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NUTRIENT CYCLING IN *Eucalyptus* AND *Pinus* PLANTATIONS ECOSYSTEMS: SILVICULTURAL IMPLICATIONS

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ABSTRACT - Distribution and movement of mineral nutrients (N, P, K, Ca and Mg) were studied in an 11 years old stand of **Eucalyptus saligna** and in a 14 years old stand of **Pinus caribaea** var. **hondurensis**, located respectively near Piracicaba and near Agudos (State of São Paulo -Brazil). In the **E. saligna** stand annual mean leaf-fall was 4,490 kg/ha with 27.3 kg of N, 2.2 kg of P, 16.7 kg of K, 44 kg of Ca and 9.3 kg of Mg. In the stand of **P. caribaea** the annual leaf-fall was 8,373 kg/ha with 43.7 kg of N, 2.2 kg of P, 22.2 kg of K, 20.4 kg of Ca and 6.4 kg of Mg. The above-ground biomass of **E. saligna** stand was estimated in 186 t/ha and accumulated 219 kg of N, 58 kg of P, 190 kg of K, 954 kg of Ca and 81 kg of Mg. **P. caribaea** biomass was 153.6 t/ha including 304 kg of N, 16.2 kg of P, 150.6 kg of K, 103.7 kg of Ca and 34 kg of Mg. The leaf-litter accumulation in **E. saligna** stand was also estimated at 7936 kg/ha and at 20238 kg/ha in P**. caribaea** var. **hondurensis** stand. Nutrients export by biomass harvesting, taking into account total tree or traditional bole explotation, was compared with the atmospheric input in the ecosystem. Considering the total quantity of mineral nutrients included in the above-ground biomass and the low reserves in the soil of the stands, it V/as found to be improper the utilization of very short rotation and whole-tree harvesting. It was recommended that silvicultural rotations should not be shorter than the ecological rotations and consequently the equilibrium between nutrient removal in harvested material and natural or artificial replacements to the site must be maintained.

RESUMO - Para se conhecer o padrão de ciclagem dos nutrientes em ecossistemas de plantações florestais foram quantificados os estoques e a movimentação dos elementos N, P, K, Ca e Mg num talhão de **E. saligna**, plantado em Piracicaba e num talhão de **Pinus caribaea** var. **hondurensis**, plantado em Agudos. A queda de folhedo foi estudada durante um período de 3 anos, sendo que no talhão de **E. saligna** foi registrada uma deposição anual de 4490 kg/ha contendo: 27,3 kg de N, 2,2 kg de P, 16,7 kg de K, 44 kg de Ca e 9,3 kg de Mg e no talhão de **P. caribaea** uma deposição anual de 8,373 kg/ha contendo 43,7 kg de N, 2,2 kg de P, 22,2 kg de K, 20,4 kg de Ca e 6,4 kg de Mg. A biomassa do talhão de **E. saligna**, aos 11 anos de idade, totalizou 186 t/ha contendo 219 kg de N, 58 kg de P, 190 kg de K, 954 kg de Ca e 81 kg de Mg. 0 talhão de **P. caribaea**, aos 14 anos, com uma biomassa total de 153,6 t/ha apresentou o seguinte conteúdo de nutrientes: 304 kg de N, 16,2 kg de P, 150,6 kg de K, 103,7 kg de Ca e 34 kg de Mg. O acúmulo de nutrientes na serapilheira foi estimado em 7936 kg/ha no talhão de **E. saligna** e em 20238 kg/ha no talhão de **P. caribaea**. A saída de nutrientes do sítio pela exportação da biomassa arbórea, considerando o sistema de exploração total da árvore ou apenas do tronco, foi comparada com a entrada de nutrientes por via atmosférica. Os resultados são discutidos face às

implicações ecológicas e silviculturais, tendo em vista o baixo estoque de nutrientes disponíveis no solo.

INTRODUCTION

The State of São Paulo is located in the southeast region of Brazil and is crossed by the Tropic of Capricorn. It includes tropical and subtropical areas, which one hundred years ago were covered in 80% by tropical rain forests along the coast and by semi-evergreen subtropical forest in the central part, including also some spots of natural savannas (Campos cerrados).

According to VICTOR (1973) at present only 5% of the land in the State of São Paulo is covered by forests which are mainly located 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 plantations, and pastures. Beside this transformation, the State of São Paulo has become the most industrialized state of Brazil.

In 1984, just to supply the manufacture of pulp and paper of São Paulo, about 15 million m^3 of wood were utilized coming from **Eucalyptus** and **Pinus** plantations (ANFPC, 1984).

According to REIS (1982) man-made forests in Brazil, planted with fiscal incentives, amount to 4,500,000 ha. In 1981 forest plantations with **Eucalyptus** and **Pinus** species in the State of São Paulo amounted to respectively 287,000 and 130,000 hectares, while natural forests covered 2,070,000 hectares including almost all the areas of permanent preservation (IBOF, 1983).

The wood shortage for industrial supply, the distance of natural forests, 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 with nutrient cycling.

According to PRITCHETT (1979), the most notable interruption in the nutrient cycle of managed forests results from routine harvest. This paper presents several data showing nutrient distribution and transfers in the ecosystems of **Eucalyptus** and **Pinus** plantations. A general budget of macronutrients is presented with several considerations about silvicultural implications.

THE EXPERIMENTAL STANDS

The stand of **Eucalyptus saligna** is located near Piracicaba (Lat. 22° 42' 30" S, Long. 47° 38' 00"O, Alt. 540m) and the stand of **Pinus caribaea** var. **hondurensis** is located near Agudos (Lat. 22° 25' S, Long. 48° 50' O and Alt. 600 m). The climate of the two regions belongs to Cwa (Köppen classification) with annual rainfall around 1200-1300 mm, mean temperature 21-22°C, hot and rainy summers and moderate winters.

E. saligna plantation is growing on a podzolic soil with low/medium fertility and **P. caribaea** on a very sandy and infertile latosol. The stand of **E. saligna** was planted in December 1969, in the spacing 3.5 x 2.0 m. Before beginning this study two thinning were carried out reducing the stand density to 452 trees per hectare which in September 1980 had a mean diameter (D.B.H.) of 19.4 cm and mean height of 18.5 m.

The stand of **P. caribaea** var. **hondurensis** was planted in October 1966,in the initial spacing 2.5 x 2.0 m. Two thinning were also carried out respectively during 1974 and 1976, reducing the density of the stand to 990 trees per hectare which had in October 1980 a mean diameter (D.B.H.) of 19.4 cm and a mean height of 18.1 m.

METHODS

A single 0.36 ha plot located in the central part of the stand with 20 randomly placed litter traps (1 x 1m) were established in each plantation in July 1977. These traps caught the coarse litter, but allowed moisture and fine materials to pass through. Leaves that accumulated in the traps were collected the first of each month beginning in August 1977. The amount of leaves reaching the forest floor was calculated from data obtained from the monthly collections.

Leaf accumulation on forest floor was calculated from 50 samples (0.5 x 0.5 m) collected randomly in each 0.36 ha plot of the two plantations.

Leaf-fall and forest floor samples were dried at 70°C and ground before analysis. Total nitrogen was determined by micro-kjeldahl. Phosphorus was determined calorimetrically by vanadomolybdate method and potassium, calcium and magnesium were analyzed from the acid solution by atomic absorption spectrophotometry.

In order to determine tree biomass, 20 trees of the **Eucalyptus** stand and 15 trees of the pine stand were selected from the five D.B.H. classes, felled and limbed. Each component of the tree (leaves, branches, bark and wood) was separated and weighted 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 D.B.H. 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 weighted and sealed in polyethylene bags for laboratory analysis. Moisture content of the different components were then determined and the dry weight of each tree calculated. Weighted values for moisture content in the samples were used to convert component green weight to oven dry weight. After oven-drying, leaves, branches and stem samples (Wood and bark separately) were ground in a Wiley mill and passed through a 20 mesh sieve. Chemical analyses were performed similar to leaf-fall.

In the two stands, four trenches 1.8m deep were dug. Soil samples for chemical analysis and bulk density determinations were taken 10, 40, 90 and 150 cm deep at four positions in the trench. Bulk density and chemical analyses were performed according to EMBRAPA (1979).

RESULTS AND DISCUSSION

Nutrients deposition by leaf-fall

Annual amount of leaf fall observed during the three years and the general mean for the two stands are shown in Table 1. Leaf-fall mean for the three years was 4490.4 kg/ha in the **Eucalyptus** stand and 8373.6 kg/ha in the **Pinus** stand. Leaf-fall data observed in the **E. saligna** stand agree with the observations of TURNER & LAMBERT (1983) who studied litter fall in forest plantations of **Eucalyptus grandis** located near Coffs, Harbour

(Australia) .However **Pinus caribaea** at Agudos showed a higher deposition of leaves than the **Pinus caribaea** stands studied by EGUNJOBI; & ONWELUZO (1979) near Ibadan (Nigeria). This fact suggests that when tropical tree species are planted in subtropical regions with colder and drier winters, they may suffer an ecological stress with increase of annual fall of needles.

Table 1 also shows a higher deposition of nitrogen in the **Pinus** stand, but the **Eucalyptus** stand set down more calcium and magnesium. However, the two species present a low nutrient deposition if compared with natural forests located in adjacent areas.

Studying mounth distribution of litter deposition in the **E. saligna** stand, a more evident leaf-fall during summer was noted related with the high temperature; however, in the **Pinus** stand the more intensive period of needle deposition was related with the dry periods during spring and autumn.

Nutrients accumulation on the forest floor

The leaf-litter accumulated on the forest floor of the 11 years old **E. saligna** stand, totalized 7.9 t/ha, while the 14 years old stand of **P. caribaea** var. **hondurensis**, accumulated 20.2 t/ha. Nutrients accumulated on the forest floor of the two stands are shown in Table 2.

Table 1. Quantities of leaves and nutrients fallen each year in the stand of *E. saligna* and *P. caribaea* var. *hondurensis* (kg/ha).

	Years	Leaf-fall	Nutrients				
			N	P	K	Ca	Mg
	1977 - 78	5046.1	31.5	1.9	21.5	47.7	10.7
	1978 - 79	4304.3	25.9	2.4	13.1	42.3	9.2
E. saligna	1979 - 80	4120.7	24.5	2.3	15.4	42.1	7.9
	1977 - 80 mean	4490.7	27.3	2.2	16.6	44.0	9.2
	1977 - 78	9189.3	44.7	1.8	26.2	21.3	8.0
	1978 - 79	8360.0	44.3	2.7	22.4	20.4	6.1
P. caribaea hond.	1979 - 80	7571.5	42.1	2.1	18.1	19.6	5.1
	1977 - 80 mean	8373.6	43.7	2.2	22.2	20.4	6.4

Table 2. Nutrients accumulated in the leaf-litter on the forest floor of *E. saligna* and *P. caribaea* var. *hondurensis* stands (kg/ha).

	Leaves	N	P	K	Ca	Mg
E. saligna	7936.0	50.2	4.6	10.6	59.5	14.6
P. caribaea	20238.0	155.6	8.5	19.8	38.2	8.9

It is possible to see that needles accumulated on the forest floor of the **Pinus caribaea** stand amount to almost three times the leaf-litter accumulated on the forest floor of the **Eucalyptus** stand. EGUNJOBI & ONWELUZO (1979) observed in a forest plantation of **Pinus car1baea**, located in Nigeria, an accumulation on the floor of 20.6 t/ha of needles and their contents of nutrients were also similar to data presented in Table 2. The largest accumulation of litter in **Pinus** plantations results from the higher rate of deposition and slower rate of decomposition than observed in broad-leaved forests.

Nutrient distribution in tree biomass of Eucalyptus and Pinus stands

Biomass and nutrient distribution are shown in Tables 3 and 4.

The data show that comparatively the **Eucalyptus** stand produced more biomass and, except for nitrogen, accumulated more nutrients than the **Pinus** stand. It is important to point out that crown biomass (leaves + branches) represent only 9 - 13% of total biomass, however, they incorporated around 40% of macro-nutrients. As shown in Table 3, the bark of **E. saligna** accumulates 47% of total calcium but corresponds only to 5% of total biomass. Comparing Table 3 with Table 4, the lower contents of calcium and magnesium in the **Pinus** stand, mainly in the wood compartment, are quite noticeable.

Nutrients uptake, retention in tree biomass and return to the soil of the stand

Net annual accumulation of nutrients in trees biomass may be considered as the difference between total nutrient uptake and that returned to the soil in form of dead roots, litter and canopy leaching (PRITCHETT, 1979).

Table 3. Quantities of biomass and nutrients in the standing crop or the 11 years old stand of E. saligna.

Tree components	Biomass t/ha	Nutrients k/ha				
		N	P	K	Ca	Mg
Leaves	4.0	49.6	4.8	29.3	106.7	11.8
Branches	13.8	31.7	11.1	40.0	296.3	23.3
Bark	9.5	25.1	12.2	47.9	448.3	30.5
Wood	158.5	112.5	30.1	72.9	103.0	15.8
Total	185.9	219.0	58.1	190.5	954.3	81.4

Table 4. Quantities of biomass and nutrients distribution in the standing crop of the 14 years old stand of P. caribaea var. hondurensis.

Tree components	Biomass t/ha	Nutrients k/ha				
		N	P	K	Ca	Mg
Leaves	10.4	100.7	5.8	44.0	19.7	7.7
Branches	10.5	23.0	1.4	11.8	13.6	4.2
Bark	18.4	43.6	2.2	34.2	13.2	3.7
Wood	114.3	137.1	6.8	60.5	57.1	18.3
Total	153.6	304.5	16.2	150.6	103.7	33.9

A major portion of nutrients taken up annually by above ground components of trees is returned to the soil in litter-fall and canopy wash and varies with species, site and stand age.

Table 5 shows the average of annual uptake, retention and restitution of nitrogen, phosphorus, potassium, calcium and magnesium in the stands of **E. saligna** and **P. caribaea**.

It is possible to see that the **E. saligna** stand presents a high uptake and retention of calcium, mainly in the bark (Table 3). **Pinus caribaea** var. **hondurensis** shows a lower requirement and retention than **E. saligna** mainly of phosphorus, calcium and magnesium. It is also possible to observe in the **Pinus caribaea** stand, that percentage of return by leaf-fall of all the mineral nutrients are higher than percentages of retention. This suggests a more efficient biochemical internal transfer and strong adaptability to soils with low fertility.

Nutrients distribution in the two forest plantation ecosystems and silvicultural implications

General distribution of mineral nutrients in the system "Tree biomass - litter -soil (180 cm deep)" is shown in Table 6 for the **Eucalyptus** and **Pinus** plantations, with the respective percentage.

Nutrients accumulation in forest plantation biomass depends on the tree species, soil and climatic conditions. Different species accumulate different quantities of nutrients. According to PRITCHETT (1979), a major avenue of loss of nutrients from forest ecosystems is through removal in the harvest crop. Estimates of losses have been monitored for many years, especially by European foresters, and they are known for several species and sites.

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 immobilized in commercial stem wood and bark, while the remainder returns to the soil reserve as foliage, branches, fruits, and roots:

Table 5. Estimate of nutrient uptake, retention and return by leaf-fall to soil of Eucalyptus and Pinus stands (kg/ha/years).

	Eucalyptus saligna stand		
Nutrients	**Uptake**	**Retention**	**Return**
Nitrogen	47.2	19.9	27.3
%	(100)	(42.3)	(57.8)
Phosphorus	7.4	5.2	2.2
%	(100)	(70.2)	(29.7)
Potassium	33.9	17.2	16.7
%	(100)	(50.7)	(49.3)
Calcium	130.7	86.7	44.0
%	(100)	(66.3)	(33.6)
Magnesium	16.7	7.4	9.3
%	(100)	(44.3)	(55.7)
	Pinus caribaea var. **hondurensis** stand		
Nitrogen	65.4	21.7	43.7
%	(100)	(33.2)	(66.8)
Phosphorus	3.3	1.1	2.2
%	(100)	(33.3)	(66.7)
Potassium	32.9	10.7	22.2
%	(100)	(32.5)	(67.5)
Calcium	27.7	7.3	20.4
%	(100)	(26.3)	(73.6)
Magnesium	8.8	2.4	6.4
%	(100)	(27.3)	(72.6)

In this sense, considering the fast growth of forest plantation in the tropics, mainly **Eucalyptus** and **Pinus** species, a large amount of nutrients is accumulated during the early stage of growth in tree biomass (POGGIANI, 1983). This amount of nutrient may represent sometimes over 50% of total nutrients contained in the ecosystem, including soil and litter.

Table 6 shows that tree biomass accumulates 48% phosphorus and 40% potassium in the **E. saligna** stand and 50.4% of the potassium contained in the system of the **P. caribaea** stand.

Data included in the Tables 3 and 4 show a heavier removal nutrient by the harvest of **E. saligna** than **P. caribaea** except for nitrogen.

Generally the harvest of hardwoods removes more nutrients from a site than the harvest of an equal volume of conifers. When the soil of a forest stand presents good fertility, nutrient losses by conventional harvest are relatively small on an annual basis. Such losses can probably be replaced by soil weathering and natural inputs. But, when mineral reserves in the soil are very low, fertilization becomes necessary to assure a permanently productive forest.

At present, forest plantation in Brazil has the tendency to occupy Infertile and sandy soils that do not contain sufficient mineral reserves to sustain a good tree growth under intensive management. On the other hand, the general tendency to a more complete utilization of tree components and the adoption of shorter rotations could significantly reduce the capacity of many marginally deficient soils to replace the nutrients removed during harvest.

Management of the site nutrient capital becomes increasingly important as the proportion of the capital that is removed increases and as the rate of removal approaches or exceeds the natural rates of replacement.

According to KIMMINS (1974) a silvicultural rotation should be an ecological rotation or a tree rotation which permits the return of the site to the ecological conditions that existed prior to rotation.

Table 7 compares annual atmospheric inputs with the annual accumulation of mineral nutrients in the different components of tree biomass considering that actually, whole-tree harvesting may be an economically feasible alternative source of energy in the State of São Paulo.

Table 6. Distribution of mineral nutrients in the systems "Tree-biomass-litter-soil (180 cm deep) in kg/ha and percentages.

Eucalyptus saligna stand (11 years old)					
Components	**Nutrients**				
	N	**P**	**K**	**Ca**	**Mg**
Tree biomass	219.0	58.1	190.5	954.3	81.4
%	(14.8)	(48.1)	(39.9)	(10.6)	(6.0)
Litter	50.2	4.6	10.6	59.5	14.6
%	(3.4)	(3.8)	(2.2)	(0.6)	(1.1)
Soil	1204.0	58.0	276.0	7956.0	1243.0
%	(81.7)	(48.0)	(57.8)	(88.7)	(92.8)
Pinus caribaea var. **hondurensis** stand (14 yeas old)					
	N	**P**	**K**	**Ca**	**Mg**
Tree biomass	304.5	16.2	150.6	103.7	33.9
%	(17.4)	(21.5)	(50.4)	(16.3)	(25.5)
Litter	155.6	8.5	19.8	38.2	8.9
%	(8.9)	(11.3)	(6.6)	(6.0)	(6.7)
Soil	1290.0	50.7	128.0	429.0	90.0
%	(73.7)	(67.2)	(42.9)	(77.6)	(67.7)

The higher inputs, shown in Table 7, were recorded by LIMA (1985) in Agudos, alongside **P. caribaea** var. **hondurensis** plantation and the other data were taken from papers of COUTINHO (1979) and VERDADE & KUPPER (1973) who analyzed rain - water in the central part of the State of São Paulo.

The higher data recorded by LIMA (1985) probably are due to the increasing expansion of sugar cane plantations for alcohol production, which are usually burned from April to September, and release a considerable amount of nutrients to the atmosphere.

Table 7 shows that atmospheric input may supply almost the total requirement of phosphorus, potassium, calcium, and magnesium for annual growth of **Pinus caribaea**, however, **E. saligna** atmospheric nutrients supply is below its requirement, mainly if harvesting of the total tree is considered.

POGGIANI **et alii** (1983) and POGGIANI (1985) showed that the very low contents of nutrients observed In soils of large areas of Brazilian savannas, where man-made forests are being established, precludes the normal growth of trees and an adequate mineral fertilization becomes necessary. Also maintenance of a minimum organic matter in the soil should be a very important aim for mineral cycling equilibrium in forest plantations. In this respect, the utilization of larger tree rotations in forest plantations is also recommended.

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