18 Coppicing Ability of Teak (*Tectona grandis*) after Thinning

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Abstract

The research was carried out at the Forest Industry Organization's Thongphaphum Plantation in Kanchanaburi province, Thailand. The main objective was to determine the effects of different thinning methods on coppicing ability of 17-year-old teak leading to two canopy levels. Teak stumps were planted in 1980 at a spacing of 4 x 4 m and average survival rate was 72%. In 1997 the thinning experiment was set up in a randomised block design with 3 replications and 4 treatments : low thinning, 1:1 mechanical thinning, 2:2 mechanical thinning, and clearcutting. Average stand density after thinning was 40 trees plot^{-1}, equivalent to 250 trees ha^{-1}. The thinned teak had average diameter breast height (dbh) of 18.5 cm and a commercial volume of 0.2411 m^3 tree^{-1}. Thinning methods did not affect shoot density, but affected shoot growth. Three months after thinning, there were 11.6 shoots stump^{-1}. This dropped to 7.9 shoots stump^{-1} at 1-year-old, due to competition. Average dbh and total height of 1-year-old shoots varied with available space after thinning having maximum figures for clearcutting (dbh 3.2 cm, height 2.91 m), followed by 2:2 thinning (dbh 2.6 cm, height 2.29 m), 1:1 thinning (dbh 2.5 cm, height 2.20 m), and low thinning (dbh 2.1 cm, height 1.75). The findings indicate that shoot growth is promoted by wider gaps after thinning due to the light-demanding characteristics of teak.

INTRODUCTION

Teak is indigenous to the Indian peninsula and continental Southeast Asia in a discontinuous or patchy distribution pattern in India, Myanmar, Thailand and Lao PDR at latitudes between 9°-25°30'N and longitudes between 73°-104°30'E. Teak in Indonesia is considered to be naturalised (Kadambi 1972, Siswamartana 1999). An introduction of teak from India to Nigeria in 1902 was the first transfer out of Asia (Ball *et al.*1999). Now it is one of the most widely cultivated hardwood timber species in the world having a total plantation area of 2.25 million ha (Ball *et al.* 1999), although according to Kaosa-ard (1996), India and Indonesia alone had 2.6 million ha.

In Thailand, the first teak plantation was established in 1906 by the Royal Forest Department (RFD) in Phrae province. Dibbling or direct seeding methods applied initially have been replaced by stump planting since 1935. In 1968 the state enterprises, Forest Industry Organization (FIO) and Thai Plywood Company (TPC), started growing teak and extensive commercial planting by the private sector started in 1992 with financial support from the RFD's Reforestation Fund during the first five years. Total area of teak plantation in Thailand in 1998 was about 300 000 ha; 69% owned by RFD, 27% by FIO, and 4% by the private sector (Thaiutsa 1999). Teak is planted in the North (79%), Central Plains (12%), Northeast (9%) and South (0.1%). Spacings of 3 x 3 m and 4 x 4 m intercropped with upland crops such as

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upland rice and pineapple are the most common practice leading to a rotation of 30-40 years with 3-4 thinnings.

A major problem of teak plantations in Thailand is appropriate site selection. Growth and yields are site-dependent. Based on site quality analysis of Chanpaisaeng (1977), a 30-year-old rotation of teak in northern Thailand can produce as high as 184 $m^3 ha^{-1}$ from superior planting site (6.13 $m^3 ha^{-1} yr^{-1}$) with a mean of 140 $m^3 ha^{-1}$ (4.67 $m^3 ha^{-1} yr^{-1}$). Table 1 shows site quality index of plantation teak in the North of Thailand.

Productivity of teak in northern Thailand was found to be the lowest in a comparison of mean annual increment at 50 years rotation age on different sites in various countries (Table 2). For example, such figure was 4.70 $m^3 ha^{-1} yr^{-1}$ for the best site in Thailand (Chanpaisaeng 1977), but they were 10.0 $m^3 ha^{-1} yr^{-1}$ in India, 17.3 $m^3 ha^{-1} yr^{-1}$ in Myanmar, and 21.0 $m^3 ha^{-1} yr^{-1}$ in Indonesia (Ball *et al.* 1999).

The degree of plantation manipulation is a factor affecting growth and yields of most planted trees including teak. Thinning is defined as removals made in an immature stand to stimulate the growth of trees that remain leading to increase total yield of useful material from the stand (Smith 1962). There are several methods of thinning. Mechanical thinning seems to be very common for the first thinning, while selection thinning may generate some income from the thinned wood due to cutting of the commercially dominant trees. The appropriate method of thinning, age of stand to be thinned, and thinning frequency vary with tree species, original spacing, planting site and preference of owners. In Myanmar, tree height determines the timing of the first two thinnings which are mechanical or modified mechanical method. Teak plantations with an initial spacing of 1.8 x 1.8 m are generally considered for the first mechanical thinning when the stems reach an average height of 7.6-9.1 m. The second thinning in good quality plantations is when stem height reaches 12.2-13.7 m (Myanmar Department of Forestry 1999). The intervals of thinning cycles at 10, 15, and 20 years of age are practised by the Thailand's FIO plantations for good sites, while such intervals would be 15, 22, and 30 years of age for poor site with the rotation length of 30 and 40 years, respectively.

Table 1. Commercial volume of plantation teak in northern Thailand

Age (yr)	Site quality (30 yr)		
	Poor	Medium	Good
	$m^3 ha^{-1}$		
10	23	52	81
20	67	103	144
30	96	140	184
40	122	166	213
50	142	190	235
60	162	212	259

Source: Chanpaisaeng, 1977.

Table 2. Mean annual increment (MAI) at 50 years rotation on poor, average and best site classes

Country	Site Classes		
	Poor	Average	Good
	MAI ($m^3 ha^{-1} yr^{-1}$)		
India	2.0	5.8	10.0
Myanmar	4.3	8.7	12.0
Indonesia	9.6	13.8	17.6
Thailand	2.8[*/]	3.8[*/]	4.7[*/]

Source: Ball *et al.* 1999; [*/] Chanpaisaeng 1977.

As a result of thinning, new shoots may sprout from the stumps to form new stands in the following rotations. A stand originating vegetatively from stump sprouts is referred to as "coppice", which normally grows faster than seedlings and enables a much shorter rotation. Another advantage of a coppiced stand is the low cost of establishment because little or no site preparation is required for regeneration from stump sprouts. Coppicing ability varies with tree species and cutting conditions. Teak coppices well after clearcutting, however, its coppicing ability after thinning requires investigation.

The main objective of this research is to determine the effect of thinning methods on the ability of young teak to coppice which may result in a two-storey management system for teak plantations in future.

MATERIALS AND METHODS

Study Site

The study site was located at Thongphaphum Plantation belonging to the Forest Industry Organization (FIO) in Thongphaphum district, Kanchanaburi province, western Thailand at the latitude of 14°8'-14°46'N and the longitude of 98°37'-98°46'E. It is considered a relatively superior site for teak plantation because its elevation of about 400 m is about 300 m below the upper limit for growing teak in Thailand. Another advantage of Thongphaphum Plantation is its landform surrounded by limestone mountains resulting in Pakchong Soil Series of Reddish Brown Lateritic Soils and Oxic Palcustults. Top soil is as sandy clay loam about 30 cm deep. Some soil physical and chemical properties reported by Teejuntuk (1997) are summarised in Table 3.

Table.3. Physical and chemical properties of soil at Thongphaphum Plantation, Kanchanaburi

Soil Property	Value
Sand %	47.4
Silt %	24.3
Clay %	28.3
Moisture %	30.4
Bulk density g cc^{-1}	0.93
pH	5.35
Organic matter %	8.06
Total N %	0.40
Available P ppm	7.78
Exchangeable K ppm	267
Exchangeable Ca ppm	1269
Exchangeable Mg ppm	391
CEC meq 100 g^{-1} soil	24.1

Source: Teejuntuk 1997.

The climate of Thongphaphum Plantation is generally affected by monsoons and can be divided into hot, rainy and cold seasons. April is the hottest month with the average temperature of 36.7°C, while January is the coldest month with average temperature of 15.8°C . However, critical minimum and maximum temperature might range between 6-42°C. Rainy season starts from early May to late October with the average rainfall of 1765 mm yr^{-1} and 156 rainy days yr^{-1}. Dry periods cover about 6 months, from early November to late April having only 187 mm of rainfall equivalent to 10.6% of the annual rainfall during such period.

The investigation was started in April 1997 at the 17-year-old teak plantation planted in 1980 with the original spacing of 4 x 4 m. One-year-old stumps were used as planting material. Survival rate prior to thinning experiment was 71.5% and the stand density was 447 trees ha^{-1}.

Experimental Design

A completely randomised block design with 4 treatments and 3 replications was used. Methods of thinning were considered as treatments as follows:

A : Low thinning
B : 1:1 mechanical thinning
C : 2:2 mechanical thinning
D : Clearcutting

A plot of 40 x 40 m (0.16 ha) consisted of 81 planted teak. Two outer rows of each plot were treated as guard rows. Diameter breast height of all trees, including in buffer zones, was recorded prior to thinning, while total height was recorded from the thinned trees to estimate stem volume.

Aboveground biomass of stems and branches were measured by weighing. Numbers of sprouts as well as their heights and diameters were measured at 3 months and 1 year of age for statistical analysis. Parameters such as aboveground biomass of undergrowth, percentage ground cover, soil properties and light intensity were also recorded but they are not reported in this paper.

RESULTS AND DISCUSSION

Three methods of thinning together with clearcutting resulted in differences in gap size and light intensity. Low thinning provided the smallest gap, followed by 1:1 mechanical thinning and 2:2 mechanical thinning, while clearcutting left no trees at all, i.e., the largest gap and full sunlight. Growth parameters of the thinned teak are in Table 4. Low thinning had the lowest dbh because of the small-tree cutting leading to minimum commercial volume per hectare.

Growth parameters of the trees from the clearcutting plot can be considered as the representative figures of this plantation. That is, the 17-year-old teak plantation has an average dbh of 21.1 cm, 109.38 t ha^{-1} total biomass, commercial volume of 0.3433 m^3 tree^{-1} and 171.87 m^3 ha^{-1}. The MAI of 10.11 m^3 ha^{-1} yr^{-1} showed that site quality of this plantation is superior to teak plantations in northern Thailand reported by Chanpaisaeng (1977), because of better soil factors, higher annual rainfall and many rainy days. Moreover, this MAI value is higher than the values of average site classes in India and Myanmar reported by Ball *et al.* (1999).

Table 5 presents the numbers of shoots per stump for 3 months and 1-year-old. However, they were not statistically significant between treatments. Reduction of the number of sprouts is a result of competition for light which is similar to the report of Sukwong *et al*. (1976) who studied the coppicing ability of teak in natural stands in the North and found that teak with dbh of 30 cm might have as many as 19 sprouts per stump after havesting. If intercropping is introduced to the coppiced stand, this competition would also reduce the yield of intercrops (Verinumbe and Okali 1985). Further decrease in the numbers of sprouts per stump will occur as they become older due to natural thinning. To manage the coppiced stands for commercial purpose, the sprouts should be thinned to leave only one sprout per stump.

Height and dbh growth of the 1-year-old shoots after thinning given in Table 6 showed that both height and diameter increased with increasing gap sizes. Shoots of low thinning had the smallest dbh (2.1 cm), followed by those of 1:1 mechanical thinning (2.5 cm), 2:2 mechanical thinning (2.6 cm), and clearcutting (3.1 cm). Total height also

Table 5. Numbers of sprouts per stump after thinning the 17-year-old teak

Thinning	Number of shoots per stump	
	3 months	1 year
Low	10.9	7.3
1:1 mechanical	11.9	8.7
2:2 mechanical	12.2	8.6
Clearcutting	11.5	7.1
Mean	11.6	7.9

Table 4. Growth parameters of the thinned teak from the 17-year-old plantation

Thinning regime	Dbh	Commercial volume		Biomass (t ha^{-1})		
	(cm)	(m^3 tree^{-1})	(m^3 ha^{-1})	Stem	Branch	Total
Low	14.8	0.1117	30.52	21.18	4.36	25.54
1:1 mechanical	19.7	0.2866	74.37	37.44	8.34	45.78
2:2 mechanical	18.3	0.2229	57.83	31.93	6.98	38.91
Clearcutting	21.1	0.3433	171.87	88.96	20.42	109.4

showed the same trend with the average of 2.6 cm for dbh and 2.3 m for height. Based on statistical analysis, both dbh and height were found to be significantly different at 95% confidence level. The figures also indicated that coppice sprouts grew faster than seedlings. Sukwong *et al.* (1976) suggested that coppiced teak should have dbh not larger than 30 cm in order to have maximum numbers of shoots per stump and total height of shoots. However, increased sprout number is of little importance if they are reduced to a single sprout per stump for commercial purposes.

Table 6. Diameter and total height of the 1-year-old shoots after thinning the 17-year-old teak

Thinning	Diameter bh (cm)	Height (m)
Low	2.1a	1.75a
1 : 1 mechanical	2.5b	2.20b
2 : 2 mechanical	2.6b	2.29b
Clearcutting	3.1c	2.91c
Mean	2.6	2.29

Numbers with a different letter are significantly different at the 5% level.

CONCLUSION

Methods of thinning did not affect shoot density, but affected dbh and total height of shoots. Both height and diameter growth of new shoots varied with space available due to thinning, maximum for clearcutting, followed by 2:2 mechanical thinning, 1:1 mechanical thinning, and low thinning. The findings suggest that modified mechanical thinning, such as 2:2 mechanical thinning, would be the thinning method recommended for faster growth of new shoots, if the clearcutting is not able to be applied.

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19 Site Characterisation and the Effects of Harvesting on Soil Tillage on the Productivity of *Eucalyptus grandis* Plantations in Brazil

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Abstract

Two commercial eucalypt sites were selected in São Paulo State, Brazil, to evaluate productivity and soil chemical and physical properties before clearcutting, and the effect of harvesting and soil tillage system on productivity of second rotation. At site 1, the *Eucalyptus grandis* plantation was 7 years old, on its first rotation, and reached 21 m mean height, 13.6 cm diameter breast height (dbh), an estimated commercial volume of 479 m^3 ha^{-1} and a mean annual increment of 68 m^3 ha^{-1} $year^{-1}$. At site 2, *E. grandis*, also on its first rotation, but 12-years-old, had 25 m mean height, dbh 16 cm, an estimated volume of 662 m^3 ha^{-1} and a mean annual increment of 55 m^3 ha^{-1} $year^{-1}$. Litter collected at site 2 before harvesting totalled 19.8 t ha^{-1}, and after harvesting and new planting, litter left on surface totalled 2.64 t ha^{-1}. At site 1, 31.3 t ha^{-1} of litter accumulated before harvesting and 7.6 t ha^{-1} after new planting. Soils of both sites are classified as Dark Red Latosol (Oxisol), having loam texture at site 2 and clay texture at site 1. Clay content difference between sites was around 10 %, available soil water content between sites varied less than 0.02 cm^3 cm^{-3}. Penetrometer soil resistance measured before harvesting and after new planting was less than 21 kg cm^{-2}, at 50 cm besides tree row, on both sites. Greater soil resistance measured at tree row was found at 15-cm depth, in both sites. Soil of site 1 has greater CEC, base saturation and organic matter content compared to site 2. One year after planting eucalypts growing on soil tilled with subsoiler with one shrank were smaller at site 2.

INTRODUCTION

The harvesting of timber affects ecosystems in various ways, including degradation of site, reduced forest water supply and soil loss. Where natural forests are replaced by short-rotation plantations there will be changes in nutrient storage and cycling processes due to factors such as harvesting wood, changed organic matter quality, fertilisation, erosion, and leaching. However, plantation forestry not only offers opportunities for meeting wood demands and reducing deforestation by decreasing pressures on natural forests, but can restore degraded soils and enhance biodiversity (Parrotta 1992).

There is increasing information on nutrient cycling in tropical plantations which suggests long-term sustainable production will rely on management practices which maintain soil organic matter, conserve nutrient stores and minimise direct nutrient losses. The risk that plantation forestry will not be sustainable depends on the alignment of interdependent variables that include ecological capabilities of the site, intensity of management, impact on soil, water and other environmental values (Nambiar and Brown 1997).

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The greatest impacts from management inputs occur due to operations associated with harvesting, site preparation, planting and early silviculture, including fertilisation and weed control. Soil degradation on *Eucalyptus* sp. commercial plantations, due to heavy and intense harvesting machine traffic and soil tillage operations for regrowth or new plantings, influences soil structure, causing compaction, and plant growth, reducing its development (Greacen and Sands 1980). Soil deformation, caused by changes in soil physical and chemical properties, occurs mainly by: increasing soil resistance to root penetration, reducing aeration, changing soil water and heat flux and soil water and nutrient availability (Lacey *et al.* 1994, Rab 1994, Shetron *et al.* 1988). This can cause plant development restrictions, depending on soil type, climatic conditions, type and stage of plant development.

Maintenance of productivity on forest areas has been always a problem, considering the size of plantation areas and, by being private property, they would be used to produce the same species for many years. Among natural factors that affect plant productivity, soil is the most easily modified by management. Restoring soil physical conditions, that can reduce plant development, can be reached by soil tillage. Completely reclaiming soil conditions is difficult and this implies greater costs, lowering profits and reducing sustainability of these areas.

The main objectives of this study were as follows:

- to evaluate the impact in the long-term of different harvesting and soil tillage methods on compaction and site productivity of eucalypt plantations;
- to develop soil tillage systems to alleviate soil compaction effects and to reclaim eucalypt plantation sites; and

Table 1. Soil chemical properties from the two *E. grandis* sites

Site	Soil depth	pH	CEC	Base saturation	Al saturation	Organic matter
	cm	$CaCl_2$	$c.mol_c\ dm^{-3}$	%	%	$g\ dm^{-3}$
Mogi-Guaçú (site 2)	0-10	3.78	8.53	11.8	62	20.2
	10-20	3.99	7.16	12.8	59	12.0
	20-30	4.03	6.21	14.6	51	8.1
	30-50	4.10	5.82	14.1	48	7.0
São Miguel (site 1)	0-10	3.83	10.83	14.4	61	37.6
	10-20	3.90	10.00	18.4	53	29.4
	20-30	3.92	9.45	16.9	55	25.7
	30-50	3.90	7.97	19.5	50	15.2

Table 2. Soil particle distribution analyses from the two *E. grandis* sites

Site	Soil depth	Sand			Silt	Clay
		total	coarse	fine		
	cm	$g\ 100\ g^{-1}$				
Mogi-Guaçú	0-10	69	48	21	11	20
	10-20	68	45	23	10	23
	20-30	69	45	24	9	23
	30-50	67	43	24	8	25
São Miguel	0-10	51	26	25	19	31
	10-20	49	22	26	19	33
	20-30	50	21	29	16	34
	30-50	49	20	29	16	36

- to test different residue management in eucalypt site exploration and its effects on site sustainability.

SITE DESCRIPTION

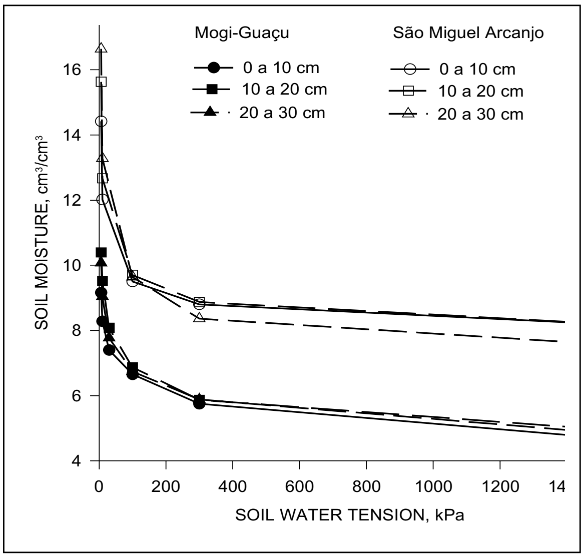
Site 1. – Suzano Paper and Cellulose Co., São Miguel Arcanjo- São Paulo State (SP) (23°51'S, 47°46'W and 715 m asl), a dark red clayey latosol, in a commercial *E. grandis* plantation aged 7 years. Site 2 – Champion Co., in Mogi-Guaçu-SP (22º07'S, 47°03'W and 680 m asl), a dark red sandy latosol, in a commercial *E. grandis* plantation aged 12 years.

Chemical data and particle distribution data from soils of both sites are given in Tables 1 and 2. In Fig. 1, curves of soil water retention are presented for soils from both sites and at three different soil depths. Soil chemical and physical analyses were made before harvesting.

Methods

At site 1, São Miguel Arcanjo, seven treatments (T1 to T7) were tested including different levels of fertilisers, two types of subsoiling and residue management, distributed in randomised blocks, four replications and 100 trees per plot.

Figure 1. Soil water retention curves from two sites growing *E. grandis*, at three soil depths, before harvesting



T1. All above ground organic residue removed from the area, including crop tree residue and accumulated litter. Soil surface organic matter was not disturbed. Soil tillage for next plantation was performed with one unit subsoiling and fertiliser dose will be 80 g $tree^{-1}$ of the formula 8-32-16. For eucalypt harvesting a feller was used;

T2. All trees were harvested. Residue from crop trees, as branches and bark, was left on site. Soil tillage and fertilisation was as in T1;

T3. Same procedures for harvesting and fertilisation as in T2, soil tillage for next plantation was performed with a two unit subsoiling;

T4. Same as T3, but soil tillage with a three unit subsoiling;

T5. Same procedures for harvesting and soil tillage as in T2, but an increase the fertilisation level compared to the preceding treatments;

T6. Harvesting and soil tillage system as in T3 and fertilisation as in T5.

T7. Harvesting and soil tillage system as in T4 and fertilisation as in T5.

At site 2, Mogi-Guaçu eight treatments (T1 to T8) were tested including different levels of industry residue, two soil tillage systems and tree residue management, minimised in randomised blocks, five replication and 60 trees per plot, with the following treatments:

T1. All above ground organic residue including crop trees and litter was removed from the plots. The soil organic matter on the surface was not disturbed. Soil for next plantation was tilled with a three unit shrank subsoiler and fertilisation was 80 g $tree^{-1}$ with NPK 8:32:16.

T2. All commercial stems were harvested and removed from the site, including tree bark. Others crop residues were left on site surface well-distributed. Soil tillage and fertilisation were the same as T1;

T3. Harvesting methods were those commonly used by the owner, soil tillage and fertilisation were the same as in T1;

T4. Harvesting and soil tillage were the same as in T3, and fertilisation was with 7.5 t ha^{-1} of cellulose residues and 2 t ha^{-1} of lime;
T5. Harvesting and fertilisation were the same as in T4, and soil tillage was performed with an one-unit subsoiler;
T6. Harvesting and soil tillage were the same as in T4, and fertilisation was completed with 15 t ha^{-1} of cellulose residues and 4 t ha^{-1} of lime;
T7. Harvesting and soil tillage were the same as in T5, and fertilisation was the same as in T6;
T8. Harvesting and soil tillage were the same as in T4, and fertilisation was the same as in T6.

Data Collection

Preharvest stand

Twenty eucalypt trees from 20 planting lines (400 trees) had their height and dbh measured before harvesting to estimate wood volume and biomass produced. Litter production was also estimated before harvesting and samples taken for chemical analysis.

Tree growth

The height and diameter of 12 eucalypts in three planting lines on each treatment plot were measured at 1 year after planting.

Soils

Bulk density, soil resistance to penetration and hydrological properties were measured in each treatment before harvesting, and at 1 year after new planting. At the same time, samples were collected from the soil profile for chemical analysis.

RESULTS AND DISCUSSION

All measurements taken from 12-year-old eucalypt trees were greater than those from 7-year-old trees (Table 3). However, mean annual increment was greater for the 7-year-old tree site. This is probably due to competition and the row and tree intervals being used, at both sites 3 x 2 m. Soil at site 1 has better chemical properties, especially CEC, base saturation and organic matter content (Table 1). Soil at site 1, has larger percentage of clay (Table 2) which is an advantage in terms of plant nutrient and water retention. Fig. 2 shows that soil water available content is very low (less than 10%) for both sites, considering the amount of water between 6 and 1500 kPa soil water tension. About 2% more soil water is available in soil from site 1 than from site 2.

Figure 2. Available soil water content at the two *E. grandis* sites before harvesting

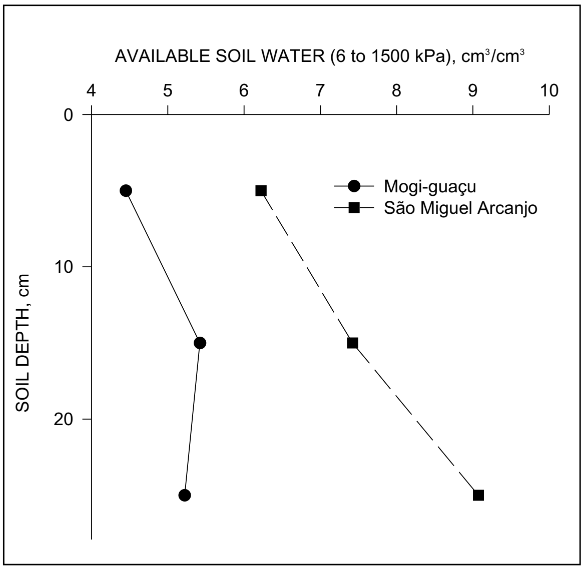


Table 3. *Eucalyptus grandis* productivity at Mogi-Guaçu and São Miguel Arcanjo

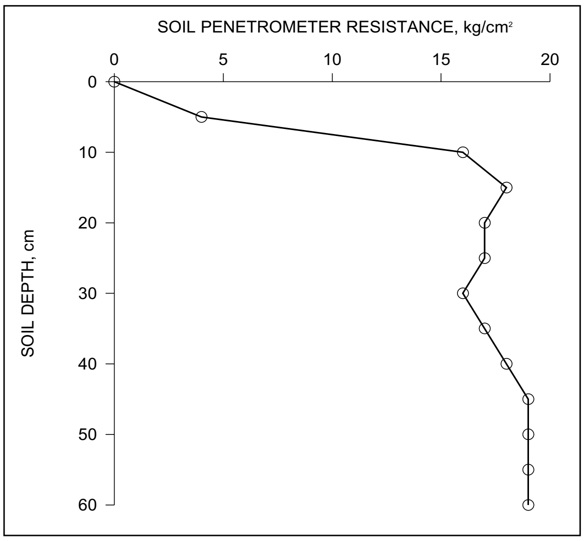
Site	Age yr	Height m	dbh cm	Volume m^3	Survival %	Volume $m^3\ ha^{-1}$	MAI $m^3\ ha^{-1}yr^{-1}$
Mogi-Guaçú	12	25.4	15.8	0.554	80	663	55.2
São Miguel	7	21.0	13.6	0.394	81	479	68.4

Litter collected at site 2 before harvesting, totalled 19.8 t ha^{-1} and after harvesting and new planting, litter left on surface of plots without residue totalled 2.64 t ha^{-1}. At site 1, there was 31.3 t ha^{-1} of litter before harvesting. After harvesting and new planting the amount of litter on plots with no residue left was 7.6 t ha^{-1}. These two sites had a very different harvesting procedures. At site 1, only commercial stems were taken from the plantation area, while in site 2, almost the entire tree was taken from the site. At site 2, the entire tree was skidded to the border area, where debarking and other procedures were performed.

There was little difference in nutrient content in litter obtained from both sites before harvesting. Among the macronutrients, content of P and Ca differed in litter from the two sites, and Fe content, among the micronutrients. The differences in P and Ca content in litter could be a matter of fertiliser quantities used. The larger amount of Fe presented in litter from site 1 could be a matter of soil type, especially due to its greater clay content.

Soil penetrometer resistance at site 1 was performed before harvesting and after new planting. Figure 3, based on the means of 22 points, shows data for soil resistance only before harvesting. Measurements were made 50 cm apart from the planting row. Considering a limiting value 20 kg cm^{-2}, no sample reached this limit.

Figure 3. Soil penetrometer resistance in a dark red clayey latosol under a commercial *E. grandis* plantation at São Miguel, Brazil



At site 2, all seven treatments were measured one year after planting *E. grandis* (Fig. 4). The tree heights in treatments that received cellulose residues as additional fertilisation did not differ statistically. Tree heights differed statistically in those treatments that received only chemical fertilisers at planting time. It is important to point out that the only two treatments prepared with a one-unit-shrank subsoiler were the tallest. Soil water availability must be playing an important role in tree growth. The treatment that had all harvesting residues removed from the soil surface had the lowest tree height, and when all residues were kept on soil surface there was better growth than the normal harvesting treatment. Treatment 6 that received the highest level of fertilisation had the greatest standard deviation (20%). and was ranked second for height growth.

Soil resistance data obtained with a penetrometer before harvesting, immediately after new planting and one year after planting are summarised in Fig. 5, for site 2 only. Measurements of soil penetrometer resistance were made counting the number of impacts to go through a 10 cm of soil layer and the data transformed by an equation presented by Stolf (1991). They represent an average (20 points) of the measurements of soil resistance before harvesting. and after soil tillage and new planting. Measurements were taken in two different plots:

Figure 4. Height growth of one-year-old *E. grandis* under different systems of soil tillage, fertilisation and harvesting, Mogi-Guaçu, Brazil

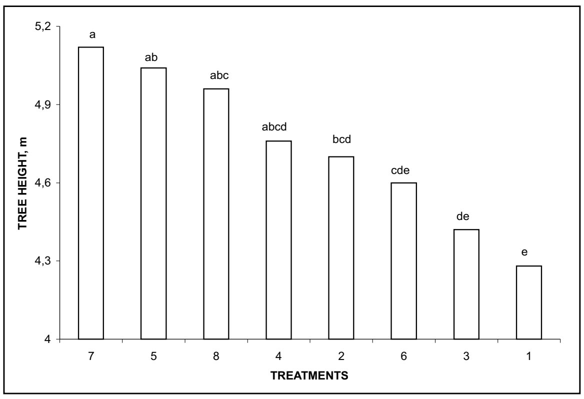
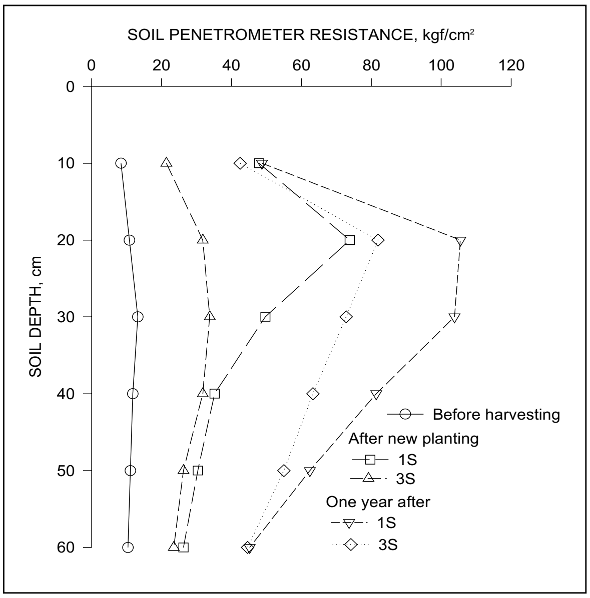


Figure 5. Soil penetrometer resistance using different tillage systems, in a *E. grandis* plantation, Mogi-Guaçú, Brazil



1. 3S–soil tilled with a three-shrank subsoiler; and
2. 1S–soil tilled with a one shrank subsoiler.

Differences in soil moisture at measuring times were less than 3% and it can be seen that harvesting operations can increase soil resistance very much (Fig. 5). Measurements were made 50 cm from the planting line, and it can be observed that tilling with a one-shrank subsoiler did not overcome most of the soil compaction, or at least not as well as a three-shrank subsoiler. One year after new planting, soil resistance has increased where soil was tilled with a three-shrank-unit subsoiler and did show much variation from the one-unit-shrank subsoiler tillage system. Even at greater soil resistance, *E. grandis* growing in soil tilled with one-unit-shrank subsoiler had greater height growth. Perhaps, for this kind of soil, with a high sand content and very high water permeability due to the dominance of macropores, a little compaction may increase soil water retention and less soil movement could reduce deep-water drainage.

CONCLUSIONS

Based on data collected before harvesting it was concluded:

- *E. grandis* volume production was greater at site 2 with 12-year-old trees;
- soil fertility at site 1 was greater than at site 2, based on CEC, base saturation and organic matter content;
- soil from site 1 had higher clay content and more soil water available for plants.

From data collected one year after new planting at site 2 (Mogi-Guaçu), it was concluded:

- trees had greater height growth in treatments where soil was tilled with a one-shrank-unit subsoiler;
- soil penetrometer resistance was higher in those treatments with taller trees; and
- retention of all tree residues on the soil surface increased tree height growth compared to normal harvesting when the same soil tillage system and fertilisation level were applied.

Table 4. Nutrient content of the litter before clearcutting of *E. grandis* at two sites at different tree ages

Sites	N	P	K	Ca	Mg	Cu	Fe	Mn	Zn
			g kg^{-1}				mg kg^{-1}		
Mogi-Guaçú	6.89	0.23	0.56	8.61	0.77	10	1341	232	13
São Miguel	7.01	0.44	0.54	5.57	0.90	8.9	4013	346	24

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Quantification of the Biomass and Nutrients in the Trunk of *Eucalyptus grandis* at Different Ages

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Abstract

The accumulation and cycling of nutrients in planted forest is essential to the establishment of management practices that can lead to the sustainable production of the forest site. The uptake, accumulation and release of nutrients depend on tree age and stage of development. The knowledge of accumulation and cycling of nutrients allows the estimation of output and replacement of nutrients to the forest site. This makes it possible to correct nutritional disorders caused by the use of inadequate management techniques. The usual method of sampling biomass and nutrients is always destructive making it impossible to establish permanent plots for nutritional monitoring. This study aimed at selecting models to estimate the biomass (volume and weight) and the nutrient contents in different parts of the trunk of *Eucalyptus grandis*, and reducing costs of sampling and analysis. Forty-five trees were selected from the dominant class (15 trees), co-dominant (15 trees) and suppressed (15 trees) in commercial plantations of *E.grandis* at ages 3, 5 and 7 years, in the municipality of Itatinga, SP, Brazil. Samples were taken of bark, sapwood and heartwood separately. Models to estimate volume and weight in the different components of the trunk were generated from the diameter at breast height (dbh) using regression analysis. Models to estimate content of N, P, K, Ca and Mg in the bark, sapwood and heartwood from the nutrient contents in a section of the trunk were also defined, so enabling a recommendation for non-destructive sampling.

INTRODUCTION

Soil analysis is not an efficient tool for monitoring nutritional status of trees. The presence of nutrients in the soil does not mean that the tree is satisfactorily nourished. The availability of nutrients to the trees is conditioned by the content of water in the soil, soil aeration, soil temperature, soil microorganisms and the efficiency of the root system to absorb nutrients (Raij 1981). Samples of tree tissues are valuable tools to establish the relationship between growth and nutritional status of the trees. However some factors can modify the nutrient contents of the tree tissues. Among them are the sampling criteria of Lavender and Carmichael (1966), the position of the sample in the tree, the season of the year and the age of the sampled material (Evans 1979, Silva 1983, Bellote 1990). Leaves are not the only part of the tree able to represent the nutritional status of the trees, however they have been recommended for monitoring most of the nutrients (Smith 1962). Nutrient content of other parts of the trees are considered for estimating export and efficiency of utilisation of nutrients (Silva 1983). Variations of nutrient contents in the same component has been detected for instance from the base to the top of the trees (Attiwill 1979) and in the radial direction from the heartwood to the sapwood (Ferreira *et al*. 1993). These variations enhanced the importance of

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quantifying the proportion of heartwood and sapwood to infer the processes of mobilisation and translocation of nutrients in the stem.

Research on distribution and accumulation of nutrients in the stem and other compartments of *Eucalyptus* trees in plantations, has intensified since the early 1980s. These studies are very important for estimation of nutrient removals from the site, identification of more efficient trees and species, and nutritional implications of whole tree harvesting (Bellote 1979, Silva 1983, Pereira *et al*. 1984). Furthermore, the knowledge of nutrient quantities in different parts of *Eucalyptus* trees is useful for the estimation of the nutritional rotation age, and replacement of nutrients to the soil.The precision of the estimates of quantities of nutrients removed depends on a better knowledge of the sampling and its precision. So, the main objectives of this paper are:

- To improve the precision of the estimates of nutrients in different compartments of the tree, by improving sampling procedures;
- To reduce costs of sampling and analyses of samples;
- To select mathematical models that enable estimation of accumulation and export of nutrients, volume and biomass by non-destructive methods.

MATERIALS AND METHODS

Trees of *E. grandis* were sampled from plantations 3, 5 and 7 years old, planted at 3 x 2 m spacing in the municipality of Itatinga. All areas belong to Companhia Suzano de Papel e Celulose S.A, a pulp and paper forest enterprise. A total of 45 trees per age group, from three different canopy classes, (dominant, co-dominant and suppressed trees), were sampled according to the method of Zöttl and Tschinkel (1971). Wood discs were collected from the base to the top at 1 m intervals, including the diameter breast height (dbh), to a minimum diameter 4 cm. Diameters with and without bark were measured and also the extent of heartwood and sapwood, when heartwood was present. The specific gravity of each sample was estimated according to the M14/70n ABCP (Brazilian Association of Pulp and Paper) rule. Also, samples were collected from each disc for nutrient content determination. The total volume including bark, sapwood and heartwood was estimated using the regressions of Silva (1996). The total content of nutrients in the bark, sapwood and heartwood was obtained by adding the contents of each segment. Mathematical models were developed through regression analysis. They were intended to evaluate contents of nutrients in the different compartments by means of non-destructive methods and ease access sampling points.

RESULTS AND DISCUSSION

Removal of stems with bark is the component that most contributes to the export of nutrients from the site. Table 1 gives the quantities of nutrients in a *Eucalyptus grandis* trunk at ages 3, 5, and 7 years. Nutrient accumulation was greater between the third and the fifth years (223%) than between the fifth and seventh years (20%). Competition among the trees is probably the reason for the decrease observed. The quantities of Ca, K and P increased from the third to the seventh year, while N leveled off after the third year and Mg decreased. The reason for the decrease of Mg content is the internal cycling of the nutrient for new tissues and a possible lower demand as age increased.

The mathematical models for estimation of nutrient contents in the bark of *E. grandis* at 3, 5, and 7 years old are presented in Table 2. Segments of the bark from different positions in the stem were selected as independent variables. To estimate the contents of the nutrients it is emphasised that all samples for all nutrients studied can be taken from 1-2 m stem height. At age 3 years the squared correlation coefficients (r^2) were all above 0.96 and the highest standard deviation obtained was 18.5%. The precision shown by these values is more than sufficient for the objectives of this paper. Almost the same results can be reported for the ages 5 and 7 years, and for different nutrients in the bark. The squared correlation coefficients were no lower than 0.943 and the maximum standard

Table 1. Nutrient accumulation and biomass of the trunk of *Eucalyptus grandis* at ages 3, 5 and 7 years

Age (yr)	Nutrient accumulation (g)					Biomass (kg)
	N	P	K	Ca	Mg	
3	44.5	5.5	43.9	44.9	11.7	38.8
5	78.5	10.6	56.0	87.0	28.5	88.8
7	78.1	18.4	67.1	107.9	23.2	106.8

Table 2. Equations for indirect estimation of nutrient accumulation in the bark of Eucalyptus grandis at ages 3, 5 and 7 years

	Nutrient/Equation	r^2(1)	S_{XY}%(2)
3 years			
	$N = 10,2536^* N_{1m}$ (3)	0.98	12.81
	$P = 8.7925^* P_{1m}+10.1343^*{}_{1.3m}$	0.97	18.51
	$K = 41.7454^*K_{1.3m}$	0.99	8.89
	$Ca = 24.3941^*Ca_{1.3m}$	0.99	12.39
	$Mg = 8.8574^*Mg_{1m}$	0.99	1.98
5 years			
	$N = 85.8013^* N_{1.3m}$	0.95	23.30
	$P = 9.9600^* N_{1.3m}$	0.99	17.08
	$K = 52.4622^*K_{1.3m}$	0.90	14.80
	$Ca = 4.7158^*Ca_{base}$	0.96	22.33
	$Mg = 11.2591^*Mg_{1m}$	0.95	23.42
7 years			
	$N = 50.9402^* N_{1.3m}$	0.98	12.92
	$P = 2.7638^* N_{1.3m}+13.3973^*N_{1m}$	0.98	14.25
	$K = 6.4473^*N_{1.3m}+31.2538^*N_{1m}$	0.96	21.16
	$Ca = 4.9205^*Ca_{1m}+18.0455^*Ca_{1.3m}$	0.98	13.52
	$Mg = 48.0414^*Mg_{1.3m}$	0.97	18.16

Note: (1) squared correlation coefficient; (2) standard deviation % (3) 1 and 1.3. indicate samples at 1.0 m and 1.3 m height

deviations no higher than 23.4%. All samples needed for the estimates can be taken from the base, 1.0 and 1.3 m height in the trunk, as detailed in Table 2.

The rate of biomass accumulation of bark was lower than the whole trunk biomass (Table 1) for all ages. There is a tendency of levelling the relative amount with age. The bark represents 10.4%, 8.0% and 7.5% of the biomass of the trunk for ages 3, 5 and 7 years, respectively. Also, *E. grandis* accumulates relatively small quantities of nutrients in the bark (10% of N, 20% of P and 25% of K) as compared to the total nutrients in the leaves. However, depending on species, the bark can accumulate 39-48% of the total Ca present in the crown. Despite accumulating less quantities of mobile nutrients in the bark, they are in an available form and play an important role in the growth of new branches (Bowen and Nambiar 1984). The bark also accumulates larger quantities of Ca and Mg than the sapwood and heartwood. The rate of Ca accumulation in the bark is higher from the third to the fifth year and lower from the fifth to seventh year (Table 3). This trend was also observed for K and P, but in a lesser rate. A similar behaviour to K and P were observed for Mg and N with higher accumulation being from the third to the fifth year. This behaviour can be associated with the mobility of these elements in the tissues and also with an increase of the amount of dead tissues in the bark. The quantity of P in the bark increased with the age.

The coefficients of the mathematical models for the quantification of nutrient contents in the sapwood of *E. grandis* are presented in Table 3 and the quantities of nutrients accumulated with age in Table 4. The estimates were obtained from small segments of sapwood collected at the base of the trees, and from 1.0 m and 1.3 m up the trunk.

Models for estimating contents of nutrients in the sapwood had satisfactory precision as shown by the squared coefficient of correlation values, low standard deviations and acceptable distribution of residuals obtained (Table 4). The precision of the equation coefficients for Ca, K, N and Mg was higher from the third to the fifth year. This can be explained by the maximum accumulation of nutrients occurring when trees are 7 years old. Also the distribution of the standard deviations improved as the nutrient quantities mounts in the trunk reached the maximum accumulated at age seven years.

The quantities of Ca and Mg in the bark of *E. grandis* is higher than in sapwood at 3, 5 and 7 years old. On the other hand, N, P and K were higher in the sapwood than in the bark. (Table 5). The Mg and N had similar trends of accumulation as in the bark but even more intensive at age 5 years. A comparison between the biomass of the trunk and the biomass of sapwood shows that sapwood represents 88.5, 58.2 and 56.4% of

Table 3. Nutrient accumulation and biomass of the bark of *Eucalyptus grandis* at 3, 5 and 7 years of age

Age (yr)	Nutrient accumulation (g)					Biomass (kg)
	N	P	K	Ca	Mg	
3	14.15	2.26	11.81	33.07	6.27	4.2
5	23.42	4.10	17.18	64.15	13.77	7.1
7	21.22	8.61	20.48	77.14	12.08	8.0

Table 4. Equations for the estimation of nutrient quantities in the sapwood of *Eucalyptus grandis* at age 3, 5 and 7 years

	Nutrient/Equation	r^2(1)	S_{XY}%(2)
3 years			
N	$= 35.7751^* N_{1m}$ (3)	0.98	13.33
P	$= 39.0684^* P_{1.3m}$	0.98	14.83
K	$= 38.1580^*K_{1.3m}$	0.98	14.08
Ca	$= 6.6860^*Ca_{base}$	0.98	17.88
Mg	$= 35.6887^*Mg_{1.3m}$	0.97	17.71
5 years			
N	$= 14.3834^* N_{1m}$	0.98	14.55
P	$= 68.1484^* P_{1.3m}$	0.98	16.70
K	$= 12.1259^*K_{1m}$	0.98	14.63
Ca	$= 8.8852^*Ca_{base}$	0.95	23.89
Mg	$= 52.9199^*Mg_{1.3m}$	0.98	12.92
7 years			
N	$= 6.8581^* N_{1.3m}+33.2438^*N_{1m}$	0.99	8.48
P	$= 27.2632^* P_{base}+30.9341^*P_{1.3m}$	0.87	21.71
K	$= 13.5624^*K_{1m}$	0.99	9.36
Ca	$= 15.3568^*Ca_{1m}$	0.98	14.18
Mg	$= 54.2122^*Mg_{1.3m}$	0.99	11.97

Note: (1) squared correlation coefficient; (2) standard deviation % (3) at base and 1.0 m and 1.3 m height.

the total biomass for ages 3, 5 and 7 years respectively. So the proportion of trunk biomass increased relatively more than the sapwood biomass. This can be explained by the increase in the heartwood biomass after the third year.

Nitrogen, P, Ca and K were higher in the sapwood than in the bark. The same nutrients also show a trend of continuous accumulation in the sapwood through the rotation. The coefficients obtained for the models developed in order to estimate nutrient quantities in the heartwood of *E. grandis* are presented in the Table 6. In general the squared coefficients of correlation were high. The lower values were obtained for Ca at 3 years and K at 5 years. The distribution of the standard deviations was not satisfactory, mainly at younger ages, due possibly to the differentiation of the sapwood into heartwood and a heterogeneous migration of the mobile nutrients generated very different concentrations of nutrients in the heartwood for the different trees at the same age.

An approximate estimate shows that sapwood accumulates 2.5 to 3.0 times more nutrients than heartwood (Tables 5 and 7). This strongly suggests that the nutrients migrate to the sapwood and other parts of the trees in a process similar to the migration of nutrients from old and senescent leaves to new tissues (Marschner 1995). The larger differences between sapwood and heartwood relate to K. Although heartwood is 63.9% of the sapwood

Table 5. Nutrient accumulation and biomass of the sapwood of *Eucalyptus grandis* at ages 3, 5 and 7 years

Age (yr)	Nutrient accumulation (g)					Biomass (kg)
	N	P	K	Ca	Mg	
3	30.3	3.2	32.0	11.8	5.4	35.9
5	38.4	6.0	36.0	11.7	10.8	51.7
7	41.3	9.2	43.4	14.4	7.8	60.3

Table 6. Equations for the determination of nutrient quantities in *Eucalyptus grandis* heartwood at ages 3, 5 and 7 years

Nutrient/Equation			r^2(1)	S_{XY}%(2)
3 years				
N	=	$4.6722^* N_{1m}$ (3)	0.97	17.03
P	=	$4.7796^* P_{1.3m}$	0.98	14.49
K	=	$7.5584^*K_{base}+3.1887^*K_{1.3m}$	0.98	10.56
Ca	=	4.4865^*Ca_{1m}	0.96	18.00
Mg	=	$0.1705^*Mg_{base}+1.5451^*Mg_{1m}$	0.98	2.10
5 years				
N	=	$33.2659^* N_{1.3m}$	0.99	9.27
P	=	$33.4577^* P_{1.3m}$	0.99	8.91
K	=	7.3175^*K_{base}	0.98	15.35
Ca	=	$34.5843^*Ca_{1.3m}$	0.99	7.40
Mg	=	9.9419^*Mg_{1m}	0.99	8.20
7 years				
N	=	$35.5906^* N_{1.3m}$	0.99	9.11
P	=	$35.1882^* P_{1.3m}$	0.99	9.81
K	=	$-2.7928^*K_{base}+48.7976^*K_{1m}$	0.99	5.53
Ca	=	$36.0385^*Ca_{1.3m}$	0.99	9.16
Mg	=	$35.7885^*Mg_{1.3m}$	0.99	7.82

Note: (1) squared correlation coefficient; (2) standard deviation % (3) at base and 1.0 m and 1.3 m height

Table 7. Nutrient accumulation and biomass of *Eucalyptus grandis* heartwood at ages 3, 5 and 7 years.

Age (yr)	Nutrient accumulation (g)					Biomass (kg)
	N	P	K	Ca	Mg	
3	0.04	0.0007	0.018	0.02	0.007	51.22
5	16.65	0.58	2.8	11.17	3.91	29953.99
7	15.61	0.59	3.22	13.34	3.29	38559.01

volume, at age 7 years, the amount of K is some fifteen times less, which implies a smaller removal of the nutrient relative to the wood volume exploited.

Heartwood biomass is quite undeveloped until the third year, mainly for trees with dbh smaller than 13 cm (Bellote *et al.* 1993). For instance, heartwood is 0.14, 57.9 and 63.9% of the total biomass of the trunk at ages 3, 5 and 7 years respectively. As shown in Tables 5 and 7, there is a high migration of nutrients when heartwood is being formed, and this is a process extremely important to the economy of nutrients. The mobilisation does not occur for all nutrients. For instance, Ca is a quite immobile nutrient and is a component of the tree tissues being present in the cellular membrane. The fact that sapwood and heartwood have almost the same quantities of Ca, despite the heartwood biomass being much smaller, is clearly due to a higher concentration of Ca.

The bark, which represents 7.5% of the trunk at age 7 years old, accumulates more N, P, K, Ca, and Mg than branches and heartwood. It is emphasised that the bark is a component that accumulates larger quantities of Ca than the sapwood (Silva 1983).

In the bark and sapwood, N and Mg quantities increased between the third and the fifth year. However, after that age, N and Mg quantities levelled off although bark and heartwood biomass increased. This suggests an intensive migration of mobile nutrients as sapwood is transformed into heartwood. As an important mechanism for the economy of nutrients and the sustainability of forest ecosystems, the timing of heartwood formation should be considered when exploitation plans are developed.

CONCLUSION

The sampling methodology proposed in this paper shows acceptable results for estimating volume, biomass weight and nutrients content in different components of *E. grandis* trees. The methodology proposed allows the determination of nutrient contents by means of non-destructive sampling and the use of mathematical equations to estimate the accumulation of nutrients. Samples can be taken up to a maximum trunk height of 2 m without felling the trees. The precision of the equations is acceptable to estimate accumulation and removal of nutrients through harvesting.

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Nutrient Export by Clear Cutting *Eucalyptus grandis* of Different Ages on Two Sites in Brazil

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Abstract

At two sites, where *Eucalyptus grandis* plantations were 7 and 12 years old, twelve dominant trees were cut and measured. The 12-year-old-trees were 29.4 m mean height, 19.9 cm diameter over bark and estimated volume 0.40 m^3 $tree^{-1}$. The 7 year-old trees were 30.7 m mean height, 20.6 cm diameter and estimated volume 0.49 m^3 $tree^{-1}$. Of total biomass, 92% was trunk (sapwood, heartwood and bark). Based on a population of 1500 trees ha^{-1}, there is an export of biomass of 296 t ha^{-1} from 302 t ha^{-1} being produced, when the entire trunk is removed. When only commercial stems are removed, there is an export of 277 t ha^{-1}. Within a whole tree, N is the nutrient present in greatest amount, followed by K, Ca, Mg and P. When parts of the tree are analysed, calcium is the nutrient present in greatest amount in bark. Phosphorus was not detected by the chemical analysis in heartwood in trees of 12 years of age, but it was present in trees aged 7 years. The amount of N and K extracted from soil by the trees is greater than the amount of these nutrients supplied by fertiliser, usually around 20 g $plant^{-1}$ of N and 15 g $plant^{-1}$of K_2O. More than 50% of N, Ca and Mg are in the heartwood, sapwood and bark. Even if only commercial stems are taken from the plantation area, most of the nutrients will be exported.

INTRODUCTION

From the environmental point of view, *Eucalyptus* plantations help reduce pressure on native forests. Nevertheless, fast-growing species in Brazil impose high demands on soil resources, especially water and nutrients. This has raised the question of sustainability of these systems under intensive cultivation. The sustainability of site productivity is a challenge for forest management. Of all practices used, the forest clear cutting is the most aggressive operation in terms of site damage including export of nutrients and soil compaction. Further the use of mechanical operations, especially in harvesting, also affects soil permeability, water infiltration, erosion, and nutrient cycling.

Harvesting only the trunk, and keeping leaves, branches and bark on site to protect the soil and to maintain the nutrients in the system is often recommended. The amount of mineral nutrients present in the aerial parts of a tree is represented by the sum of nutrients contained in the different parts. Each part has a certain amount of nutrients, according to its physiological function. The nutrient content in leaves, branches and bark of eucalypts is very impressive. These residues when kept on site reduce the impact of nutrient export. Poggiani *et al.* (1983) estimated nutrient export and biomass per area. They observed that leaves represent 9% of the biomass, branches 7%, and trunk 83%. However, 37% of the nutrients are in leaves, 10% in branches and 53% in the trunk. The nutrient export problem is made even worse by short rotations and

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exploitation of young trees (around 7 years old) which increase losses of nutrients from a site, and this can have a pronounced effect on sustainability (Pereira *et al*. 1984, Poggiani *et al*. 1983, Poggiani 1985, Pereira 1990). This situation can remove more nutrients than harvesting trees of more advanced ages (Lima 1993). In addition, soil preparation for the next rotation, sometimes includes burning of residues left on the soil surface after harvesting (Costa 1995).

This study reports the effects on nutrient export of clear cutting *Eucalyptus grandis* of different ages on two sites in São Paulo State, Brazil.

MATERIALS AND METHODS

This work was developed in two plots of *Eucalyptus grandis* at 7 and 12 years after planting. The 7-year-old eucalypt site is in the municipality of São Miguel Arcanjo (latitude $23^0$51'S and longitude $47^0$46'W, 715 m above sea level) and the 12-year-old trees were in the municipality of Mogi Guaçu ($22^0$07'S, $47^0$03'W and 680 m asl), areas belonging to the Companhia Suzano de Papel e Celulose and Champion Papel e Celulose, respectively. Both places are representative of *Eucalyptus* plantations in the State of São Paulo, Brazil. The trees were spaced 3 m x 2 m with a stocking of 1500 trees ha^{-1}. The soil in São Miguel Arcanjo is a dark red clayey latosol, and in Mogi Guaçu is a dark red sandy latosol.

After an initial survey of tree height and diameter breast height (dbh), 12 dominant trees were selected at each site representing the average growth (height and diameter) of the stand. These trees were felled and dbh, total height, commercial height measured. They were divided into leaves, branches and trunk (sapwood, heartwood and bark). All leaves were separated, weighed and a representative sample of them was taken, to determine its dry weight and its mineral nutrient content. Based on nutrient concentration, determined by chemical analysis, and on total dry weight, the amount of N, P, K, Ca and Mg (g) in leaves was determined.

Discs were collected at 1 m intervals upwards from the base of the trunk, including at dbh and commercial height (diameter >4 cm) and their diameters with and without bark measured. Sapwood, heartwood and bark were removed from each disc, their basic densities determined and they were analysed for N, P, K, Ca and Mg content. Procedures for sampling, volume calculations and dry matter weight for each part were performed according to methodology proposed by Silva (1996). Branch sampling also followed methodology proposed by Silva (1996). Branches were classified and separated according to their diameters: thin branches (less than 3 cm), medium branches (from 3 to 8 cm) and thick branches (above 8 cm). Each class was weighed in the field and a sample taken to determine its dry matter weight and mineral nutrient content. Based on this information, total dry biomass and nutrient content (N, P, K, Ca and Mg) were calculated for each tree.

RESULTS AND DISCUSSION

Eucalypts are grown in Brazil in a great variety of climate and soil conditions, with a significant variability in available soil water and mineral nutrient content for the tree growth. Mineral fertilisation is widely practised. In the State of São Paulo, tree volume productivity varies from about 20 to 100 m^3 ha^{-1} $year^{-1}$. Table 1 shows tree growth in height and diameter and the total volume of trees of 7 and 12 years of age, grown at the two sites.

Among several factors that contribute to the production variability, climate (Barros and Novais 1990), and physical (Melo 1994), chemical (Santana 1994) and biological (Facelli and Pickett 1991) properties of soil stand out. The area of lower productivity (12-year-old trees) is located on savanna-type natural vegetation and where the moisture regime includes a well-defined period of drought, lasting around 6 months. This does not occur in the area of high productivity (7-year-old trees). The savanna's soil has a lower level of natural fertility, less clay and organic matter content compared to soil in the 7-year-old plantation. These differences contribute

Table 1. Means of dominant height, diameter breast height and volume for trees and for the *E. grandis* stands

Age (yr)	Height (m)	dbh (cm)	Stem (volume with bark) Tree (m^3)	Stand (m^3 ha^{-1})
7	30.7 ± 0.5	20.6 ± 0.8	0.49 ± 0.04	735 ± 63
12	29.4 ± 1.1	18.9 ± 1.0	0.40 ± 0.05	600 ± 84
F test	*	**	**	**

[1] based on 1500 trees per hectare
F test - * and ** significant at the 5 and 1% level, respectively

significantly to differences in productivity, among the studied areas. The larger stem wood production of the 7-year-old eucalypts is related to differences in tree height and diameter. Although a variation in wood volume was observed, the same was not true of biomass production and total dry matter production per hectare for the two sites is statistically the same.

Among different tree components, the largest accumulation of biomass is in the trunk. Trees of 7 years of age had more sapwood than heartwood. In the 12-year-old trees, heartwood and sapwood were the same. At both sites, heartwood and sapwood comprise about 86% of the total biomass produced. At harvesting, generally, the trunk with all its components (heartwood, sapwood and bark) is removed from the site. For the two sites this would mean an export of 92% of total biomass and contribute to a large removal of mineral nutrients, as the bark containing the functional phloem, stores a significant amount of nutrients, (Table 3). Bark has the smallest biomass weight, among the components of the trunk but it has a larger amount of Mg than in heartwood and sapwood, also larger amounts of P and K than in heartwood. The amount of Ca in the bark is larger than in any other parts of the tree. This was also found by Bellote (1979), Bellote *et al*. (1980), Poggiani *et al*. (1983), Pereira *et al*. (1984) and Poggiani (1985). The bark is usually used for energy production but its retention as a residue on site has great importance in the sustainability of production. Export of bark through successive rotations contributes to a decrease of the forest productivity as fertilisation with NPK, a common practice in eucalypt plantations, is insufficient to restore nutrients removed in the bark.

Among all nutrients present in the biomass, the bark had 46% of the Ca, 11% of the N and 16-20% of the K. The amount of P in the bark varied as a function of the age of the tree, being larger in older trees. The amount of Mg in the bark was negatively correlated with the tree age, being larger in the youngest trees. The crown, composed of leaves, branches and toplog (trunk with diameter <4 cm), is usually left on the site, as a residue. It represents only 8% of the total biomass produced by the tree butt is an important source of organic matter and mineral nutrients. The trees aged 12 years had larger amounts of Ca and K in the crown, than the trees of 7 years of age. These results show that it is important that the determination of age at which plantations are harvested should not only be based on economic factors.

Phosphorus, K and Mg are the most limiting elements for eucalypt growth in the State of São Paulo (Bellote and Ferreira 1993). The results showed that appreciable amounts of K and Mg are kept on site if the crown and bark are retained as residues. Twelve-year-old trees had about 73% of the tree's total K and Mg in the crown and bark.

The trunk, composed of heartwood and sapwood, is the part of a tree removed from the site. The amount of all mineral nutrients in the heartwood, in both ages studied is less than in the sapwood. These data indicate that with the increase of the tree age the amount of heartwood increases. The same does not happen with the sapwood so the relative amount of nutrient removed from the site is reduced. Phosphorus was not recorded in the heartwood of the trees at 12 years of age and the quantity of all the other nutrients, except N, in the heartwood decreases with the age of the trees. In this case, it is supposed that the nutrients are

Table 2. Means and confidence interval for dry total biomass produced by *E. grandis* at 7 and 12 years of age

Age	Trunk			Crown			Total
	Sapwood	Heartwood	Bark	Leaves	Branches	Toplog	Tree
yr				$t\ ha^{-1}$			
7	145.4 ± 12	129.2 ± 17	20.2 ± 2	9.8 ± 2	14.6 ± 4	1.5 ± 0.3	321 ± 35
12	139.4 ± 16	141.7 ± 25	16.4 ± 3	7.1 ± 1	15.8 ± 3	3.9 ±0.4	324 ± 43
F test	ns	ns	*	**	ns	**	ns

F test – (ns = not significant); * and ** significant at the 5 and 1% level, respectively

Table 3. Mineral nutrients accumulated in the different parts of the trees (based on 1500 trees ha^{-1})

	Trees	Tree components ($kg\ ha^{-1}$)								Total	
	Age (yr)	Sapwood		Heartwood		Bark		Crown			
N	7	126.8	ns	78.0	ns	59.3	ns	253.5	ns	517.6	ns
	12	116.9		81.7		53.3		211.3		463.2	
P	7	8.6	**	0.4	**	3.8	**	13.2	ns	26.0	**
	12	16.6		-		14.0		15.8		45.9	
K	7	123.4	**	17.5	**	55.2	*	77.5	**	274.2	ns
	12	64.0		5.4		37.8		126.4		233.6	
Ca	7	37.0	**	22.9	**	97.6	ns	53.8	**	211.3	ns
	12	23.0		14.1		98.0		79.0		214.1	
Mg	7	21.7	**	8.8	**	39.2	**	36.0	**	105.9	**
	12	12.3		3.7		14.3		23.6		53.9	

F test – (ns = not significant); * and ** significant at the 5 and 1% level, respectively

moved from the heartwood to another part of the tree, through the well-known process of biochemical cycling.

CONCLUSIONS

- Clear cutting trees of 12 years of age exports less mineral nutrients than trees at 7 years of age.
- In the two studied ages, the amount of mineral nutrients present in the residues left on site, as bark, leaves, branches and toplog represents more than half of all nutrients in the total biomass of the trees.
- The export of nutrients from a site can be minimised by removing only the trunk (heartwood and sapwood).

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22 Changes in Biological Factors of Fertility in Managed *Eucalyptus* Plantations on a Savanna Soil in Congo

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Abstract

Biological factors of fertility were assessed through the study of litter quantity and quality, soil organic matter quantity and quality, soil microfauna, soil macrofauna, organic matter dynamic, particularly decomposition and non-symbiotic nitrogen fixation in an age series of *Eucalyptus* PF1 and one stand of *E.* urograndis (*E. urophylla* x *E. grandis*). The litter system underwent drastic changes with plot age: litterfall was higher in the older plots than in the younger ones. Soluble carbon and lignin content decreased significantly with plot age and decomposition rate increased. Change in soil organic matter amount occurred in the top layer of soil only and increased with plot age. This enhanced cation exchange capacity. Increase in soil organic matter content was due to the light organic fraction (>0.05 mm), and the amount of C did not change in the organo-mineral fraction. Soil organic matter quality changed also, and the C/N ratio increased with plot age. Evidence for N fixation was not observed. A drastic decrease in free living nematode density from savanna to young plantations was observed after which it increased slowly with plot age although in the 19-year-plots it was still about ten times lower than in savanna. The importance of *Xiphinema parasetariae*, a parasite of eucalypts, was confirmed. Its density increased markedly with plot age and the size of the patches where it occurred increased. All soil macrofauna, earthworms, termites and litter inhabiting groups, except the ant group, increased in density with plot age. Termite density decreased in logged stands but no other measured parameters showed any significant difference between plantations and clear felled areas. The long-term effect of harvesting was observed mainly in the litter systems which appeared to be strongly disturbed by previous logging. Previous logging did not affect soil organic matter and nematode populations, either free living or plant parasitic. Soil macrofauna groups slightly increased after harvesting. Total phenolic compounds and fibre content were very different in leaf litter among clones and hybrids.

INTRODUCTION

Pulp production is the aim of the 40 000 ha of fast-growing tree plantations in Congo and foresters address the problem of getting maximum production in a sustainable system which preserves soil potentialities. Biological factors of soil fertility have a tremendous importance as they determine organic matter quality and turn-over, exchange capacity and nutrient cycling, and tree health.

Previous studies carried out in “Catalytic effect of plantations” (World Bank Project, 1995-1996) emphasised the evolution of the poor native savanna environment towards a more fertile forest environment which is characterised by a set of factors including understorey vegetation, fauna, soil characteristics, and

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reduced light. The Congolese *Eucalyptus* plantations are a simple model of changing environment from savanna to forest, and give the opportunity to study the processes involved. Logging is one of the main factors which may counter environmental evolution. Eucalypts are clear-cut when 7 years old, with changes in microclimate and in organic matter input to the soil. Then the trees coppice from the stumps for another 7-year-rotation, and new trees are planted after three rotations. Because litterfall and organic matter accumulation are assumed to be the driving factor of biological fertility change, it is questioned whether successive rotations allow environmental changes to occur in the same way as in unlogged plantations.

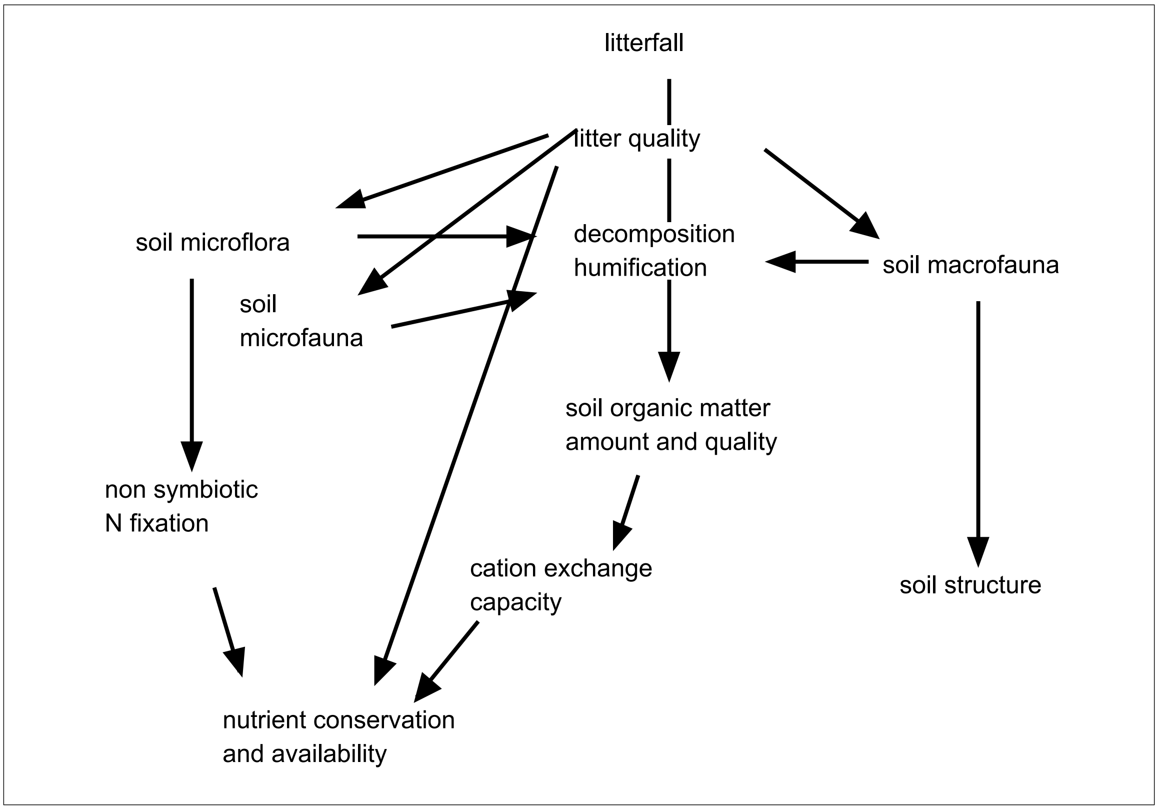
In this paper biological fertility factors are assessed through the study of litter quantity and quality, soil organic matter quantity and quality, soil microfauna, soil macrofauna, organic matter dynamic, particularly decomposition and non-symbiotic nitrogen fixation. (Fig.1).

SITES AND METHODS

The sites were chosen in the commercial eucalypt plantations near Pointe-Noire, Congo, which are grown on savanna. In this area, forest vegetation is restricted to patches mainly situated in the valleys. In the coastal area (Pointe-Noire), these forested valleys are very imbricated with the plateau savannas, but are not planted with eucalypt. Two *Eucalyptus* hybrids were considered: *E.* PF1 and *E.* urograndis (*E. urophylla* x *E. grandis*). The chosen series (Table 1) was dependent on the available situations inside the planted area, and some drawbacks were unavoidable

Litter quality was studied on freshly fallen leaf litter collected on the ground. The determinations were (Bernhard-Reversat 1999): soluble carbon by the chemical oxygen demand (DCO) with HACH reagents (Anonymous 1994), phenolic compounds by the Folin Ciocalteu method with HACH reagents on water or methanol extracts, nitrogen by acid digestion and Nessler

Figure 1. Relationships between biological factors and fertility studied in eucalypt plantations



reagent, fibres by the Van Soest (1963) method. In the age series plots litterfall was collected every one or two weeks in ten 25 dm quadrats or in fifteen 56 dm^2 quadrats. Litter decomposition was measured in 1-2 mm mesh litterbags with 12 replication after a 4-week or 12-week *in situ* incubation.

Soil organic C and N were analysed on 6 replicates of soil samples from 0-10 cm and 10-20 cm depth. The particle size fractionation of soil organic matter was performed on three replicates of soil samples 0-5 cm depth. Nematodes were sampled in 424 ml soil cores taken on contiguous tree lines on one from two trees, at 0-15 cm depth. Nematodes extraction from soil was made with the two-flask technique (Seinhorst 1955). Macrofauna was sampled according to the TSBF (Tropical Soil Biology and Fertility Program) method (Anderson and Ingram 1993.): 10 samples were taken in each plot, 5 m apart along a randomly chosen transect. Each sample was a block of soil, 30 cm deep on area of 25 x 25 cm. The macrofauna was sorted out by hand. Assymbiotic nitrogen fixation was measured in the laboratory as ARA (acetylene reduction activity) on core samples taking together the litter and the 0-5 cm layer of soil. Three replications were made in each plot (Le Mer and Roger 1999).

RESULTS AND DISCUSSION

Changes in biological factors with plantation age

The litter system was shown to undergo drastic changes with plot age: litterfall, litter quality, and litter decomposition were affected. Litterfall was higher in older plots than in younger ones (Table 2). Litter quality was less affected but soluble carbon and lignin content decreased significantly with plot age (Fig. 2), and the responsible factor is not known; lignin content is known not to be related to soil nutrient content (Tissaux 1996). Decreasing

Table 1. Characteristics of the studied plots

plot	hybrid	clone	plot age	tree age	forest	present exploitation	previous exploitation
T 92-82E	PF1	1-41	6	6	high forest	no	0
T 92-82	PF1	1-41	6	0	high forest	clear felled	0
L 85-10	PF1	1-41	13	6	coppice	no	1
L 84-06	PF1	1-41	14	0	coppice	clear felled	1
K 79-37 T	PF1	1-41	19	7	coppice	no	2
K 79-37 F	PF1	1-41	19	19	high forest	no	0
R 90-07	PF1 & urogr.	sub plots var. clones	8	8	high forest	no	0
R 92-04	PF1	sub plots var. clones	6	6	high forest	no	0

Table 2. Litterfall in g m^{-2} $year^{-1}$ (and standard error in brackets) in the studied eucalypt plots

plot		hybrid	age	Leaves	twigs & barks	fruits	total
T 92-81e	H	PF1	6	431 (75)	256 (80)	0	688 (107)
L 85-10	C	PF1	13	831 (27)	256 (48)	0	1087 (54)
K 79-37 T	C	PF1	19	664 (28)	271 (37)	0	938 (46)
K 79 37 F	H	PF1	19	888 (44)	378 (57)	25 (3)	1290 (76)
R 90-07	H	urograndis	8	684 (27)	320 (72)	0	1004 (77)

Because of the calculation method, the standard error refers to the seasonal as well as to the spatial variability, except for the T 92-81e plot, for which the standard error refers only to the seasonal variability. H: high forest plot; C: coppice plot

Figure 2. Change of soluble organic matter and lignin content in eucalypt litter with plot age

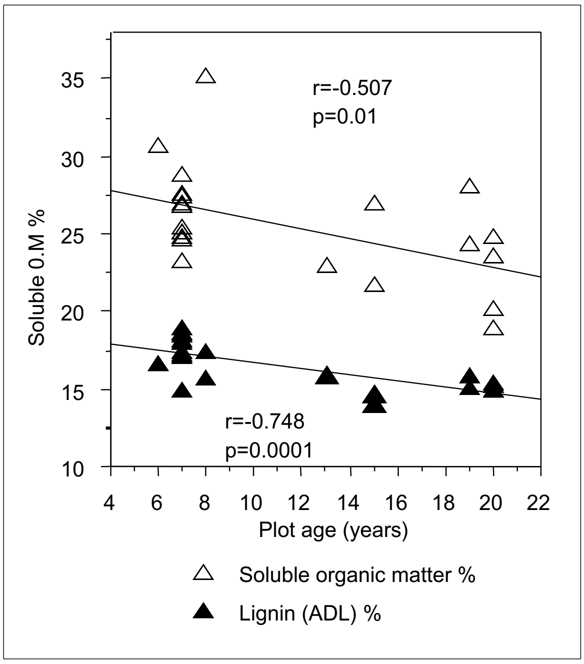
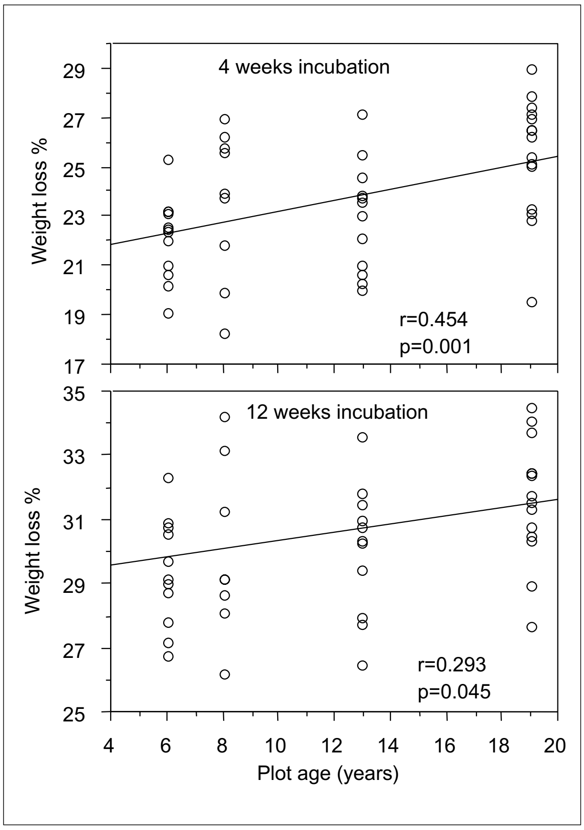


Figure 3. Increase of *in situ* decomposition rate with plot age



lignin content might be one of the causes of the small but significant increase in decomposition rate with plot age (Fig. 3). The decomposition rate of eucalypt litter is slower in plantations than in native Australian eucalypt forest (Spain and Le Feuvre 1987, Bernhard-Reversat 1993) and limits nutrient cycling. Increased decomposition rate together with increased litterfall in ageing plantations is assumed to enhance nutrient cycling and particularly direct cycling from litter to roots, which occurs in tropical forests on poor soils (Jordan 1982). Bargali *et al.* (1993) observed a decrease in decomposition rate with age in *E. tereticornis* plantations from 1 to 8 years old, related to the decrease in litter and top soil content in N, P, and K. In the older plantations of the present study, leaf litter nutrient content did not change with plot age. Although soil nutrient content was not measured, the decrease of pH with age observed by Bandzouzi (1993) was an indication of decreasing nutrients, and direct cycling could help alleviating soil nutrient deficiency.

Change in soil organic matter amount with age was also significant although it occurred in the top layer of soil only (Fig. 4). The increase in soil organic matter enhanced cation exchange capacity (Fig. 5) and was assumed to improve the retention of nutrients from rainfall, throughfall and litter. The increase in soil organic matter content with plot age was due to the light organic fraction (>0.05 mm), and the amount of C did not change in the organo-mineral fraction, (Fig. 6) as observed in other sandy soils (Feller *et al* 1991). Soil organic matter quality changed also, and the C/N ratio increased with plot age due to the fine particle size fractions (<0.2 mm). The savanna organic matter was replaced by N-poor eucalypt organic matter. This could result in N shortage in the long term. Evidence for N fixation was not observed either in litter or in soil; only potential fixation activity was observed in litter when glucose was added, mainly in the older coppice (Le Mer and Roger 1999), unlike the situation in Australian natural eucalypt forests (O'Connell and Grove 1987).

Free living nematodes are the most abundant microfauna group in soil and contribute

Figure 4. Change of soil C content with plot age in eucalypt plantations

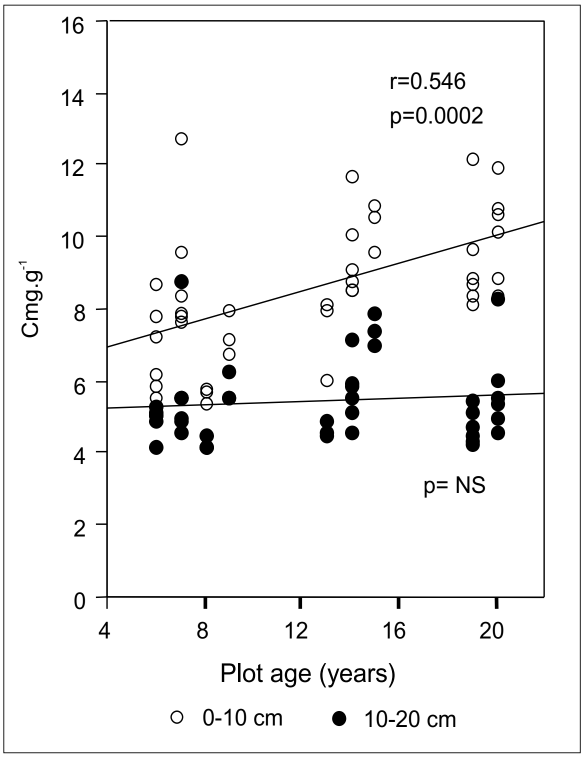


Figure 5. Change of cation exchange capacity (CEC) with plot age in eucalypt plantations before and after organic matter oxydation by oxygen peroxide, showing the part of CEC due to organic matter

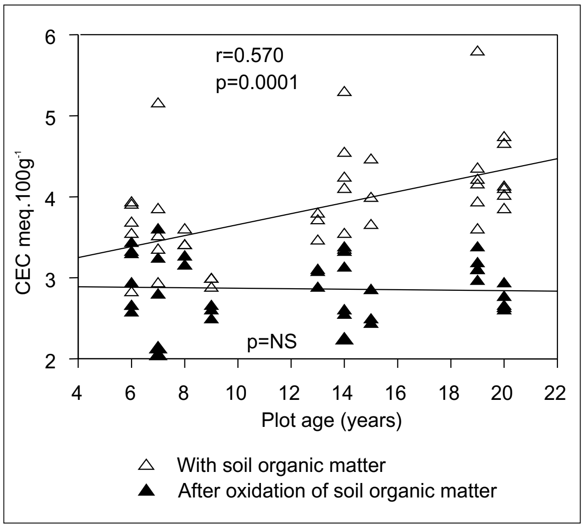
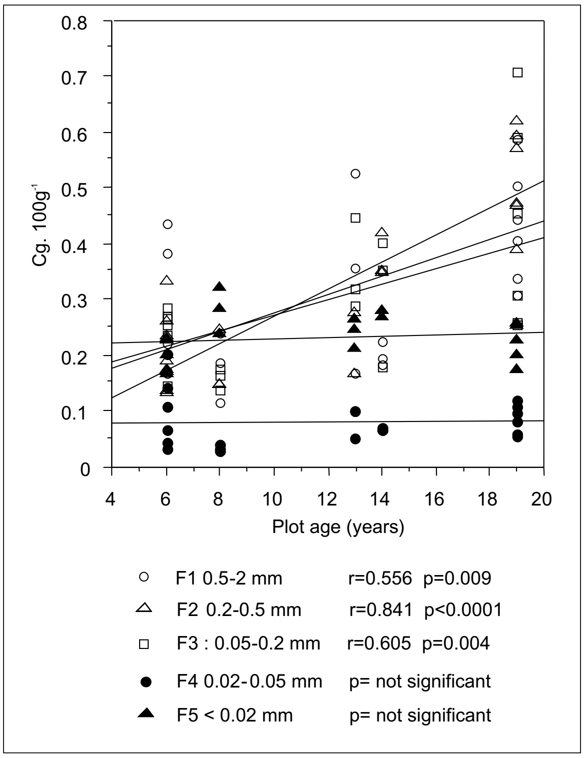
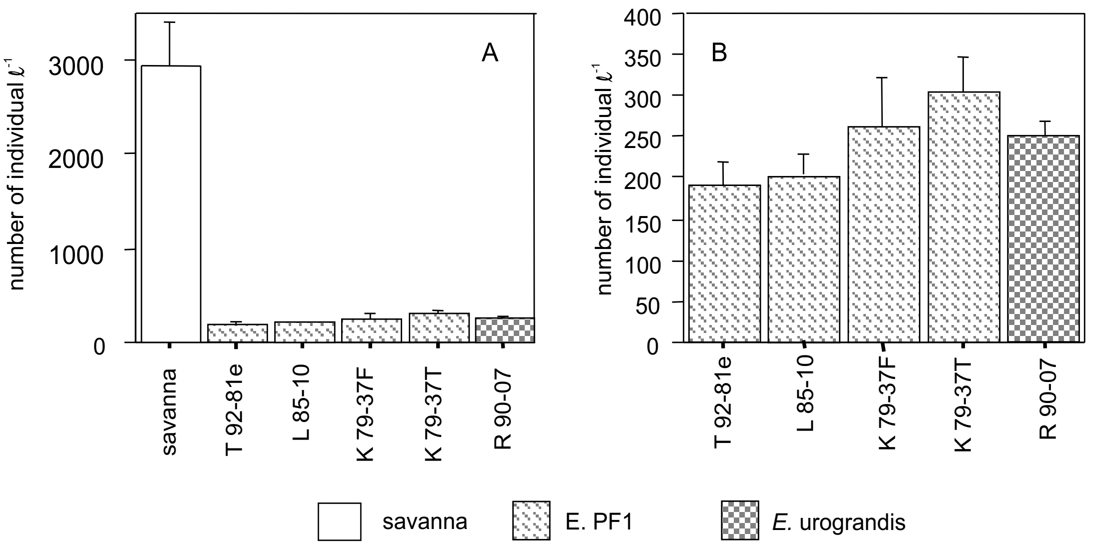


Figure 6. Carbon in particle size fractions in eucalypt plots of increasing age. Open and solid symbols show show light and organo-mineral fractims, respectively



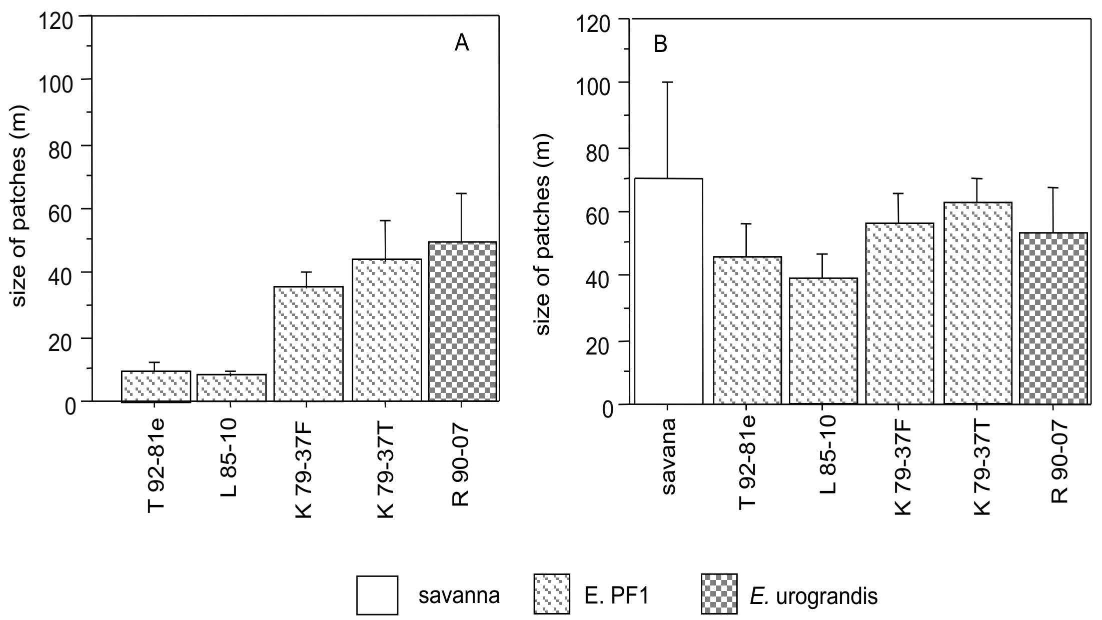
to the organic matter and N turn-over and control the micro-food web (Lavelle *et al.* 1993). A drastic decrease in free-living nematode density from savanna to young plantations was observed (Fig. 7). Then free-living nematode density increased slowly with plot age although in the 19-year-plots it was still about 10 times lower than in savanna. Among the plant parasitic nematodes, the importance of *Xiphinema parasetariae,* a parasite of eucalypts, was confirmed. This nematode was present in the savanna as parasites of some leguminous herbs and very scarce in young eucalypt plots. Its density increased very significantly with plot age. This nematode was distributed in patches, and the size of the patches increased from an average of 8 m in the 6-year-old plot to an average of 50 m in the 19-year-old plot, whereas the size of the patches free from nematodes decreased with plot age (Fig. 8). These results suggested that continuous eucalypt cultivation will result in an entirely infested area.

Figure 7. Free living nematode density in eucalypt plots of increasing age



A: In savanna and eucalypt plantation,
B: In eucalypt plantations

Figure 8. Average length of patches of nematodes in eucalypt plantations



A: Patches of samples with *Xiphinema parasetariae*,
B: Sum of the lengths of patches of samples with nematodes and patches without nematodes

The effect of this parasite on eucalypt growth is not well known although the genus *Xiphinema* was found on eucalypt plantations in South Africa (Marais and Buckley 1993, Spaull 1998). The most probable injurious effect will be on young cuttings replanted on old eucalypt plots, because they are more susceptible than adult trees.

Changes in macrofauna distribution were observed in the industrial plantations, as well as previously in experimental plantations (Mboukou-Kimbatsa *et al*. 1998). Earthworms, termites and the litter inhabiting group increased in density with plot age (Fig. 9). Only the ant group did not increase. Improved soil functioning is expected from the increase in density of earthworms, termites and litter fauna, related mainly to a faster organic matter turn-over and an improved soil structure (Lavelle *et al*.1997).

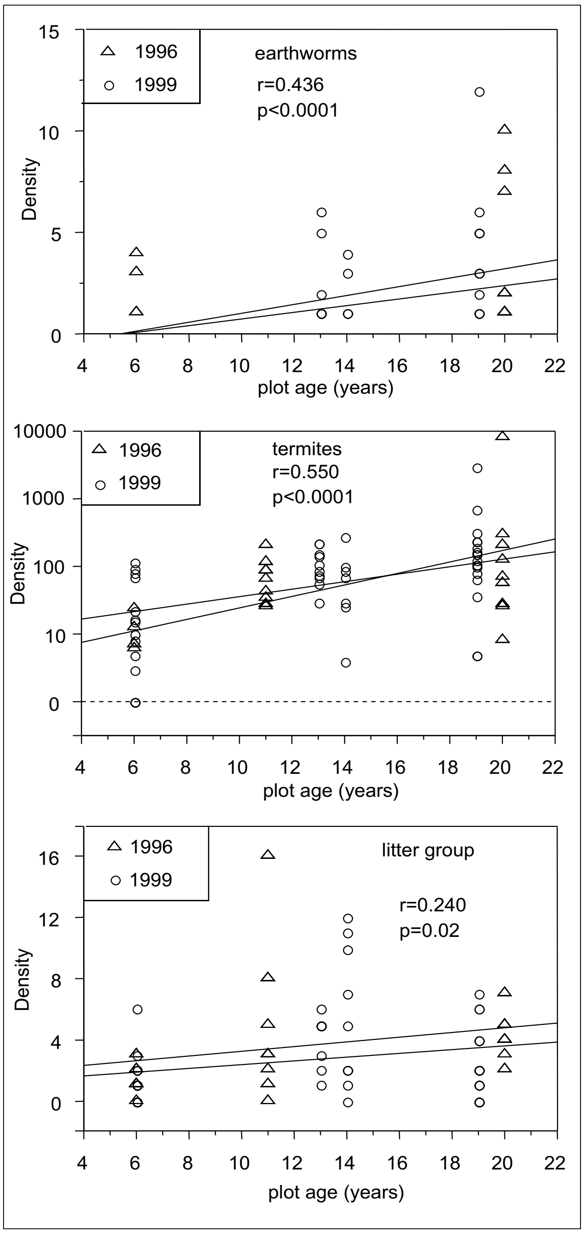
Effect of the present exploitation practices on biological fertility

Eucalypts are logged every 6-8 years and logs above 7 cm in diameter are removed. Part of the remaining woody material is collected to make charcoal. Leaves and twigs are laid on the soil, either in swathes or spread on the whole surface. The main immediate changes when trees are clear-felled concern microclimate and litter input.

The two 6-8-year-old plots and the two 13-14-year-old plots allowed the study of biological factors before and after clear-felling. None of the measured parameters on litter and soil organic matter showed significant differences. Among the macrofauna, the termite group alone showed a slight significant difference, with a decreased density after clear felling perhaps because of changing micro-climatic conditions. On the whole, clear-felling did not bring about major perturbations among the measured parameters.

The long-term effect of harvesting was studied in the 19-year-old coppice and high forest plots, and in the 14-year-old coppice. In the 19-year-old plots, litterfall was significantly higher in the high forest plot than in the coppice and resulted in a greater amount of nutrient cycling through litter. The similarity of the litter nutrient contents in the two 19-year-old plots was noticeable. The comparison of the two coppices (13-year-old and 19-year-old) suggested that litterfall could decrease with successive logging, possibly because of the physiological or pathological ageing of the rooting system, or nutrient shortage. Litter decomposition rate was 1-5% lower in the coppice than in the high forest of the same age, according to the season. Litter accumulation in the high forest plot was more than twice that in the coppice. The litter systems

Figure 9. Change in soil macrofauna population densities (number per TSBF samples) in eucalypt plantations with plot age



appeared to be strongly disturbed by previous logging. However the soil organic matter was apparently not affected by previous exploitation. It has been estimated that about 22 t ha^{-1} of biomass remains on the ground after clear-felling in a 7-year-old plot (Laclau 1997), which is the equivalent of 3 t $year^{-1}$. This amount was approximately the annual difference in litterfall input between the coppice and the high forest and could make up for it. The branch wood is easily humified because its lignin is less polymerised than that of the stem wood, and it has a higher nutrient content (Lemieux 1996).

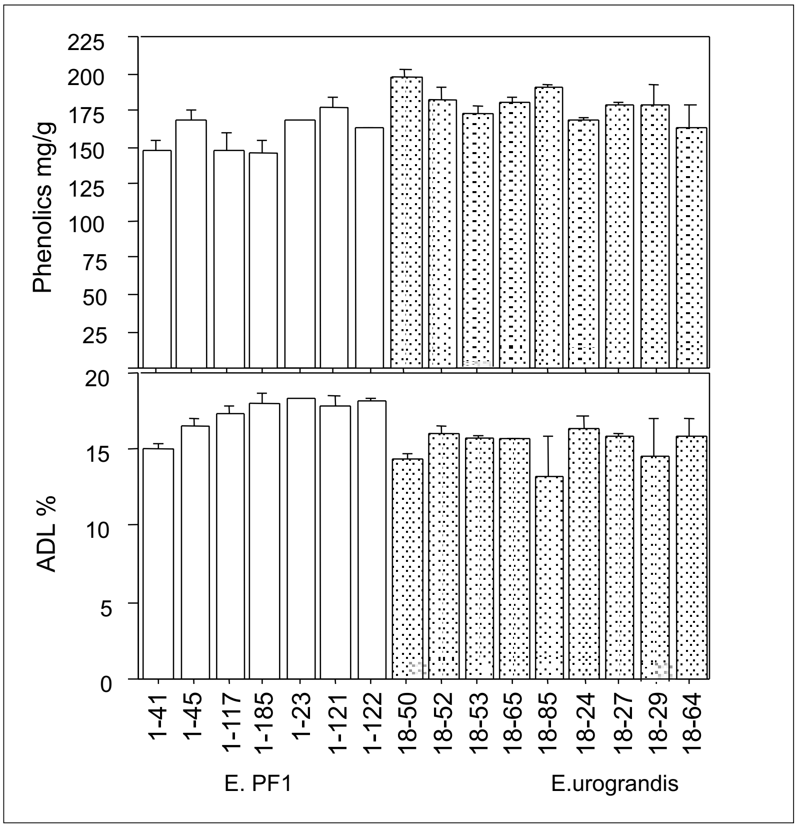
Nematode populations, either free-living or plant parasitic, were not affected by previous logging. Free-living nematodes need soil organic matter and microflora to feed on and these resources did not change with logging. With ageing of plantations, the increase in size of soil patches infested with parasitic nematodes occurred in coppice areas as well as in the high forest plots because the tree root systems were not destroyed by the logging. Soil macrofauna groups were slightly increased by the harvesting.

Few data are available on the effect of eucalypt harvesting, and the conservation of litter on the soil was recommended to prevent nutrient export (O'Connell and Sankaran 1997); the conservation of litter also contributes to the maintenance of soil organic matter content and soil fauna density.

Biodiversity due to hybrids and clones

The planting of different clones aims to introduce biodiversity in the plantations. Litter quality alone was compared between clones. Few of the studied litter characteristics were significantly different among clones, but they are important as total phenolic compounds content and fibre content (NDF, ADF and ADL of the Van Soest method) (Fig.10) were highly significantly different among

Figure 10. Methanol soluble phenolics and ADL content of clones and hybrids of eucalypt



clones. This was expected to result in different decomposition rates which will influence organic matter and nutrient dynamics. Differences in phenolics and fibres could also result in different resistance to diseases and herbivory (Landsberg and Cork 1997).

The hybrids are chosen according to their growth rate. When the chemical composition of the litter was compared between hybrids, *E.* urograndis litter was significantly poorer in N and fibres and had a higher content in phenolics than *E.* PF1. The *in situ* measurements in the studied plots (6-year-old *E.* PF1 and 8-year-old *E.* urograndis) showed that soil organic matter accumulation in top soil was greater in *E.* PF1, although litterfall was smaller, and soil organic matter from *E.* PF1 litter was consequently assumed to be less degradable than that of *E.* urograndis, at least in the fine light organic fraction (0.05 to 0.2 mm) that was mainly responsible for the difference. Litter decomposition rate was higher in *E.* urograndis during the dry season; it was attributed to soil invertebrate activity because microbial mineralisation did not occur when litter was dry; however, higher faunal activity in *E.* urograndis than in *E.* PF1 did not fit the observations on phenolic compound content, and only the lower lignin content was in agreement with greater faunal activity. It would be interesting to analyse terpene compounds in hybrids and clones because they are known, like phenolics, to be related to herbivory and disease resistance.

Mineral cycling by litter was higher in *E.* urograndis, mainly because of its higher litterfall, and because of the higher P and K content in its litter. Fauna comparison between hybrids was made more difficult by the variability of the results in two *E.* urograndis plots and further studies are required.

CONCLUSIONS

Eucalypts are generally suspected to alter soil quality and prevent plant growth. Starting from a poor savanna soil, the main tendency in this study was the opposite as organic matter, undergrowth vegetation and soil fauna density increased (Loumeto and Huttel 1997, Mboukou-Kimbatsa *et al.* 1998). However the particular features of eucalypt litter had many implications for soil biology. Phenolic compounds in litter were shown to be strongly negatively related to termite density, and could also control, together with soil C, free-living nematode density and earthworm density (p for multiple regression significance was 0.11 and 0.06 respectively). The noticeable lack of N fixation activity in soil and litter seemed also to be due to litter quality, and most of the few samples where N fixation activity was found with glucose added were taken in the plot where the litter had the lowest content of phenolics (Le Mer and Roger 1999). Indications for other disturbed microbial processes were given by the lack of nitrification (Bernhard-Reveresat 1996) and of white rot fungi for lignin degradation (Bernhard-Reversat and Schwartz 1998), and microbial processes in eucalypt plantations deserve further studies.

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Rehabilitation of Degraded Forest with *Shorea leprosula* and *S. selanica* Cuttings

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Abstract

Komatsu Ltd. and the Forest and Nature Conservation Research and Development Center (FNCRDC) of the Ministry of Forestry, Indonesia have developed a cutting propagation technique for dipterocarp species. This technique uses a fog-cooling system to lower the temperature inside cutting boxes in a greenhouse. This method is suitable for mass production of vegetative propagules of some dipterocarps species. Rooting percentage of S. *leprosula* and *S. selanica* (meranti) cuttings was 95% and 92% respectively during the experimental stage, and 67% at mass production stage. The planting stock production of the dipterocarp cuttings in 1997 and 1998 were 42 000 and 53 000 respectively. Reforestation of degraded forest by using these dipterocarp cuttings was studied on 70 ha trial plot in West Java. Planting stock from cuttings and seedlings of *S. leprosula* and *S. selanica* were planted at various spacings. Preliminary results indicated that at this site *S. selanica* grows better than *S. leprosula*, planting stock from cuttings of both species performed better than planting stock from seedlings, and closer spacing resulted in better growth and survival. These findings suggest that planting stock from cuttings can be used to reforest degraded forest.

INTRODUCTION

The dipterocarp family (Dipterocarpaceae) which makes up most of the tropical forests of Southeast Asia is important ecologically and also useful economically for plywood, building material, and furniture, etc. The diperocarps have been commercially logged for many years. Moreover, their disappearance is also due to improper slash and burn farming, agricultural land conversion, etc. However, technical problems remain in reforestation techniques so planting with dipterocarps is not advanced.

Reproductive characteristics influence reforestation by the dipterocarps as their flowering pattern is irregular (Ashton *et al.* 1988) and seed storage period is short (Sasaki 1980), so making continuous seedling production on a large-scale difficult. Hence, the establishment of a planting-stock production method is important for reforestation. The use of vegetative propagules offers a feasible solution to this problem. There are reports of vegetative propagation methods for the dipterocarps (Aminah 1991, Smits 1983). However, there are no reports of large-scale experiments or successful mass production.

A unique propagation method called “fog-cooling system” has been developed by the Forest and Nature Conservation Research and Development Center and Komatsu (Sakai *et al.* 1994). Basically the system controls humidity, temperature and light intensity at a suitable level for transpiration and photosynthesis. Since it was developed, the system has been used to produce more than one hundred thousand vegetative propagules of *Shorea* species including *S. leprosula, S. selanica, S. javanica, S. pinanga, S. seminis*, and *S. stenopthera*. However only *S. leprosula, S. selanica*, and *S. javanica* at this stage can be produced on a large scale using this method.

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The project is now focused on *S. leprosula* and *S. selanica*, as they are fast growing dipterocarps (Masano *et al.* 1987) and have potential for reforestation of degraded forest. So far no data on vegetative propagule performance in the field is available, and this has to be tested before they are recommended for large-scale plantation establishment.

This paper reports a study on controlling environmental conditions suitable for root formation of the stem cuttings including media, light intensity, temperature and humidity, and also growth performance of vegetative propagules on degraded secondary forest at Leuwiliang, West Java, Indonesia.

MATERIALS AND METHODS

Autotrophic shoots of the dipterocarps taken from wildlings were used as cutting material. The autotropic shoot was prepared to a length of 8 cm with two leaves. The stem cuttings were planted in a tray of 5 x 9 pots. The pot tray was placed inside a propagation box, which was covered by a clear plastic cover. Crushed coconut fibre with rice husk mixed was used as the medium. Two levels of humidity (80% and above 95%) and two levels light intensity (*ca.*1100 and 4600 lux) were used to test their influence on rooting percentage of the cuttings. A shading net regulated light intensity. The fog-cooling system was operated to lower the temperature inside the propagation box daily from 10 am until 4 pm with a timer and a thermostat controller. One nozzle was installed for each 2.5 m^2 area, which sprayed 70 ml $minute^{-1}$ of water as fog. The number of rooted cuttings was evaluated after two months. Rooted cuttings were transplanted to plastic bags and raised in the nursery. Planting stock from cuttings and seedlings of *S. leprosula* and *S. selanica* was used to test their field performance. Four different spacing regimes i.e. 2 x 2 m, 3 x 3 m, 4 x 4 m, and 5 x 5 m were applied. The planting site was degraded secondary forest with hilly-terrain and prone to soil erosion. The trees of each treatment were planted in a square plot 100 m x 100 m.

RESULTS AND DISCUSSION

Fog Cooling System

The fog-cooling system was used to control the environment of the greenhouse (Fig. 1). The environmental conditions suitable for root formation of the cutting can easily be controlled using an air conditioner, a fluorescent lamp and a humidifier, but the cost of producing vegetative propagules is very expensive, especially for large-scale production. The fog-cooling system was designed to produce planting stock on a large scale at low cost. Cooling of this system is by spraying very fine water particles (fog) into the air. Evaporating fog takes heat from the surroundings to lower the temperature inside the greenhouse below 30^{o}C (Fig. 2). In addition, a shading net and misting unit were provided to control light intensity, and clear plastic covered propagation box was used to keep humidity above 95%.

Effect of Humidity

Cuttings are susceptible to dehydration due to poor absorption of water. Hence, intensive transpiration from leaves due to unfavourable environmental conditions must be avoided. To suppress transpiration, humidity must be kept high (above 95%). Ninety cuttings of *S. leprosula* and *S. selanica* were tested. There was a significant effect of humidity on root formation. Lower humidity (80%) resulted in no root formation of the cuttings, whereas higher humidity (about 95%) resulted in 95% and 92% rooted cuttings for *S. leprosula* and *S. selanica* respectively.

Effect of Light Intensity

Adequate light energy is required by cuttings to perform photosynthesis for root formation. The test comprised 117 cuttings of *S. selanaca* at a low light intensity (1139 lux) and 90 cuttings of *S. selanica* at a high light intensity (4637 lux). Higher light intensity resulted in better rooting percentage (91%) as compared to lower light intensity (33%) after 2 months. On the other hand, increased light radiation increases the temperature inside the greenhouse and subsequently increases

Figure 1. The design of the greenhouse with the fog cooling system

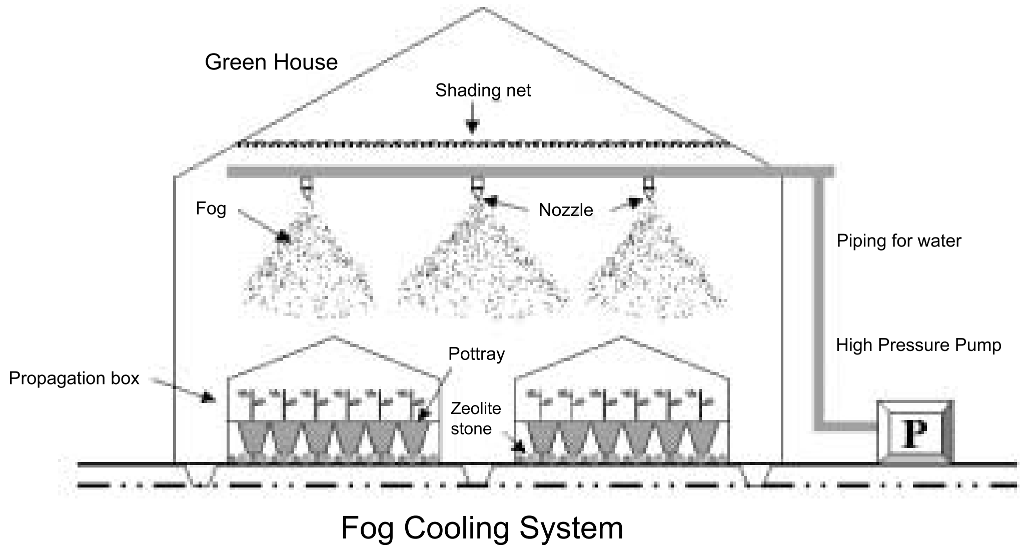
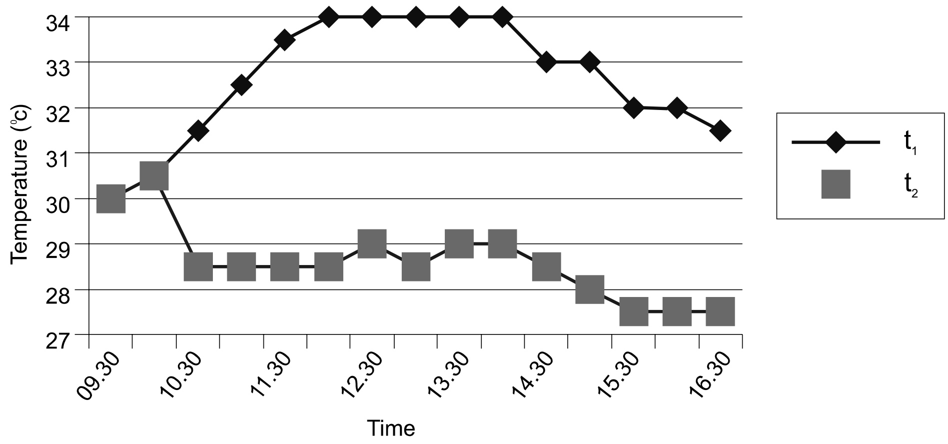


Figure 2. Temperature control by fog cooling system



t_1 = temperature inside the propagation box without fog cooling system

t_2 = temperature inside the propagation box under fog cooling system transpiration of the cutting leading to cutting dehydration. Successful vegetative propagation of the dipterocarps appears to require a condition in which the cuttings receive enough light but the temperature must be kept below 30°C.

Mass Production

The fog cooling system has been used to produce large-scale vegetative propagules of dipterocarps. In 1997 and 1998 the collaborative project produced about 42 000 and 55 000 cutting propagules respectively. During mass production of cuttings, rooting percentage dropped to about 50%. This decline was due to human error during maintenance of vegetative propagules, such as not closing the plastic cover tightly after watering the cuttings resulting in lower humidity in the propagation box. Another source of decline was the algae growing on the plastic cover, which reduced light intensity inside the propagation box. In 1999 the propagation box was improved to minimise these problems, and rooting percentage improved to about 72%.

Field Performance of the Cuttings

Vegetative propagules of *S. leprosula* and *S. selanica* in this planting site showed a steady height increment up to 18 months after planting. Survival and growth rate of both species planted in higher density plots were higher than those in lower density plots (Table 1). Planting stock from cutting of both species planted at 4 x 4 m spacing performed better than those from seedling at the same spacing (Table 1). At this particular site, the performance of *S. selanica* was similar to *S. leprosula*. These findings suggest that planting stock from cuttings of *S. leprosula* and *S. selanica* can be used to reforest this degraded forest.

CONCLUSION

Humidity, temperature and light intensity are the critical environmental conditions for the vegetative propagation of dipterocarps, and their mass production requires a method to control environmental conditions. The method must be economical so the price of vegetative propagules is not too expensive for practical application. The fog cooling system is a suitable technique for mass propagation of *S. selanica* and *S. leprosula*. Planting stock from cuttings of *S. leprosula* and *S. selanica* are recommended for rehabilitation at this degraded site in West Java. Planting at closer spacing gave better survival and growth than at wider spacing and the performance of cuttings was better than seedlings.

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Table 1. Growth and survival of *S. leprosula* and *S. selanica* of different origin at different spacings at age 15 months from planting at Leuwiliang

Treatment		*S. leprosula*		*S. selanica*	
		Height (cm)	Survival (%)	Height (cm)	Survival (%)
Cuttings	2 x 2 m	128.9	76	131.5	83
Cuttings	3 x 3 m	100.4	59	129.1	75
Cuttings	4 x 4 m	100.1	72	94.2	78
Cuttings	5 x 5 m	109.2	45	97.9	53
Seed	4 x 4 m	68.7	56	85.2	65

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An Overview of Development Processes and Farmers' Interactions in a Participatory Forest Fire Prevention Programme in Jambi Province, Indonesia

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Abstract

The participatory forest fire prevention programme of Forest Fire Prevention Management Project (FFPMP) aims at intensive fuel management and fire control with the integrated green belt on community land on the boundary of Berbak National Park, Jambi Province, Sumatra. It aims to motivate farmers to cultivate their land continuously, reducing fire hazards and risks through formation of fuel breaks around the forest. Participating farmers face technical limitations in seedling production, land preparation without burning, and crop planting and protection. They cannot easily perceive benefits of the green belt with line planting of the small number of trees. Land-oriented farmers experienced in growing crops and constructing facilities are more advantaged than local farmers dependent on forest resources. Current socio-economic conditions have accelerated diverse programme evolution with farmers' different responses. FFPMP has funded materials and facilities to substitute for farmers' lack of technical and economic capabilities. It may also modify the programme to optimise farmer participation and facilitate effective fuel break formation, including flexible design of planting sites along the green belt with various crops, new land preparation technologies, establishment of pilot small-scale nurseries, and strengthening of community organisations for less advanced farmers. This paper addresses the socio-economic sustainability of the participatory green belt programme.

INTRODUCTION

The Forest Fire Prevention and Management Project (FFPMP) has implemented a participatory forest fire prevention programme at its site around Berbak National Park, Jambi Province, Sumatra, since 1997. The programme stresses park-border communities' active participation in long-term prevention of wild fires on their land through establishment of integrated green belts (IGB) with fire-resistant tree rows along the park boundary, associated with intensification of farmers' land uses. Through IGB trials FFPMP has determined crucial socio-economic factors for successful programme development at the community level.

This paper aims to analyse current progress and constraints on IGB trials of FFPMP at the Jambi site and to recommend viable programme modifications.

Site Description

The programme is implemented at Rantau Rasau and Sungai Rambut villages, Rantau Rasau Sub-District, Tanjung Jabung District, Jambi Province (Fig. 1). Both villages are situated along the boundary of Berbak National Park that protects indigenous lowland swamp forests. Inhabitants

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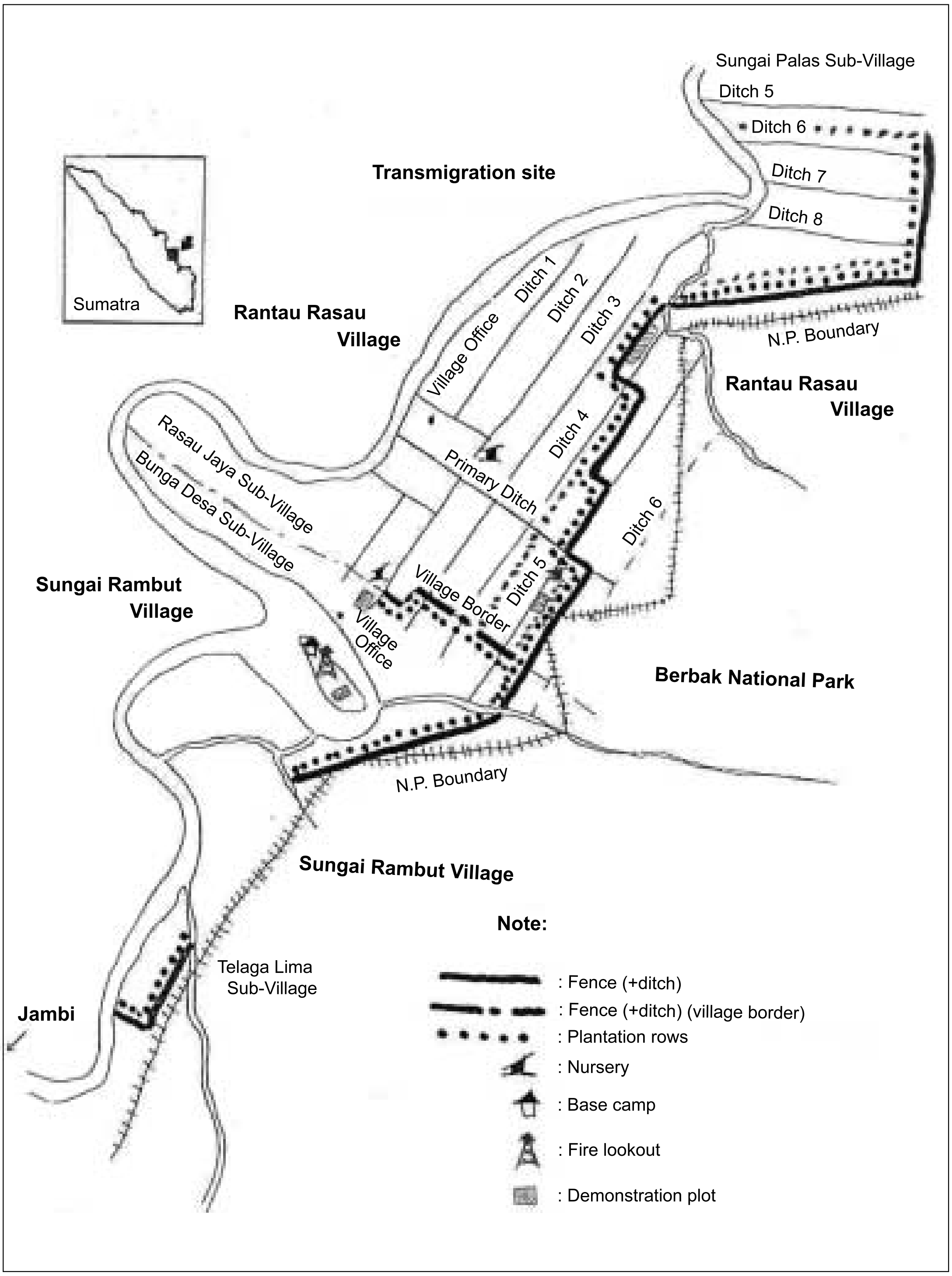
Figure 1. Project site



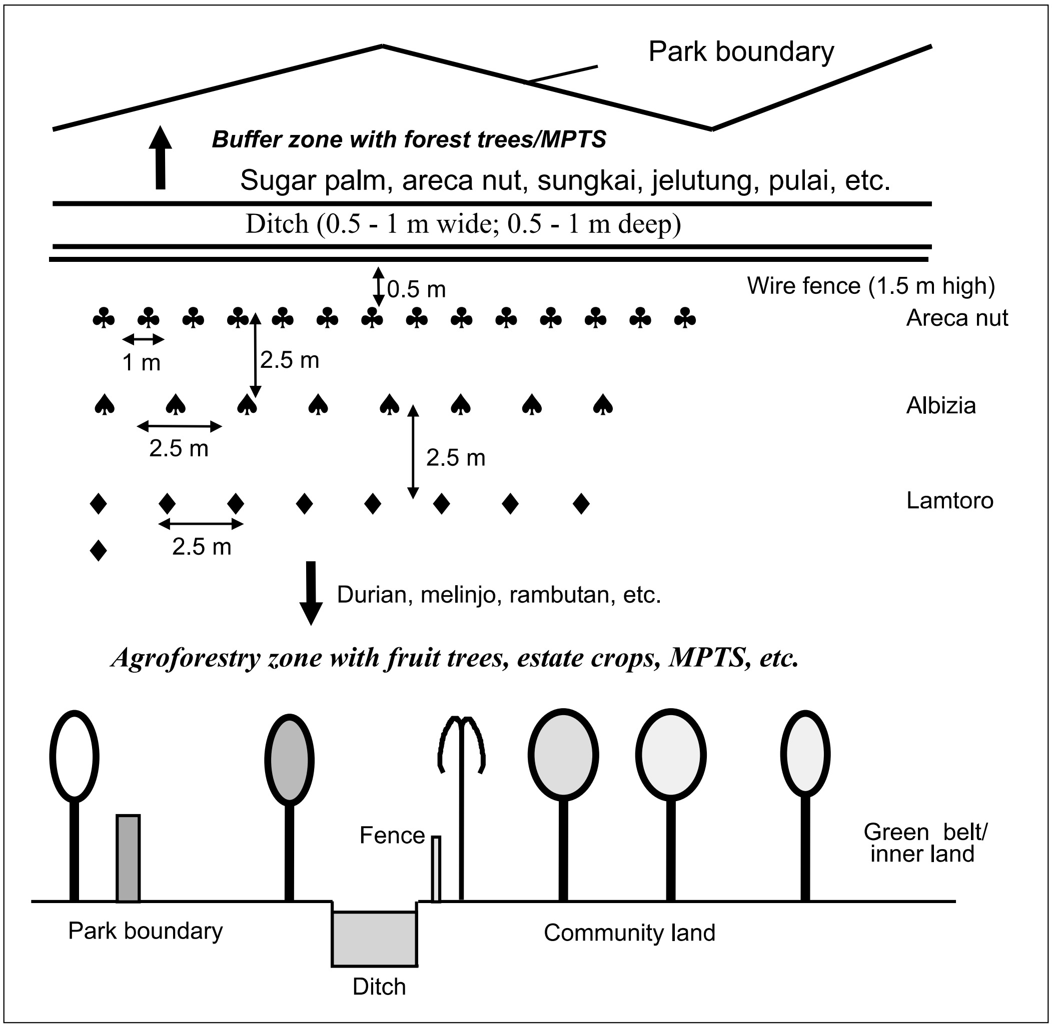
consist of local in-migrants (Malay), Javanese transmigrants, and spontaneous in-migrants from South Sulawesi (Buginese). Most of the Malay live along the riverside for riverine fisheries and rice farming, while other ethnic groups live in inland areas and grow various crops. Communities' settlements are well-organised along primary and secondary ditches, divided into small administrative units called neighbourhood associations (RT).

CONCEPT OF PARTICIPATORY INTEGRATED GREEN BELTS

Integrated green belts (IGB) aim to safeguard the park forests against wild fires and community land against wild boars through promotion of farmers' land use intensification. IGB is established along the border of the existing cultivation land close to the park boundary with the expectation of farmers' active participation. IGB consists of a wire fence, a ditch, and tree rows (Fig. 2). The wire fence is effective to block wild boars, while the ditch cuts off surface and ground fires and stores water for initial suppression. The tree rows are expected to control both surface fires and wild boars, and then stimulate farmers' intensive cropping on their land.

Suitable tree species had to be selected for effective fire prevention (fuel control and fire resistance) and for economic benefits to farmers preferably with non-timber products. The selected trees have to be adapted to grow well on the wet and peaty soils of the site. Three species were

Figure 2. Model of Integrated Green Belt



selected from farmers' preferences and the project needs for the first stage. They were areca nut (*Areca catechu*), albizia (*Paraserianthes falcataria*), and lamtoro (*Leucaena leucocephala*). Areca nut is planted along the wire fence to prop it up when existing wooden props decay. Albizia is one of the more valuable timber species, yielding profitable timber in a short period while forming tree stands quickly. Some farmers prefer lamtoro for its multipurpose functions, including soil improvement and fodder production. In the initial green belt design FFPMP restricted the number of tree species, based on fire prevention and ease of cultivation. At the second stage other promising species were introduced to study their fire prevention effectiveness. Fruit trees and multipurpose trees (MPTS), such as durian (*Durio zibethinus*), rambutan (*Nephelium lappaceum*), and melinjo (*Gnetum gnemon*), were planted inside the fence. Demonstration plots were established to test these new tree crops on the inner community land. The green belt is being expanded both toward the inner community land (inside the fence) and the park boundary (outside the fence) with the selected tree species. Nurseries were established in the two site villages to produce seedlings and improve farmers' abilities to grow seedlings.

These tree crops are expected to be fire-resistant to some degree, although this needs to be examined during the trials. Farmers have observed that trunks of areca nut are fireproof due to their thick bark. Long branches of albizia can effectively control undergrowth and weeds on the ground, outweighing the vulnerability of its trunk to fire. Lamtoro is similar to albizia, but its trunk is more resistant to fires. Durian, rambutan, and melinjo are generally resistant to fire due to their long branches and high moisture of their trunk. The immediate benefit of IGB is to effectively control wild fires from community land or forests. However, it is also expected that IGB will facilitate reduction of inflammable undergrowth and farmers' land burning by ensuring reliable growth of annual and perennial crops on their land. Target group farmers are expected to participate actively in green belt activities with material assistance from FFPMP.

SUMMARY OUTCOMES OF PARTICIPATORY IGB PROGRAMME

Up to March 1999, over 12 km of the fence has been constructed at two villages. The length of the ditch reached 10 km. The row of areca nut extends the full 12 km along the fence. However, the albizia and lamtoro are less successful on account of unfavourable site conditions. In addition to these three species, various other species were introduced to the green belts and three demonstration plots, including durian, rambutan, melinjo, coconut (*Cocos nucifera*), sugar palm (*Arenga pinnata*), breadfruit (*Artocarpus communis*), sungkai (*Peronema canescens*), jelutung (*Dyera lowii*) and pulai (*Alstonia scholaris*).

The green belt is being expanded from the initial three rows to about ten rows. Several forest trees such as jelutung, pulai, and sungkai, and MPTS such as areca nut and sugar palm are being tried in the park buffer zone outside the fence, while other new species are being tested on the inner community land free of wild boars. More than 160 000 seedlings were produced, or provided from the outside, for planting the green belts and demonstration plots. The rate of seed germination ranges between 75 and 90%. Three pilot nurseries with 39 seedbeds were built in the villages. Supporting facilities were constructed, including a base camp and a 23 m high fire lookout. Over 310 households in 13 groups have participated in the IGB activities. Self-help groups were organised out of the existing neighbourhood associations and farmer groups.

Costs and Self-help Abilities of Participating Farmers

IGB requires initial investment to support its various activity components. Table 1 analyses activity costs and farmers' self-help abilities in IGB development. A large amount of funds and labour had to be allocated for wire fence construction, including provision of wire, props, nails, and tools as well as their transportation. A sharp rise of prices of wire and other materials has also influenced the cost of the wire fence construction, particularly since the economic crisis in early 1998. Farmer groups worked very hard on a voluntary basis plaiting wire and setting up fences, reflecting their strong desire to control wild boars on their land. Ditch construction cost much less because the experienced Javanese farmers carried it out efficiently. They were strongly motivated to dig ditches by themselves in order to enhance fire prevention and wild boar control, stimulated by assistance from FFPMP for wire fences.

Nursery management required funds for construction materials, seedlings, fertilisers, and wages. Participating farmers' self-help abilities are still limited on seedling production owing to lack of their experience and skill. Consequently additional seedlings had to be purchased from the outside the site villages.

Planting activities were rather economical in terms of costs and labour inputs, except for weeding and land preparation of the idle land overgrown with thick undergrowth. Farmers often demanded small remuneration for these activities. The figures in Table 1 probably underestimate the costs and labour contributions to plant and protect trees, and may increase as the programme continues. Transportation of seedlings inside the village and fertilisation are somewhat laborious and costly, although farmers show strong interest in various perennial crops, expecting income generation in the future. Nursery establishment and seedling provision could be a big challenge to sustainable planting activities on the community land, especially when farmers are unfamiliar with tree growing technologies.

Initial funds were indispensable to develop IGB, particularly for wire fences, even though the programme is to be carried out with farmers' self-help efforts. Farmers have difficulty in meeting all the costs of the intensive IGB establishment. Another emerging constraint on farmers' activities is protection of crops, fences and other facilities. They cannot afford to maintain all of the activities for a long period without immediate tangible benefits, so protection of the planted trees and the fences is a burden. Costs of fertilisation will increase when farmers introduce fruit trees, such as durian and rambutan, which require large doses of fertilisers.

Table 1. Assessment of activity costs and farmers' self-help abilities in IGB development

Activity	Activity cost			Voluntary contributions from farmer groups		
	Unit cost (Rp.)	Fund allocation (%)	Assistance	Labour input (person days)	Labour input (person days tree^{-1})	Activity
Wire fence construction	5305 m^{-1}	32.9	Wire, props (partly), nails, tools, transportation	10 770	0.85	Plaiting of wire, gathering of props, setting up of fences
Ditch construction	106 m^{-1}	0.5	Remuneration/wages, tools (hoes, etc.)	2400	0.23	Digging of soils
Nursery/ seedling production	315 tree^{-1}	14.6	Wooden materials, fertilisers, pesticides, wages, transportation	2450	0.03	Weeding, watering, guarding
Seedling provision	635 tree^{-1}	48.2	Seedlings, seeds, transportation	-	-	
Planting on the green belt	356 tree^{-1}	3.8	Fertilisers, transportation, remuneration for weeding/land preparation	825	0.04	Weeding/land preparation (planting holes), planting, protection

Table 2. Outcomes of the IGB trials at two villages (up to March 1999)

Outcomes/Village		Rantau Rasau	Sungai Rambut
Ethnic group of participating farmers		Javanese, Buginese (in-migrants)	Malay (local) Partly Javanese
Participating farmers (households)		192	118
Wire fence (km, % target length)		10.2 km (97%)	2.4 km (59%)
Ditch (km, % target length)		9.6 km (90%)	0 km (0 %)
Green belt planted (km, % target length)		10.2 km (97%)	1.9 km (46 %)
Seedlings produced (trees)		50,710	44,355
Trees planted on the green belt		18,515	3420
Activity cost per unit	Wire fence	Rp. 4778 m^{-1}	Rp. 7565 m^{-1}
	Ditch	Rp. 106 m^{-1}	——
	Nursery	Rp. 184 $tree^{-1}$	Rp. 465 $tree^{-1}$
	Planting	Rp. 243 $tree^{-1}$	Rp. 971 $tree^{-1}$
Labour contributions from farmer groups (person x day, person x day per unit (m or tree))	Wire fence	8280 (0.81)	2490 (1.04)
	Ditch	2400 (0.23)	0 (0.00)
	Nursery	1970 (0.04)	480 (0.01)
	Planting	530 (0.03)	295 (0.09)

RESPONSES OF FARMER GROUPS TO INTEGRATED GREEN BELTS

This section analyses various responses of farmer groups to the IGB development.

Acceptability of ethnic groups to IGB

Outcomes of the IGB development are quite different among the participating farmer groups. Table 2 compares farmers' performances in the IGB development between the two villages. These data show that in-migrant farmers (the Javanese and Buginese) at Rantau Rasau performance was better in terms of cost effectiveness and self-help abilities than local inhabitants (the Malay) at Sungai Rambut in all of the activities. Farmers of Rantau Rasau established the green belts more quickly with lower costs than those of Sungai Rambut. They were also active in seedling production.

In contrast, higher activity costs were caused by delayed implementation, price increases for wire and other materials, greater input of materials such as wire and props, and wage labour for weeding and land preparation at Sungai Rambut. Local farmers could not plait wire efficiently, and used more wire to set up fences than farmers at Rantau Rasau. Their self-help capabilities are also seriously limited in land preparation and farming. They cannot initiate ditch construction by lack of experience in digging soils with hoes.

This variation in farmers' performance may derive from their diverse acceptability to the IGB programme, affected by their socio-cultural backgrounds[4]. The Javanese and Buginese farmers as in-migrants are more motivated to take initiatives for new activities to improve their

[4] The authors presume that the initial IGB development was disadvantageous to the local Malay farmers as compared with the in-migrant Javanese and Buginese farmers based on observation of their activities with field staff. However, it can definitely not be generalised that the Malay groups have the same tendency in all activities everywhere, as the assumption is supported by nothing but a case from the site villages. Nevertheless, the authors recognise the significance to understand farmer groups' diverse responses to the IGB programme at the site for appropriate programme modifications. In the follow-up activities FFPMP will document evolution of both local and in-migrant farmers' interactions and performances in the modified IGB programme to assess its adaptability to the site communities.

livelihoods at new settlements even at the risk of failure. They are very eager to make a success of their new life after leaving their homeland in Java or Sulawesi. These in-migrants have gained wide experience and interest in various activities, and evolved many communication channels though migration, which expedites their active participation in new activities with their own knowledge and skills. The Javanese have a strong tradition of hoeing the land, and very experienced in intensive farming with various annual and perennial crops. The Buginese are also acquainted with intensive farming with coconut and citrus. Both groups still maintain strong social bonds and are good at organising collective actions such as mutual assistance (*gotong royong*) for ditch construction and land cultivation. Conversely, local Malay groups maintain their traditional life usually along the riverside, depending on riverine fisheries, tapping latex of jelutung, and gathering of other forest resources besides rice growing for their livelihood. Part of the Malay inhabitants also migrated into the site out of other villages, but their experience and communication are still limited within the living sphere of the Malay. They are reluctant to run a risk in new activities without substantial experience, and are less positive about participation in the IGB activities before seeing benefits of the programme to other Malay farmers. Even the success of the Javanese and Buginese is not a convincing example for them due to different cultural backgrounds. They are unfamiliar with collective actions in the project, and tend to seek quicker benefits than the Javanese and Buginese on account of their poorer economic situations. They prefer rice and other annual crops to tree growing.

It is concluded that the initial IGB activities are more acceptable to the in-migrant farmers than the local farmers because of higher adaptability of the former groups to land preparation and planting activities.

Farmers' preferences for tree planting

Although the IGB development aims at intensive tree planting in a row along the border of farmers' cultivation land, they often show more interest in tree planting on their inner cultivation land especially at Sungai Rambut, as suggested in Table 3. In particular they prefer to plant areca nut on their dryland or home gardens to gather seeds more easily. This adversely affects their willingness to maintain the green belt by weeding and fertilisation. It is often observed that they actively weed the inner land rather than the green belt farther from their houses. It might also be because they cannot yet perceive the benefits of the green belt before harvest of products from the planted trees. Line planting of small number of trees and high maintenance costs for a long period may be less satisfactory to them. Out of the three initial species, some albizia and lamtoro seedlings remained unused in the nursery.

Often farmers failed to schedule timely tree planting owing to inundation of the lower land, delayed rice harvest caused by the preceding long drought, and other income supplementing activities. Synchronisation of tree planting with farmers' activities is difficult, aggravated by unforeseeable natural conditions and their unstable economic status.

Table 3. Planting areas of three major species up to March 1999

Village Area/ species	Proportion of planted trees (%)								
	Rantau Rasau			Sungai Rambut			Total		
	Areca nut	Albizia	Lamtoro	Areca nut	Albizia	Lamtoro	Areca nut	Albizia	Lamtoro
Green belt	75.4	48.4	50.3	59.1	15.1	14.3	67.3	36.0	36.1
Inner land	17.3	0.0	0.0	33.5	0.0	0.0	25.4	0.0	0.0
Replacement	6.1	15.9	19.2	1.2	4.5	5.9	3.6	11.6	14.0
Not yet planted	1.3	35.7	30.5	6.2	80.4	79.8	3.7	52.3	49.9

Condition of crops based on farmers' observations

Growing condition of farmers' crops may largely affect their responses to the on-going IGB development. Table 4 compares mortality of six major crops and its causes in the green belt, based on a questionnaire survey with the participating farmers. Areca nut survives quite well, while the mortality rate of albizia, lamtoro, and melinjo is higher. Acid soils and inundation killed areca nut trees, while albizia and lamtoro mortality was mostly due to acid soils. Durian and rambutan survive best so far, though they are newly planted and so their growth needs to be carefully monitored. Melinjo was affected by not only inundation but also other various factors, especially wilt and pests, possibly due to farmers' inadequate treatment. Some melinjo and rambutan seedlings were trampled by passers-by or cattle. It is expected that crops on the inner land will be more susceptible to disturbance by people and livestock, as compared with the initial species along the fence.

These results generally coincide with the plot survey of growth of the initial three species in five plots. The mortality rate is 0% in areca nut, 34% in albizia, and 28% in lamtoro. It is concluded that better growth of areca nut compared to albizia and lamtoro is due to its high adaptability and good planting environment on the embankment along the ditch. Some albizia and lamtoro trees were killed by inundation on the lower land.

The condition of planted tree crops has been influenced by farmers' enthusiasm for crop protection, but simultaneously it may largely affect their concern with the crops. In this respect timber trees have so far few good prospects for development on the wet community land, discouraged by uncertain timber markets, despite initiatives of FFPMP and farmer groups for formation of the green belt with fast-growing timber species.

IMPEDIMENTS TO SUSTAINABLE IGB DEVELOPMENT

As discussed in the preceding sections, farmers' participation in the IGB development is not yet optimal particularly at Sungai Rambut. The following obstacles confront the participating farmers during implementation of the IGB programme:

High initial investment costs

Initial investment in material assistance such as wire and seedlings will be a limiting factor for sustainable development of IGB in terms of cost-effectiveness. The wire fence is an effective tool to control wild boars, yet its cost may already be too high to be borne by farmers themselves. Meanwhile, no promising alternative technologies have yet been found for this site. Hedgerow trees might be recommended for formation of live fences by cuttings, such as waru (*Hibiscus* sp.) as observed at part of the site, but their survival rate is uncertain on the wetland.

Inadequate nursery technologies

Nursery establishment and seedling provision are another difficulty at the site villages. Seedlings of farmers' favourite tree species are quite hard to produce at the village level, above all fruit trees,

Table 4. Mortality of crops and its causes by farmers' observation (%)

Species	Mortality	Causes of crop death							
		Inundation	Acid soils	Wilt	Destruction by passers-by	Pests	Fungi	Livestock	Others
Areca nut	17.8	57.3	33.8	1.1	0.0	0.3	0.0	0.9	6.6
Albizia	39.6	6.5	89.9	1.5	0.0	0.3	1.0	0.1	0.8
Lamtoro	37.2	9.8	87.2	0.0	0.0	0.7	0.0	1.4	0.9
Melinjo	37.2	48.9	10.9	20.7	0.0	4.4	4.4	4.8	6.1
Rambutan	7.8	0.0	0.0	77.8	22.1	0.0	0.0	0.0	0.0
Durian	9.2	0.0	0.0	96.0	0.0	4.8	0.0	0.0	0.0

owing to technical limitations. Few farmers can afford to purchase these seedlings.

Difficulty of land preparation without burning

Farmers encountered serious problems of land preparation through clearance of thick undergrowth and weeds without burning. The current government policy bans farmers from burning their land or spraying herbicides, but they have not yet worked out alternative land preparation technologies that they can apply easily.

Insufficient green belt protection

Farmers cannot easily protect the green belt due to their lack of capital and motivation. Their land cannot be cleared or cultivated continuously on the green belt and without enough capital or labour is quickly invaded with weeds and undergrowth. Furthermore, tree growth is stagnant without sufficient funds for fertilisation. Several fast-growing timber trees would be easier to grow on the favourable land, but are so far less attractive to farmers on account of uncertain marketing opportunities. Part of the green belts run across critical land, such as peat swamps or flood plains, which incurs high costs of soil amelioration and land improvement.

Uncertain benefits of line planting

Although line planting of tree crops might be advantageous in maintaining inner agricultural land in accordance with instructions by the local government, it is less favourable to farmers because crop harvests are small. A number of farmers are more concerned with broad-scale tree planting on the inner land.

Disadvantage of local farmers

Local farmers cannot easily develop their skills for the IGB activities as compared with in-migrant farmers. They lack experience in collective actions and land cultivation, as they still live on natural resource gathering for quick income. They are inclined to expect more short-term in-kind or cash incentives during the development of IGB. Consequently funds had to be provided to encourage their activities.

MODIFICATIONS OF THE PARTICIPATORY IGB PROGRAMME

Although the IGB model is attractive to accomplish long-term fire prevention with tree planting at the community level, several constraints must be overcome to sustain farmers' active participation for a long period. This section recommends technical and institutional programme modifications.

Diversification of crop species

In the later period of implementation FFPMP tried to give participating farmers better opportunities to design more suitable planting models through diversification of crop species, with more attention to their skills and interest. Farmers were encouraged to select their favourite crops that they can grow easily within their economic abilities. Table 5 shows the current preferences for perennial crops based on the questionnaire survey of 336 participating farmers. It indicates that a large number of farmers want estate crops such as local coconut, hybrid rubber (*Hevea brasiliensis*), cacao (*Theobroma cacao*), and coffee (*Coffea arabica*). The Javanese and Buginese groups (216 farmers) at Rantau Rasau favoured local coconut and citrus, while the Malay groups (120 farmers) at Sungai Rambut requested hybrid rubber and local coconut. Farmers' preferences are more diverse at Rantau Rasau than at Sungai Rambut, reflecting variation in their cropping experience. Timber trees are less popular on account of few economic benefits, and even fruit trees are not favoured, except citrus and rambutan, because of long growing periods and high costs of management including fertilisation. Farmers' choices of perennial crops are greatly influenced by marketing environment of the products rather than non-commercial factors.

These crops have various characteristics for fire prevention. Cacao is supposed to be resistant to fires, and effective in green belt formation due to its fast growth. Nonetheless, the fire-resistance of cacao must be closely studied at the FFPMP site. Trunks of rubber and coconut may be quite susceptible to fires, but they will effectively control weeds and undergrowth. At first FFPMP did not

Table 5. Farmers' proposals for perennial crops

Total (152 965 trees)		Rantau Rasau (106 172 trees)		Sungai Rambut (46 793 trees)	
Species	%	Species	%	Species	%
Local coconut	29.0	Local coconut	32.9	Hybrid rubber	34.8
Citrus	15.7	Citrus	20.0	Local coconut	20.2
Hybrid rubber	12.8	Cacao	10.1	Areca nut	9.5
Areca nut	8.8	Areca nut	8.5	Local rubber	7.2
Cacao	7.1	Rambutan	5.2	Rambutan	6.0
Rambutan	5.5	Coffee	3.7	Citrus	5.9
Others (29 sp.)	21.1	Others (28 sp.)	19.7	Others (17 sp.)	16.4

approve the estate crops, afraid of exacerbation of farmers' forest encroachment and fire occurrence. However, these crops are not suitable to grow outside the fenced area where there are more critical soils and pests. Farmers are also expected to be more careful with the use of fire after their land is planted with their selected crops. FFPMP will try a variety of perennial crops in and around the green belt to examine their resistance to fires, motivating farmers to plant and protect them.

Modification of planting sites

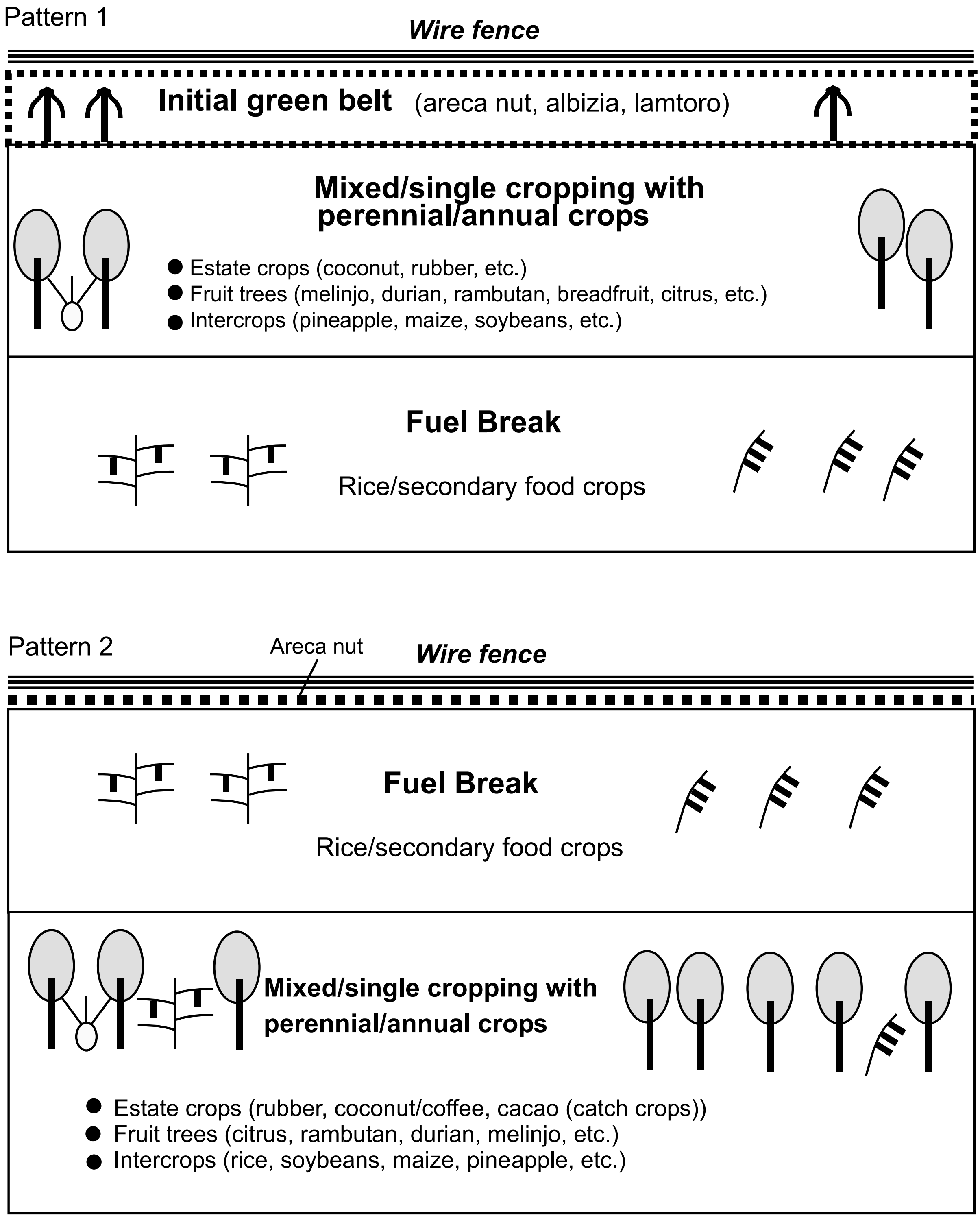
FFPMP will help farmers determine appropriate planting sites more flexibly in and around the green belt to guarantee optimal growth of the selected crops without heavy land improvement work. Figure 3 classifies farmers' ideas which emerged in the questionnaire survey for tree planting in and around the green belt. Pattern 1 aims to expand the existing green belt along the fence with farmers' favourite tree crops together with annual and short-cycle intercrops, which suits the project objective best. On the inner land farmers grow rice and food crops every year, developing fuel breaks. Pattern 2 is to develop the fuel breaks with annual crops along the fence and the row of areca nut on the lower land, accompanied by the tree planting on the higher land. For this pattern, the effects of the fuel breaks to suppress weeds and undergrowth, and cut off surface fires will be examined, while closely monitoring farmers' skills of controlled burning in land preparation. Patterns 3 and 4 are oriented to alley cropping with annual or short-cycle crops on the inner land, parallel or perpendicular to the initial green belt. Trees will be planted on ridges, embankments, or other higher topography, or otherwise indigenous wetland species will be introduced on the lower land. Pattern 2 is to be applied to areas where tree planting is difficult just along the fence due to frequent inundation or flood, but could be converted into Pattern 3 upon farmers' initiatives, if the fuel breaks turn out to be ineffective in control of fuel and wild fires.

Farmers will be encouraged to mix several perennial and annual crops on the green belt and the inner land for economic and ecological stability. In spite of this, they may prefer single cropping of estate crops, above all rubber, to try to maximise cash incomes. Nevertheless, farmers will be advised to space out rubber and other estate crops and to intercrop them with rice or other food crops for several years. It is expected that farmers will be more eager and responsible to prepare their land and then plant and protect their selected tree crops with the modified models, while the functions of the green belt will be strengthened. Coupled more closely with farmers' initiatives, tree growing should be more sustainable in and around the green belt, enhancing formation of fuel breaks and control of burning.

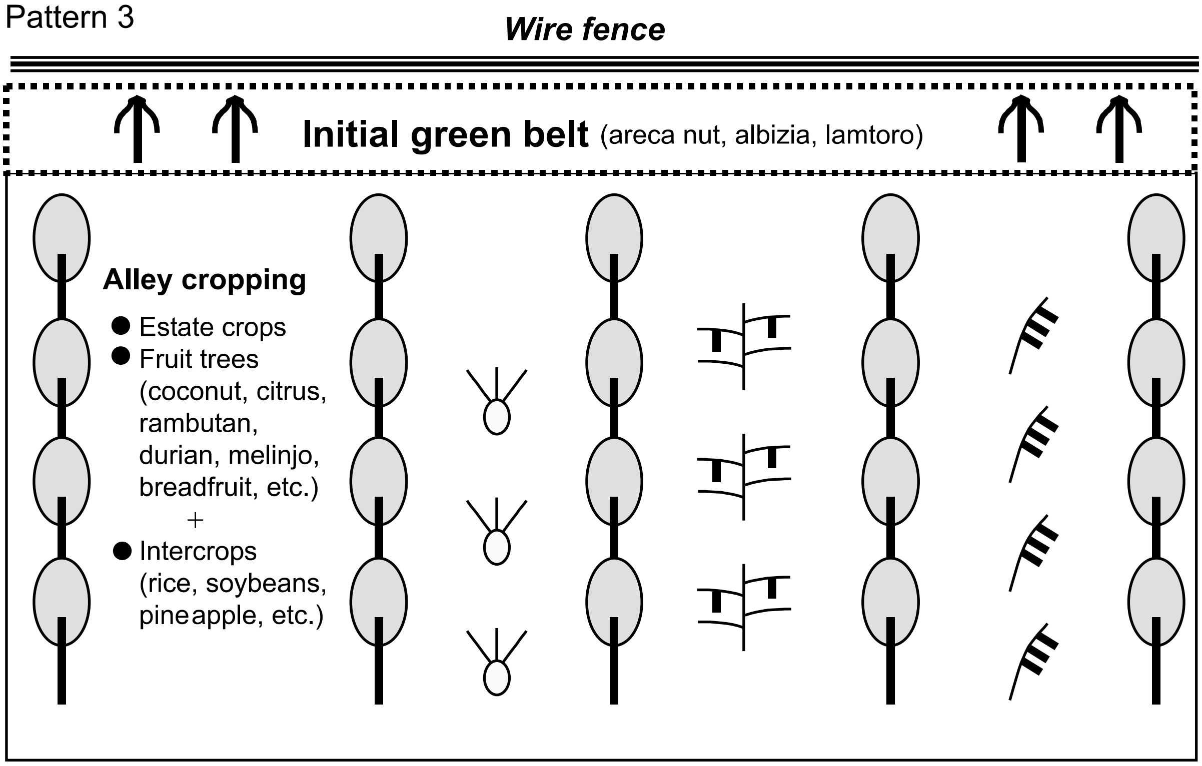
Improvement of technologies for land preparation and crop protection

Initial land clearance and subsequent weeding are still a problem for farmers without burning or spraying practices. Even though some farming tools might be helpful, farmers still feel it a burden

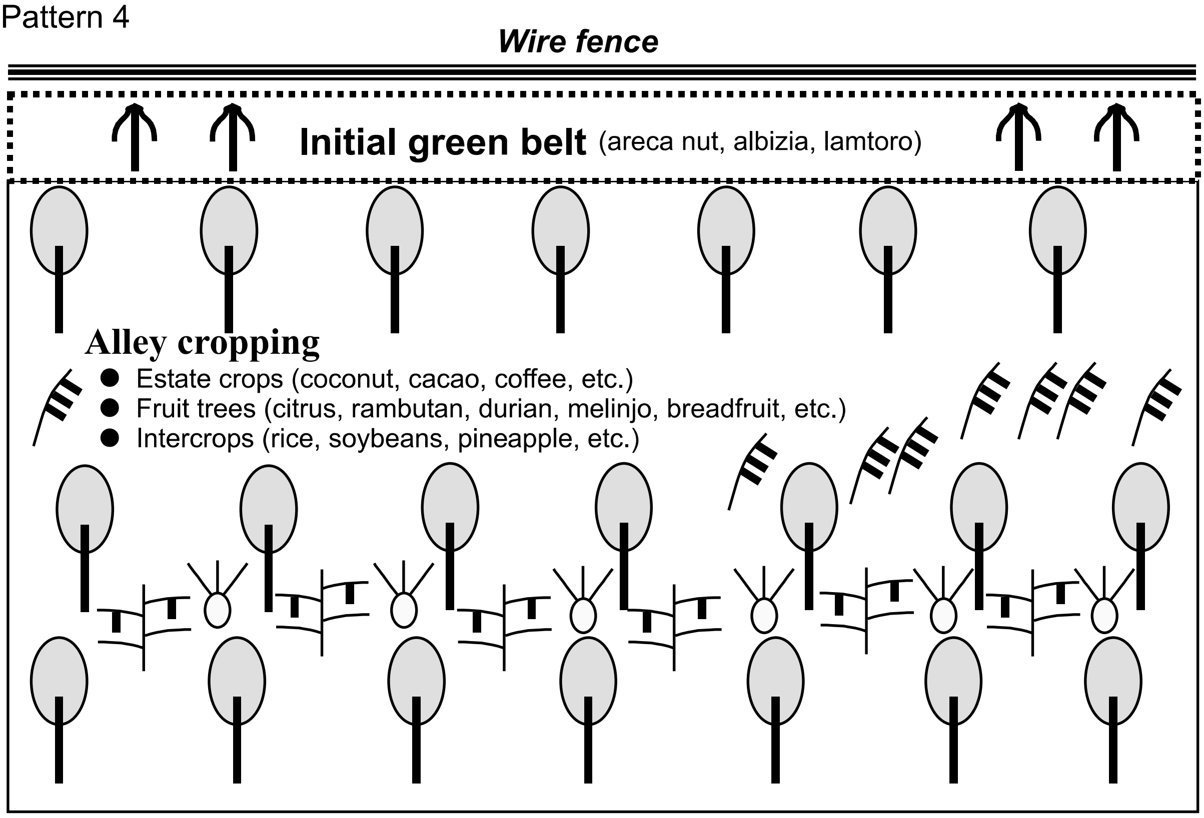
Figure 3. Farmers' ideas for land uses



Pattern 3



Pattern 4



to prepare their land by manual weeding. Assistance in food crops might be considered for participating farmers to facilitate weeding of the green belt with quick harvests. Gradual land use intensification with annual and perennial crops will help farmers prepare land more easily with reduction of weeding costs in the near future. Fertilisation problems could be surmounted by selection of crops requiring little fertiliser. FFPMP will also try to provide farmers with technical assistance in production of mulches and composts out of weeds and dung to minimise chemical fertilisation. Generation of the demand for green manure could also stimulate farmers' sound land preparation in the future.

Development of alternative fencing technologies

More simple and effective fencing technologies must be found as an alternative to expensive wire fences for wide application in other areas. A potential method would be formation of hedgerows by direct sowing of seeds of several leguminous trees such as turi (*Sesbania grandiflora*) or planting of cuttings of local trees such as bungur (*Lagerstroemia speciosa*), although its technical feasibility needs to be tested at the site.

Facilitation in seedling production and nursery building

Table 6 indicates farmers' willingness to produce seedlings inside the two villages with 27% interested in seedling growing. Farmers of Rantau Rasau (39) are more positive than those of Sungai Rambut (4). In correspondence with their crop preferences, farmers are eager to produce seedlings of coconut, citrus, cacao, rambutan, durian, coffee, rubber etc.

Table 6. Farmers' interest in seedling growing

Crop species	Interested farmers (%)		
	Rantau Rasau	Sungai Rambut	Total
Coconut	18	4	13
Citrus	15	1	10
Cacao	14	0	9
Rambutan	12	1	8
Durian	10	0	7
Others (17 sp.)	46	9	33

Farmers do not have sufficient experience for seedling production of all selected crops. Coconut seedlings are relatively familiar to farmers and growing of areca nut seedlings has been demonstrated during implementation of the project. Some farmers are experienced in producing albizia seedlings. A few have tried to plant cuttings of rubber on their land. Nonetheless, very few have raised seedlings of other species, above all fruit trees. Citrus and melinjo require special care with fertilisation and pest management to maintain the quality of their fruits. Farmers have not yet acquired grafting skills and other technologies to produce good quality seedlings of durian, rambutan, and duku (*Lansium domesticum*). They can grow jackfruit (*Artocarpus heterophyllus*) fairly well by simply transplanting wildings that germinate around their houses.

As farmers' technical and economic capacities are still limited for seedling production, small pilot nurseries need to be established and maintained for demonstration of seedling production technologies, with assistance by external agencies, including Ministry of Forestry and Estate Crops and local extension services. It is expected that the pilot seedling production will gradually assist technology transfer from farmer to farmer inside the villages.

Strengthening of community organisation

Community consultation and organisation processes are imperative to build up farmers' working abilities especially in underdeveloped areas. The organisation work must be adapted to local socio-cultural conditions, and suitable personnel who comprehend them must be appointed to enable good communication with farmer groups. Oral instructions alone will never be enough for local Malay inhabitants. Joint field trials are indispensable together with frequent technical orientation and pilot demonstration. Considerable government support will be essential for community organisation and extension for the whole period of programme implementation.

CONCLUSIONS

Although the IGB trials are a good example of participatory forest fire prevention along the forest boundary through intensification of farmers' land uses, there are obstacles to their sustainable implementation. Main limitations are high initial investment costs in materials and facilities, above all wire fences, and farmers' limited capacity for land preparation, seedling production, and protection of crops and facilities. Local inhabitants are less capable of the IGB development than in-migrant farmers.

To address these shortcomings, FFPMP will focus on more effective fuel management inside the fenced areas through agroforestry development with various perennial crops proposed by farmers. They have increasingly urged FFPMP to balance fire prevention objectives and their living needs in establishment of the green belt on their land, which results in diversification of tree crops and cropping patterns with adaptation of planting sites. FFPMP will also seek for opportunities to expand the green belt outside the fence along the park boundary with indigenous tree species resistant to pests and fires, with a view to upgrading fire prevention and wild boar control. Incentives may be indispensable for active participation of farmers, but more cost-effective funding techniques need to be explored with simpler technologies for economical fencing, sustainable seedling production, and sound land preparation and crop protection.

Careful modification and adaptation of the programme to the local conditions are crucial through positive integration of initiatives of farmers and the project to optimise outputs and minimise activity costs in the latter period of implementation. Community participation programmes inevitably involve processes of problem analyses, innovations, and programme modifications. Rigid and predetermined approaches result in ineffective programme organisation and intolerably high activity costs. Responding to various farmer groups' performances, programme options and farmer organisation skills need to be diversified as far as possible for more sustainable development of IGB. Reiterative learning processes should be given high priority for disadvantaged farmer groups. The government must support the activities technically and financially.

FFPMP will use an evaluation matrix to assess effects of the on-farm green belt trials with various perennial and annual crops in fuel management, burning control, wild fire prevention, and farmers' self-reliance. The developed expertise on participatory tree planting would be valuable for not only forest fire prevention but also rehabilitation of ex-fire forests around community settlements. It is highly expected that rehabilitation of degraded forests in park buffer zones will be facilitated through collaboration between forestry personnel and local people with evolved participatory techniques.

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