

$$R^2 = 0.94, \quad S_{yx}\% = 14.96\%$$

where C is carbon (ton/ha), I is age (years), b_0, b_1, and b_2 are coefficients, R^2 is the determination coefficient, and $S_{yx}\%$ is the standard error of estimation.

Application of this technology

To determine the best period of production, we calculated the maximum mean productivity in terms of basal area (m^2/ha), total production (m^3/ha), dry biomass (tons/ha), gross income yield (R$/ha), and carbon (tons/ha) (Hosokawa 1976 ; Hosokawa *et al.* 1997b).

Considering the carbon storage as the aggregate production of *Mimosa scabrella*, the ideal period of production is determined by the maximum mean productivity of the optimized gross income yield and would be 5 years. Applying the carbon production equation to the forest permits calculation of the productive structure observed in the field (Ps1). Table 3 shows differences in the age class areas. After controlling for the differences between forests, a continuous production regime results (Ps2). The last step is to optimize the productive structure and regulate the forest on a continuous basis (Ps3), as shown in Table 4.

For continuous production, the forest in the 30 rural farms in the optimized regime (Ps3) would consist of four age classes, each covering an area of 167.84 ha, with a permanent stock of 13,131 tons of carbon in the living *Mimosa scabrella* population. The last age class (5 years old) would be harvested and the wood sold for use as scaffolding

Table 2. Production of carbon (ton) in respective ages (years) (data observed in the field).

Age (years)	Carbon (ton/ha)	Age (years)	Carbon (ton/ha)	Age (years)	Carbon (ton/ha)	Age (years)	Carbon (ton/ha)
1	4.555	3	26.351	5	37.355	7	38.990
1	4.517	3	19.768	5	36.270	7	30.773
1	6.315	3	29.903	5	29.283	7	37.806
1	5.999	3	20.225	5	30.319	7	37.294
2	11.678	4	29.358	6	30.702		
2	22.098	4	28.926	6	30.563		
2	18.411	4	35.145	6	38.209		
2	19.056			6	37.903		

Table 3. Maximum mean productivity in : Basal Area (BA), total prduction (Tp), dry Biomass (dB), gross income yield (GY), carbon (C).

Equations of productivity (I ; age (year))	Age of max average productivity (year)
$BA = I/(0.2087239 - 0.0592329 * I + 0.053653208 * I^2)$	1.9723695
$Tp = I/(0.039983 - 0.005509 * I + 0.005199 * I^2)$	2.7731782
$dB = I/(0.09499128 - 0.01393649 * I + 0.01302957 * I^2)$	2.7000873
$GY = I/(0.024374 - 0.006340 * I + 0.001197 * I^2)$	4.5124908
$C = I/(0.154397 - 0.011314 * I + 0.026268 * I^2)$	2.4244092

Table 4. Structure of carbon fixation in forest population from *Mimosa scabrella* Benthan.

Ps1				Ps2				Ps3			
Age (years)	Area (ha)	Production (ton)	Storage (ton)	Age (years)	Area (ha)	Production (ton)	Storage (ton)	Age (years)	Area (ha)	Production (ton)	Storage (ton)
1	82.51	487		1	119.89	708		1	167.84	991	
2	118.76	2,006		2	119.89	2,025		2	167.84	2,835	
3	127.51	3,216		3	119.89	3,024		3	167.84	4,233	
4	125.64	3,797		4	119.89	3,623		4	167.84	5,072	13,131
5	112.50	3,728		5	119.89	3,972		5	167.84	5,561	
6	101.26	3,532	16,766	6	119.89	4,182	17,534				
7	171.02	6,151		7	119.89	4,312					

Legends :
Ps1 : Productive structure observed in field.
Ps2 : Productive structure regulated of Forest Basis in continuous production regime (119.89 ha/production unit).
Ps3 : Optimized productive structure regulated of Forest Basis in continuous production regime (167.84 ha/production unit).

for construction and firewood for industrial ovens. Immediately after harvest, the area would be allowed to regenerate either naturally or artificially, to form the one-year-old population.

Forest management and trade in emissions

The carbon resources could be financed based on the 1- to 4-year-old forests that constitute the permanent stock. On implementation of this system, the harvest of the oldest production unit (5 years) is followed by immediate reforestation. Simultaneously, annual maintenance procedures for the 1- to 4-year-old populations must occur, including pest control, clearing undergrowth, maintaining firebreaks, and silvicultural care to maintain tree health. This is necessary to minimize risks, while assuring safe, efficient CO_2 assimilation. This would be justified by the financing of carbon resources ; consequently, it would minimize insurance costs.

The price of a ton of achieved stored carbon would depend on the market. The market for carbon quotas, like the market for any commodity, must be characterized by prices based on mechanisms related to product supply and demand.

On the demand side, polluting enterprises need physical space to "store" the gaseous residues emitted to the atmosphere, especially those responsible for the greenhouse effect, such as CO_2. These companies will put pressure on the market, increasing the price of carbon quotas that obtain greater short-term success, and will acquire quotas in regions of higher productivity for the sequestration of atmospheric carbon. The product will be offered by enterprises that have reforested areas or have excess quotas, in addition to forest owners that are part of the forest sector market.

Meetings between producers and consumers to market carbon shares will define the prices, which will vary with supply and demand pressures. It is important to note that some investors, in some markets, need legal mechanisms that confirm the system transparency and trust. Moreover, the investors in carbon shares will be reassured when they inspect this market, and see the mechanisms that guarantee an effective return from their investments, as indicated by the marginal flux and total CO_2 stock in a given forest, in a given region.

The government will be responsible for providing technical and legal aid to attract direct international investment in the carbon quotas. In the short term, any impediment to this would damage the credibility of this market, causing investors to look to other regions.

If carbon sinks are not estimated or registered, there will not be disposable commodities to sell, exchange, or use directly to mitigate emissions. Living dynamic CO_2 stocks are subject to many variables, including soil and climate conditions, species variability, silvicultural treatment, management of the production of multiple products, forest size, species structure, tree age, wood utilization, forest population productivity classes, market, investment alternatives, risks, and economy of scale. Therefore, it is necessary for periodic control to correct any distortions.

Of relevance, a paper on the fixation of carbon atoms in reforestation states that trees smaller than the forest population average incorporate proportionally more carbon than bigger trees. This implies that the process of managing forest populations to prioritize CO_2 storage is the inverse of classic forest management procedures. Considering investment in carbon shares, the research presented in "Dinamica da assimilacao de CO_2 pelos reflorestamentos" outlines information on capitalization, discounts, amortization, etc.

The use of this new knowledge will permit the calculation of the natural ratio of carbon in the trees at any time, as well as the change. These ratios can be converted into financial values (equivalent to the carbon contained in a liter of combustibles), permitting the calculation of the real discount, investment capitalization, and amortization. If necessary, this can be done on a daily basis.

Literature cited

Baader G. (1942) Forsteinrichtung als nachhaltige Betriebsführung und Betriebsplanung. J.D. Sauerlanders Verlag, Frankfurt am Main.

Bochicchio R. (1999) Hemiceluloses do xilema do genero *Podocarpus*. Dissertacao de Mestrado, Departamento de Bioquimica, Setor de Ciencias Biologicas, Universidade Federal do Parana, Curitiba.

Carpanezzi A.A. (1988) Manual tecnico da Bracatinga (*Mimosa scabrella* Benthan.). EMBRAPA CNPF, Doc. 20, Curitiba.

Ganter J.L.M.S., Sierakowski M.R. and Reicher F. (1993) Evolution of polysaccharide research on *Mimosa scabrella*. *Ciencia e Cultura* 45: 14-18.

Hosokawa R.T. (1976) Betriebswirtschaftliche Kriterien zur Wahl der Umtriebszeit von *Araucaria angustifolia (Bert./O. Kuntze)* in Brasilien, Freiburg, Bundesrepublik Deutschland. PhD Thesis on Forest Management and Economy, Albert Ludwigs Universitat, Freiburg I. Br., 255 pp..

Hosokawa R.T., Klock U., Rocha M.P., Klitzker R.J. and Rochadelli R. (1996) Determinacao das variacoes da massa especifica basica e dos teores de lignina ao longo do fuste de *Mimosa scabrella* Benthan., Bracatinga. In *Forest 96, Anais, Belo Horizonte*, pp. 3-4.

Hosokawa R.T., Klock U., Rocha M.P., Rochadelli R., Klitzker R.J., Solter F., Santana, M.A.G. and Haag J. O. (1997a) Analise de qualidade e produtividade atraves da modelagem dos parametros bio-quimicos da madeira de povoamentos de *Mimosa scabrella* Benthan. para producao de chapas de composicao, energia e polpa. *Agrarias* 16: 129-137.

Hosokawa R.T., Klock U., Rocha M.P., Rochadelli R., Klitzker R.J., Solter F., Santana M.A.G. and Haag J. O. (1997b) Determinacao da rotacao de uma floresta de *Mimosa scabrella* Benthan. (Bracatinga) de media produtividade em sistema agroflorestal tradicional baseado nos criterios de biomassa e renda bruta. *Agrarias* 16: 201-206.

Hosokawa R.T., Klock U., Rocha M.P., Rochadelli R., Klitzker R.J., Solter F., Gottschild C.A., Santana M. A.G. and Haag J.O. (1997c) Relatorio do Grupo de Pesquisa "Qualidade e produtividade na atividade florestal Primaria". CNPq/MCT protocolo No. 3803 6483 8762 8556, Brasĩlia.

Hosokawa R.T. (1998) Sustentabilidade Florestal. In *Introducao ao Manejo e Economia de Florestas* (UFPR ed.). pp.115-128. UFPR, Curitiba.

Hosokawa R.T., Volpi-Patias N.M., Morokawa R.T. and Carnieri C. (1998) Yield Model of Improved Wood quality. *SBPN Scientific Journal* 2: 62-66.

Hosokawa R.T. (2000a) O paradoxo no Desenvolvimento Sustentavel, "conferencia". *SBPN Scientific Journal* 4: 5-8.

Hosokawa R.T. (2000b) Dinamica de assimilacao molecular de CO_2 pelos Reflorestamentos. *Semana de Tecnologia Ambiental de Sao Carlos* 4: 8-11.

Hosokawa R.T. and Hosokawa E.S. (2001a) A lei dos efeitos acelerados da Entropia e o limite no uso de recursos energeticos da Biosfera. *Revista cientifica Floresta FUPEF & UFPR* 31: 3-9.

Hosokawa R.T., Corso N.M., Martins G. and Hosokawa E.S. (2001b) Qualidade e produtividade na utilizacao da capacidade produtiva do sĩtio. *SBPN Scientific Journal* 5: 66-67.

IPT Cellulose e Panel (1988) Volume 1. IPT, Institutio de Pesquisas Tecnologicas do Estado de Sao Paulo, Segunda edicao, Sao Paulo.

Richter A. (1963) Einfuhrung in die Forsteinrichtung. Neuman Verlag, Radebeul.

Rifkin F. and Howaed T. (1990) Entropia hacia el mundo invernadero. Urano, Barcelona.

Rochadelli R. (1997) Contribuicao socio-economica de Bracatinga (*Mimosa scabrella* Benthan.), na regiao Metropolitana Norte de Curitiba. Dissertacao de Mestrado em Economia e Politica Florestal, UFPR, Curitiba.

Rochadelli R. and Hosokawa R.T. (2001) The structure of fixation of the carbon atoms in forest stands. *SBPN Scientific Journal* 5: 61-62.

Rochadelli R., Hosokawa R.T., Klitzke R.J. and Bochichio R. (2001) Hemicelluloses in the xylem and phloem of Bracatinga (*Mimosa scabrella* Benthan.) in several ages. *SBPN Scientific Journal* 5: 63-65.

Romanowski S.M.M. (1986) Estudo de substituintes em xilana de *Mimosa scabrella* (bracatinga) em diferentes estagios de crescimento. Dissertacao de Mestrado, Departamento de Bioquimica, Setor de Ciencias Biologicas, Universidade Federal do Parana, Curitiba.

Saeman J.F., Moore W.E., Mitchel R.L. and Millet M.A. (1954) Techniques for the determination of pulps constituents by quantitative paper chromatography. *Techical Association of Pulp and Paper Industry* 37: 336-343.

Soares R. and Hosokawa R. (1982) Area de ocorrencia natural da Bracatinga nos Estados de Parana e Santa Catarina. In *Relatorio FUPEF*. FUPEF, Curitiba.

Speidel G. (1972) Planung im Forstbetrieb. Verlag Paul Parey, Hamburg.