ATMOSPHERIC INPUTS COMPARED WITH NUTRIENTS REMOVED BY HARVESTING FROM *Eucalyptus* PLANTATION. IMPLICATIONS FOR SUSTAINABILITY

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SUMMARY

In the State of São Paulo and, generally in Brazil, forest plantations are located on very poor soils and, when harvested, several questions must be answered, mainly related to nutrient cycling sustainability. With this purpose, several stands of different species of *Eucalyptus: E. camaldulensis* (9-yr-old), *E. grandis* (9 and 2.5 yr-old), *E. torelliana* (11yr-old) and *E. saligna* (11 yr-old), were studied, comparing annual nutrient atmospheric inputs with nutrients annually accumulated in the compartments of trees biomass: crown, trunk, and wood. The biomass annually produced by stands of *E. grandis* (9 yr-old) was higher than the produced by the other species with similar age. *E. grandis* was also more efficient in nutrient utilization, mainly for phosphorus. However, young trees of this species (2.5 yr-old) accumulated more nutrients in the leaves and branches than mature trees, and the whole tree utilisation for pulp and energy in shorter rotation could significantly reduce the capacity of many infertile soils to replace nutrient removed during harvesting. In many cases, depending on site, stand age and *Eucalyptus* species, annual atmospheric input would be sufficient to supply annual nutrients accumulation only in the stemwood. However, to maintain site sustainability it is suggested that silvicultural rotation should be longer than they usually are at the present (5 -7 years) and only stemwood should be harvested from the stand, conserving the nutrients and increasing the organic matter in the soil.

Key word: *Eucalyptus*, atmospheric inputs, nutrient use efficiency, harvesting, sustainability.

RESUMO

Comparação entre a entrada de nutrientes via atmosfera e sua exportação em plantações de eucaliptos. Implicações para a sustentabilidade. - No Estado de São Paulo e no Brasil, de maneira geral, as plantações florestais se localizam sobre solos de baixa fertilidade e sua exploração, devido à exportação de nutrientes, gera diversas controvérsias principalmente relacionadas com o ciclo dos nutrientes e a sustentabilidade. Com esta finalidade, diversos talhões florestais de espécies diferentes de eucaliptos: *E. camaldulensis* (9 anos), *E. grandis* (9 e 2,5 anos), *E. torelliana* (11 anos), e *E. saligna* (11 anos), foram estudados, comparando-se a entrada anual de nutrientes via atmosfera com os nutrientes anualmente acumulados nos compartimentos da biomassa arbórea: copa, tronco e apenas o lenho do tronco. A biomassa produzida anualmente pelo talhão de *E. grandis* (11 anos) foi maior do que a produzida pelas outras espécies com idade semelhante. *E. grandis* evidenciou-se mais eficiente na utilização dos nutrientes e principalmente do fósforo. Entretanto, as árvores mais jovens desta espécie, com 2,5 anos de idade, acumularam proporcionalmente uma maior quantidade de nutrientes nas copas do que as árvore maduras e, neste sentido, a exploração total das árvores para celulose e energia em rotações muito curtas reduziria significativamente a capacidade do solo de repor os nutrientes exportados através da exploração da biomassa com conseqüente prejuízo da produtividade futura do sítio. Entretanto, pode-se concluir que, dependendo do local, da idade do talhão e da espécie, a entrada anual de nutrientes através da

precipitação atmosférica poderia ser suficiente para suprir os nutrientes anualmente acumulados apenas no lenho do tronco das árvores. Para manter a sustentabilidade nutricional do sítio, sugere-se que a rotação silvicultural seja mais longa do que o é usualmente (5-7 anos) e que apenas o lenho do tronco seja exportado do talhão, permanecendo as folhas, os ramos e a casca sobre o solo, conservando assim os nutrientes e aumentando a quantidade de matéria orgânica.

Palavras-chave: *Eucalyptus*, nutrientes, entradas atmosféricas, eficiência nutricional, exportação, sustentabilidade.

INTRODUCTION

The States of São Paulo and Mato Gosso do Sul are located in the Southeast and central regions of Brazil and are crossed by the Tropic of Capricorn, including subtropical areas, which one hundred years ago, were covered in 80% by tropical forest along the coast and by semi-evergreen subtropical forest in the central part, including also some areas of Savannah (Campos cerrados).

At the present, only 5% of the land is covered by forest and are located mainly along Serra do Mar and considered areas of permanent preservation by governmental laws. Almost the total area of the State is occupied by annual crops, sugar cane plantation, and pastures. Besides this transformation, the State of São Paulo has become the most industrialised state of Brazil. In 1995, just to supply the manufacture of pulp and paper, 42 million m^3 of wood were utilized, coming from *Eucalyptus* and *Pinus* plantations. Just in São Paulo, man-made forest with *Eucalyptus* and *Pinus* species amount to respectively 291,210 hectares (ANFPC, 1995), while natural forests cover approximately 2 million hectares, including almost all the areas of permanent preservation of the State. The wood shortage for industries, the distance of natural forest potential producers of wood material for industry, and the strong heterogeneity of the tropical trees, clearly show the increasing importance of man-made forests. Considering, however, that forest plantations are generally located on very poor soils, several questions must be answered, mainly related to nutrient cycling. The most notable interruption in the nutrient cycle of managed forests results from routine harvest. (Farrel *et al.*,1986). This paper presents several data showing atmospheric inputs and nutrient accumulation in the biomass of different species of *Eucalyptus* plantations, located at several places of the States of São Paulo and Mato Grosso do Sul, and discuss the implications of long-term management practices and harvesting on nutrient conservation and forest sites productivity. Also discuss the role of nutrient retranslocation among the different compartments of the trees that varies with species, ages and growing conditions.

METHOD

The amounts of nutrients, coming from the atmosphere and estimated through precipitation, were compared with nutrients accumulated annually in the biomass of *Eucalyptus* plantations, supposing those nutrients will be exported by harvesting at the end of forest rotation. Considering that forest plantations occupy in general heavily weathered infertile soils, the rate of nutrients released as a result of weathering is calculated insignificant. Soil nutrient reservoir is also very low to attend tree requirement of fast growing forest of *Eucalyptus*, and often more than 50% of nutrients cycling among the compartments of the system " tree biomass-soil " are retained in the stand biomass (Poggiani,1985a).

The atmospheric inputs, showed in Table 1, were drawn from research-papers of that analysed rain-water collected during many years in several sites of the central part of the State of São Paulo (Verdade and Kupper,1955; Lima,1985; Coutinho,1979).

Nutrients accumulated in the tree biomass of 5 forest stands of *Eucalyptus*, located at different places were estimated at different times by Poggiani (1983 and 1985b), and Schumacher and Poggiani (1993). In order to determine tree biomass, 15 - 20 trees of *Eucalyptus* stands were selected from the five DBH classes, felled and limbed. Each component of the trees (leaves, branches, bark and wood) was separated and weighed in the field.

To choose the best model to estimate the dry biomass components of the trees, a step-wise procedure was performed using as independent variables DBH and total height, and their transformed values. Samples of leaves and small sections of the branches, collected from the median part of the stem, were weighed and sealed in polyethylene bags for laboratory analysis. Moisture contents of the different components was then determined and the dry weight of tree calculated. Weighed values for moisture content in the samples were used to convert green components weight to oven dry weight. After oven-drying, leaves, branches, and stem samples (wood and bark separately) were ground in a Willey mill and passed trough a 20 mesh sieve to determine nutrient concentration, according to Sarruge and Haag (1974).

In this paper, nutrient contents in the following five stands of *Eucalyptus* are compared: 1 - *E. camaldulensis*, 2 - *E. grandis*, 3 - *E. torelliana*, respectively 9, 9 and 11 years old, growing at Anhembi Forest Science Experimental Station of ESALQ/USP (Lat. 22° 43' S and long. 48° 10' W, alt. 500 m) on Red Yellow Podzolic soil with low fertility and sandy medium texture. 4 - *E. saligna*, 11 years old growing in Piracicaba (Lat. 22° 42' S and long. 47° 38' W and alt. 540 m) on a Podzolic soil with low/medium fertility. 5 - *E. grandis*, 2.5 years old, growing at Três Lagoas - Mato Grosso do Sul (Lat 20° 47'S and long. 51° 39' W) on a sandy Red Brown Latosol with low fertility). The climate of all the regions belongs to Cwa (Koppen classification), with annual rainfall around 1200 - 1300 mm, mean temperature 21 - 23 °C, hot and rainy summer and moderate and dry winters.

Nutrient use efficiency was also calculated, mainly for stemwood, considering the amount of harvestable biomass produced per unit of nutrient accumulated.

RESULTS AND DISCUSSION

Empirical studies, about the impact of more traditional forest management regimes suggest that the whole-tree harvesting (e. g., removal of stem, branches, and foliage) increases the rate of loss of nutrients by several-fold relative to a conventional harvest (e.g., stem or wood only) in which, usually, just a small fraction of the total nutrients of the ecosystem is removed. (Crane and Raison 1980; Rezende, 1983; Poggiani, 1983).

Table 1 shows the biomass annually produced and the amounts of nutrients accumulated in total tree, trunk and only stemwood in stands of different species of *Eucalyptus*. Because nutrient requirement and within-tree allocation patterns differ among species, it should not be surprising that the impact of timber harvesting on nutrient removal is species dependent (Son and Gower, 1992). Taking in account the whole tree utilisation, it is possible to verifies that the biomass annually produced by stands of *E. grandis* is higher than the biomass produced by the other species with similar age. However, the harvesting of *E. grandis* will cause an higher nutrient exportation from the site with strong implications for the future site productivity.

Comparing the amounts of nutrients annually accumulated in the whole tree of *Eucalyptus* (9-11 years old, growing at Anhembi and Piracicaba) with the nutrients accumulated in the trunk, it is possible to verifie that 15-40% are located in the crowns (leaves + branches), 65-80% in the trunk (wood + bark). However, the stock of nutrients only in the wood are lower than 40% of the amount of nutrients accumulated in the whole tree biomass, except for nitrogen. Leaves present the higher nitrogen concentration. Poggiani (1985) found: 1.23% of nitrogen concentration in the leaves, 0,26% in the bark and just 0.071% in the wood of *E. saligna* growing at Piracicaba. Seems to be, meanwhile, that *Eucalyptus* species accumulate in general heavy amounts of calcium, mainly in the bark. Schumacher and Poggiani (1993), and Vital (1996), found the following concentration: 3.34, 1.87, 1.46, and 2.78% respectively in the barks of *E. saligna, E. camaldulensis, E. grandis* and *E. torelliana*. Thus, nutrient accumulation in forest plantation biomass , growing in similar soil and climatic conditions, depend on the tree species. Different species accumulates different quantities of nutrients. Also, Rezende *et al.* (1983) found that, apart from nitrogen, *E.saligna* stands contained more nutrients in the biomass than *E. grandis*.

Leaves and branches contributed 20% or less than total biomass, but contained 50-60% of the nutrients.

A major way of nutrient loss from forest ecosystems is through removal of the harvest crop. Estimates of losses have been monitored for many years, specially by European foresters, and they are known for several species and sites (Pritchett, 1979). A forest stand annually absorbs almost as much nutrients from an hectare of soil as some agricultural crops. However, less than one third of the absorbed nutrients are immobilised in commercial stemwood, while the remainder returns to the soil reserve as foliage, branches fruits, and roots.

At the present, several companies in Brazil, who practice a good forest management, peel the bark in the field, leaving the nutrients in the site. The comparison between annual atmospheric input and mineral nutrients accumulation in tree biomass, showed in Table 1, it makes evident that nutrients coming from rain-fall are not enough to balance the annual accumulation, if whole tree is considered, but in many cases they are sufficient to supply the growth of stemwood biomass, that will be exported by harvesting. Nitrogen is an exception, because its high concentration in tissues. However, this nutrient is incorporated in the ecosystem by other way like asymbiotic and symbiotic fixation. Nitrogen fixation rates can reach around 20 Kg/ha/year in tropical forest (Boring *et al.*,1988). In this sense, the conservation of organic matter in the soil is a very recommendable practice in man-made forest management, because increases the asymbiotic N fixation.

Comparing also the biomass annually built in the whole *Eucalyptus* stands at Anhembi and Piracicaba, crowns represent only 10% of the total, nevertheless in *E. grandis*, 2.5 years old, growing at Três Lagoas, the crowns biomass attains 35% of the total trees, including 81% of N, 63% of P, 58% of K, 86% of Ca , and 73% of Mg. This means that a young tree accumulates more nutrients in the leaves and branches than a mature tree, and the whole utilisation of tree for pulp and energy in shorter rotation could significantly reduce the capacity of many infertile soils to replace nutrient removed during harvest.

Trees can meet their annual nutrient demands by removing nutrients from aging or senescing tissues to new growing parts of the tree (Cowling and Merril,1966). This process is dynamic and varies with age and growing conditions and a particular nutrient (Landsberg and Gower, 1997). On a stand basis, retranslocation of nutrient, especially nitrogen and phosphorus, supplies a significant portion of the annual nutrient requirement. Turner and Lambert (1986) estimated that 50-60% of the annual phosphorus requirement of *Pinus radiata* plantations were met by retranslocations.

A comparison between species and between tissue types within species indicated that nutrient use efficiency for N, P, K, Ca and Mg varied widely among species (ranging up to 10-fold differences) and tissues (up to 15-fold). For the more of the studied nutrients, stemwood and large branches are the most nutrient-efficient tissue, followed by small branches, bark and then leaves (Wang *et al.*,1991).

Table 2 shows the nutrient use efficiency of the different species of *Eucalyptus*, only considering the built of woodbiomass in the trees of the stands, that will be harvested. To become comparable the results, all the data are presented as weight of biomass (Kg) annually accumulated per weight (g) of nutrient utilised.

E. saligna, 11 years old, is the most efficient for nitrogen, potassium and magnesium. However, *E. grandis* growing at Anhembi is the most efficient for phosphorus utilisation, building 25.60 kilograms of woodbiomass per gram of phosphorus invested. In general, it is possible to verify that *Eucalyptus* species are very efficient in phosphorus utilization. According to Attiwill (1980), the large adaptation of *Eucalyptus* species in Australia, may be attributed to their capacity to survive in infertile soils with very low content of phosphorus. Rezende *et al.* (1983) also found that nutrient utilisation efficiency in *E. grandis* stands was greater in higher density, however the whole tree harvesting would remove a greater proportion of nutrients from the site at higher density.

Comparing the nutrient use efficiency of

TABLE 1. Comparison between annual atmospheric input and mineral nutrients accumulation in tree biomass of different species of *Eucalyptus* planted in several sites of the State of São Paulo and Mato Grosso do Sul. **(Kg/ha/year).**

	N	P	K	Ca	Mg
Annual Inputs	**6.5 - 7.3**	**0.9**	**2.6 - 9.8**	**5.6 - 16.0**	**0.9 - 5.2**

Biomass and nutrients annualy accumulated in the:

1.1 *E. camaldulensis* stand at Anhembi (9 years old, spacing 3 x 3 m)

	Biomass	N	P	K	Ca	Mg
Total tree	14,000	29.4	1.2	20.3	33.3	4.7
Trunk	12,500	21.3	0.8	13.1	28.3	3.1
Stem-wood	11,340	17.6	0.5	6.4	6.2	1.6

1.2. *E. grandis* stand at Anhembi (9 year old, spacing 3 x 3 m)

	Biomass	N	P	K	Ca	Mg
Total tree	30,300	80.3	2.9	41.2	53.9	12.7
Trunk	27,700	63.6	1.9	29.4	42.8	9.4
Stem-wood	25,600	26.9	1.0	14.3	11.3	2.6

1.3. *E. grandis* stand at Tres Lagoas (2.5 years old, spacing 3 x 1.5 m)

	Biomass	N	P	K	Ca	Mg
Total tree	11,600	56.1	4.3	17.8	64.4	12.4
Trunk	7,500	10.9	1.6	7.5	9.6	3.4
Stem-wood	6,500	7.5	0.6	3.2	3.5	1.3

1.4 *E. torelliana* stand at Anhembi (11 years old, spacing 3 x 2 m)

	Biomass	N	P	K	Ca	Mg
Total tree	15,500	30.2	2.0	29.7	48.0	7.4
Trunk	13,900	21.2	1.7	28.4	41.3	5.8
Stem-wood	12,900	17.2	1.5	11.7	12.9	2.5

1.5 *E. saligna* stand at Piracicaba (11 years old, spacing 3 x 2 m)

	Biomass	N	P	K	Ca	Mg
Total tree	16,900	19.9	5.5	17.3	86.7	7.4
Trunk	15,270	12.5	3.8	11.0	50.1	4.2
Stem-wood	14,400	10.2	1.1	6.6	9.4	1.4

TABLE 2. Nutrient use efficiency of different species of *Eucalyptus* planted in several sites of the State of São Paulo. Referring to rates of stem-wood biomass accumulation per unit nutrient invested . **(Kg of biomass accumulated / g of nutrient).**

Eucalyptus Species	N	P	K	Ca	Mg
2.1. *E. Camaldulensis*, 9 years - Anhembi	0.64	22.60	1.76	1.80	7.00
2.2. *E. Grandis*, 9 years - Anhembi	0.95	25.60	1.79	2.26	9.80
2.3. *E. Grandis*, 2.5 years - Três Lagoas	0.87	10.80	2.00	1.80	5.00
2.4. *E. torelliana*, 11 years - Anhembi	0.75	8.60	1.10	1.00	5.16
2.5. *E. saligna*, 11 years - Piracicaba	1.40	13.00	2.20	1.50	10.30

E. grandis stand, 11 years old, growing at Anhembi, with *E. grandis* stand, 2.5 years old, growing at Três Lagoas, it is possible to conclude that the older stand is more efficient mainly for P. Also, according to Bangali (1995), the nutrient use efficiency increases wit increasing plantation age and Crane and Raison (1980) concluded that shortening rotations increases the amount of P removed per unit of wood harvested in *E. delegatensis*. A similar result was found by Poggiani *et al.* (1983) in short rotation intensively cultured plantation of *Eucalyptus grandis*. According to Silva *et al.* (1983), *E. grandis* was the most efficient in phosphorus utilization among five species of *Eucalyptus* growing on a very infertile sandy soil in the central part of the State of São Paulo.

Baker and Attiwil (1985) found in *Pinus radiata*, the annual gross demand for N and P averaged 6.1 and 0.61 g/m^2, and in *Eucalyptus obliqua* 4.9 and 0.28 g/m^2 respectively. They stand out that in *P. radiata* 34% of the demand for P came from soil reserves, but in *E. obliqua* only 10% of the demand for P came from soil reserves. The annual gross demand for P found by those researchers is very similar to the gross demand observed in *E. grandis* stand, 11 years old, at Anhembi.

Finally, it is possible to conclude that more nutrients are removed when, at the end of rotation, the older *Eucalyptus* plantations are harvested due to the greater amount of biomass harvested. Meanwhile, older stands are more efficient in nutrients utilization than younger stands, mainly for phosphorus. Moreover, the longer rotation of the older forests provide more opportunity for nutrients to be replaced by natural inputs. So, the impact of nutrient removal is site specific, also depending on annual nutrients inputs coming from atmospheric deposition. Just considering stemwood harvest, this study shows that nutrients inputs coming from precipitation may be enough, in many cases, to replace nutrients accumulated in stemwood biomass that will be harvested (Table 2). In this sense, the silvicultural rotation should be similar to ecological rotation or a tree rotation which, at last, should permit the return of the site to the nutritional conditions that existed prior to forest plantation.

To warrant the site nutrient sustenance, silvicultural rotation for *Eucalyptus* plantation in Brazil should be longer than they are at the present (5-7 years), and only the stemwood should be harvested, leaving leaves, branches and bark in the field as source of nutrients and organic matter to the soil.

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