Site Management and Productivity in Tropical Plantation Forests

Workshop Proceedings,
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Cover: Four year old *Eucalyptus* clonal plantation in Pointe-Noire

(Photo by Christian Cossalter)

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Editors Note

This collection of papers describes the experimental basis and preliminary results of the CIFOR project *Site Management and Productivity of Tropical Plantations*. They were presented at the second workshop of project partners (the first workshop was a planning meeting) held at Pietermaritzburg, South Africa, and subsequently revised and edited to provide a source of cohesive information on the current content of the project, especially the project sites.

The progress of work achieved by different partners at the time of the workshop varied for reasons including:

- Some partners had commenced new project initiatives in this area well before the CIFOR network was established, but were enthusiastic about participating in the network.
- The time needed for acquiring the resources, commitment and organisational support needed at each site varied between partners.
- The access to background knowledge and scientific skills required to develop the research plan and implement the work was not equal among partners.

The difference in the rates of progress achieved so far is reflected in the papers: detailed process-based information in some cases compared to details of project plans in others. However, for advancing the goals of the network we have included all contributions in this volume so that we have a record describing the state of the project. Each contribution in a sense reflects the experience of its authors and their writing styles. Some contributions are written by the authors to simultaneously accommodate local needs because their project in its entirety had objectives wider than those directed in the network goals. Clearly in some cases authors had strong preference for the use of units familiar to them or to their own collaborators. During the revision and editing process we decided that it was prudent to accept some of this diversity in the first proceedings at the expense of some uniformity. As the work progresses, more results become available from all sites and the links between partners and the network strengthen, we are confident that the quality and content of future proceedings will evolve to become a source of high quality information on an important aspect of the sustainable management of tropical plantation forests.

E.K.S. Nambiar
C. Cossalter

Introduction

E.K. Sadanandan Nambiar[1]

Plantation forestry is expanding worldwide, especially in the tropics and subtropics. This expansion is driven by factors which include the urgent need to meet local and global demand for wood from plantation forests, community pressure to diminish dependence on native forests for wood harvests, and the increasing opportunity to integrate plantation forests with other land uses to ameliorate land degradation.

Productivity of plantation forests grown on short to medium rotations varies greatly from 1-2 m^3 ha^{-1} yr^{-1} to 25-30 m^3 ha^{-1} yr^{-1}. Yields exceeding the latter are also reported. While the potential for achieving high productivity is recognised, there are many constraints on yield. Doubts have been expressed about the sustainability of tropical plantations both in terms of biological productivity and their potential impact on the environment. Tree plantations have been used in Asia, Africa and South America for centuries to produce materials such as rubber, coconuts, palm oil and coffee. There is also a long history of growing teak, eucalypts and casuarinas in some regions. However, large-scale plantings using short-rotation silviculture, intensive management and exotic species with potential for rapid growth are relatively new developments. The opportunities for increasing production over the long term and the potential problems in sustaining yields are poorly understood, yet the expectation of achieving high growth rates remains strong.

In this introductory paper I would like to briefly comment on the historical background of this project and place it in the broader context of sustainability, and set the framework within which the contribution of individual partners, and the results from their experimental sites, can be discussed.

Project Background

Promotion of sustainable plantation forestry in subtropical and tropical countries through strategic and applied research is an important objective of CIFOR. This project arose from discussions promoted by CIFOR among international scientists and a subsequent meeting in Bogor. The outcome from the meeting included a general project plan to investigate the basis of sustained high yields in tropical environments, the concept of a network and the establishment of a Scientific Advisory Group (SAG) to assist CIFOR to further develop the initiative, and to identify and negotiate with potential partners. Following a variety of inputs to CIFOR, it was decided to focus on a networked, medium-term, experimental approach to explore the impacts of various inter-rotation management options. It was agreed that partners from both public and private institutions would be encouraged to join this initiative, recognising the nature of ownership of plantation forests. In a follow-up workshop at the Forest Research Institute of Malaysia attended by some of us present at this meeting, the participants adopted the important concept of an international network-based research strategy to be coordinated by CIFOR, and agreed on the basic objectives and methodology. Some participants at that workshop already had significant research under way or had well-developed plans to study the issues central to this initiative. They were, however, enthusiastic about joining the network and sharing their experience.

As the following papers show, at this stage we can describe only the sites, the experimental details and in some cases preliminary results. In a subsequent workshop we will pay greater attention to reviewing and integrating the results.

Sustainability in Context

Development of plantation forestry should be placed in the context of known risk factors, capacity for management and sustainability. Figure 1 shows the pattern of interaction

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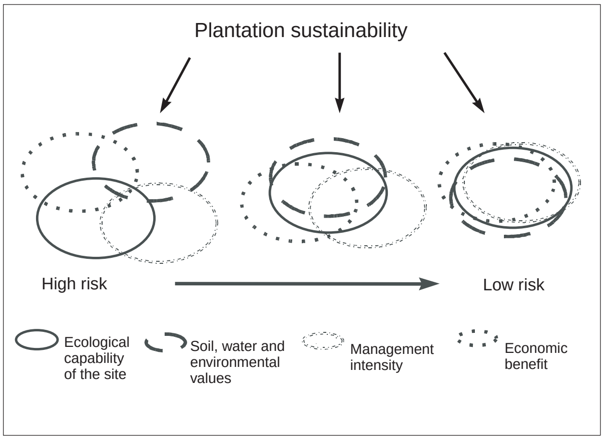
Figure 1. Interplay between ecological and management variables that govern the risks of sustainability of plantation forestry.



between some key variables and management, and how they determine risks in plantation forestry.

The variables considered are: ecological capability of the site; intensity of management; impact on soil, water and other environmental values; and economic benefit in the context of social goals. The level of risk faced by plantation forestry in a given environment will depend on the degree of alignment of these variables. Not all factors that impinge on sustainability are represented here; the aim is to demonstrate interaction and the need for a holistic and balanced approach to sustainability.

Of these variables, ecological capability is specific to a site. For our purpose here the ecological capability includes the limit set by the inherent soil and biophysical constraints, the responsiveness of the soil to inputs and management, and the genetic potential of the species and their interaction with the environment.

One practical way of advancing sustainable forestry is to integrate the elements of sustainability with the goals of plantation management. The intended use of most plantations is wood production, but as a land use system they must be managed on a sustainable basis.

The goals of plantation management should ensure that:

- the trend in plantation productivity is non-declining or positive over successive harvests while maintaining and enhancing the quality of the soil resource base;
- plantation management practices *per se* do not adversely affect the environment; and
- plantation forestry is economically viable and contributes to prosperity of local people.

One important step towards achieving the goals is to clearly recognise and manage the sources of risk to sustainability. Risk may arise at a regional scale or in a management unit (i.e. on a small scale). Two examples illustrate this.

(a) The issues related to the extent of planting in a region and its impact on overall plant use (e.g. protecting and sharing water resources) can be addressed only at a regional scale.

(b) Decisions and management practices that maximise or minimise the conservation of organic matter and impact on soil fertility (and productivity) apply at a management (operational) unit level.

Factors that contribute to unsustainability of production at a management unit level include:

- loss of soil quality: initiation or acceleration of soil degradation process which decrease productivity and increase cost of amelioration and production;
- a weak or inappropriate genetic base unadapted to the environment;
- threats from pests and diseases, an issue requiring continuous monitoring and integrated management plans;
- adverse environmental effects, for example off-site negative impacts on the quantity and quality of water in the ecosystem; and
- poor management: often a common reason for failure and leading to unsustainable ‘extractive’ practices.

The route to sustainability is to take an integrated approach to management.

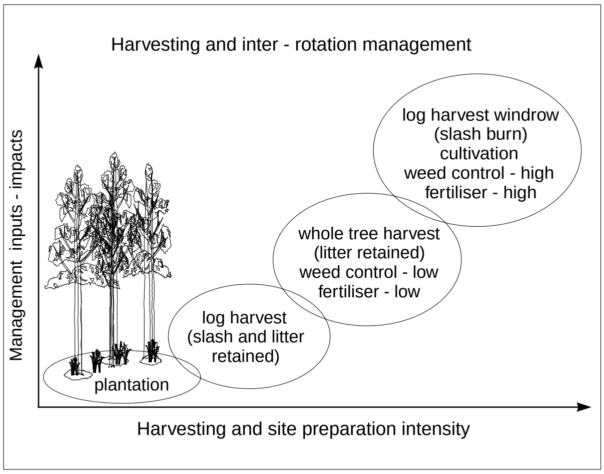
Rationale for this Research

Sustained productivity is not a result of any single management practice. But one single wrong management practice (e.g. poor harvesting methods leading to soil compaction and erosion) can cause long-term adverse effects on productivity and the environment. Sustained productivity is influenced by all management practices applied throughout the rotation and between crop cycles (the inter-rotation management). Clearly, even within a particular ecosystem, no single research project can deal with all aspects of productivity management.

As noted earlier, in this project we have chosen to focus on inter-rotation management. The phase between the harvesting of one crop and the establishment of the next is a window of considerable risk as well as opportunity. A forest site is most vulnerable to damage during this period. It is also a phase offering great opportunity to remedy past mistakes and introduce sound technology to establish a good, judiciously managed plantation. A concept of the relationship between inputs and the 'intensity' of site management practices that may be applied in plantation forestry is shown in Figure 2.

The various management scenarios described in Figure 2 can have significant effects on soil and stand productivity. They also influence environmental outcomes and indeed, in some cases, directly relate to forestry codes of practices and policies. Examples of each of the practices (Fig. 2) can often be found in a single region.

Figure 2. Management practices of different intensities which may be applied during harvesting and the inter-rotation period.



As the rationale and methodology, including the concept of core and optional treatments, are described in detail in a separate CIFOR report, those details will not be repeated here.

The principles are:

- Evaluate the impact of soil and site management practices on the productivity of successive rotations of plantations. This evaluation will be focussed on critical variables.
- Develop management options for maintaining or increasing productivity.
- Strengthen local institutional capacity to respond to new problems and opportunities.

Secondary principles are:

- Each site should play the important role of demonstrating the consequences of different management practices, including, if possible, the 'best management' option under local conditions.
- Each site should be designed to become independent and self-contained in terms of its ability to deliver local benefit, and should be able to contribute scientifically to the collective benefit.
- The core part of experiment should be relatively simple but have an underlying capacity to provide a minimum set of information to all partners.
- Experiments should be established with the participation of local managers.

This partnership research consists of several experiments dispersed among very challenging environments. Its success will depend not only on the quality of work at each site but also on the recognition of shared values, results and benefits. Some partners will contribute more to the project than others, thus reflecting the skills and resources available to each. The project is a partnership whose strength will lie in the sharing of diverse experience.

Acknowledgement

I thank Alan Tiarks and Christian Cossalter for many discussions. This introductory paper is mainly based on the sources presented below.

References

Nambiar, E.K.S. and Brown, A.G. (eds.) 1997 Management of soil, water and nutrients in tropical plantation forests. Australian Centre for International Agricultural Research (ACIAR) Monograph No. 43. ACIAR, Canberra.

Tiarks, A., Nambiar, E.K.S. and Cossalter, C. 1998 Site management and productivity in tropical plantations. Center for International Forestry Research (CIFOR) Occasional Paper No. 16. CIFOR, Bogor, Indonesia.

1. Eucalypt Plantations in the Humid Tropics: São Paulo, Brazil

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Abstract

This paper reports the effect of site management practices of minimum and intensive cultivation of the soil on the growth of a stand of *Eucalyptus grandis*, the chemical and physical characteristics of the soil, the nutrient cycling, and the configuration of the root system. The study site is a commercial plantation of *Eucalyptus grandis* in Itatinga district, São Paulo State, Brazil. The natural vegetation of the area is cerrado, the climatic and soil conditions of which are representative of extensive blocks of homogeneous forest on the São Paulo plateau. The studies began in July 1995. In this paper we present some results of the effect of the treatments on tree growth and on physical characteristics of the soil (moisture and temperature) as well as on nutrient uptake and cycling. These results show significant effects on a number of processes that are important for plantation productivity.

Introduction

Increasing domestic and international demand for forest products, and awareness of the need to minimise pressure on exploitation of Brazilian native forests, have resulted in public and private initiatives to establish large-scale forest plantations with fast-growing species. Brazil has about 6 million ha of plantation forests dominated by species of *Eucalyptus* (52%) and *Pinus* (30%). Financial incentives given by the Government from 1967 to 1987 were one of the main stimulants to the development of production activities to support wood-based industries. Now, the plantation forest industries play an important part in the Brazilian economy.

Beside the increasing relevance of forestry in the country, many questions are being asked about the sustainability of planted forests in the medium and long term. One important concern is that the great majority of these plantations have been planted on soils covered with cerrado vegetation, which has only a small reserve of nutrients. In addition, to increase productivity, forest plantations in Brazil are managed very intensively. Because of these factors, high productivity and wood harvesting can lead to nutrient depletion. It is necessary to study the physical, chemical and biological processes that govern the nutrient dynamics among the different compartments of the ecosystem: soil, above and aboveground biomass, and litter. Through understanding these processes, it will be possible to develop technical recommendations for soil and residue management that promote optimum use of nutrient reserves.

In the last 10 years, Brazilian forestry has adopted the 'minimum cultivation system'. This involves soil preparation confined to the lines of planting or planting holes and retaining all slash residue at the site. However, the study of key issues including nutrient cycling, mineralisation processes and root system development under the changing field practice is at an early stage.

This study had four broad objectives:

a) to compare the effect of different harvest residue management on the chemical and physical characteristics of the soil, and on the growth of *Eucalyptus grandis* stands;

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b) to study the dynamic decomposition and nutrient release that happens in the residue layer and in the soil organic matter;
c) to determine the flow of nutrients among the several compartments of a forest stand, under different systems of soil preparation; and
d) to study the configuration of the root system of the developing stand.

Table 1. Physical characteristics of the soil.

Depth	Sand	Silt	Clay	Bulk density	Particle density
(cm)		(%)		($g\ cm^{-3}$)	
0-10	77	3	20	1.25	2.22
10-20	77	3	20	1.25	2.22
20-30	76	2	22	1.30	2.25
30-50	76	2	22	1.30	2.25
50-100	74	2	24	1.31	2.25

Material and Methods

Description of the Experimental Area

The study site is located in a commercial plantation of *Eucalyptus grandis* Hill ex Maiden, Itatinga district, São Paulo State, Brazil. The geographical coordinates of the location are 23°00'S latitude, 48°52'W longitude and altitude 750 m. Before establishing plantations these sites were occupied by 'Cerrado', the native vegetation typical of the area. At the beginning of the study the stand was 7-year-old *Eucalyptus grandis*. The climate of the area is Köeppen type Cwa, that is winter with median temperature for the coldest month (July) less than 18°C, and wet summer with the hottest month (January) more than 22°C. The annual average precipitation of the area is about 1580 mm, 57% of this falling during the months of December to March. There is no pronounced water deficit. The soil of the area is characterised as a red-yellow latosol (oxisol) with medium texture and dystrophic, and the topography flat to gentle relief. The physical and chemical characteristics of the soil are presented in the Tables 1 and 2.

These conditions of climate, soil and vegetation are representative of extensive areas planted with *Eucalyptus* in the São Paulo plateau.

Site Preparation

The experimental treatments consisted of operational practices designed to provide a range of disturbances of different intensities for the soil and residues. The first set of four treatments parallel the core treatments in the CIFOR Network.

BL_0 Clear-cut the stand. Aboveground matter including the crop trees, understorey, slash and litter removed.

BL_1 Clear-cut the stand. Whole stemwood harvested. All the bark, understorey, slash and litter retained with minimum disturbance to site. (Note that in BL_1 treatment as per the CIFOR Protocol aboveground parts, including bark of the commercial-sized crop stems, are removed).

BL_2 Clear-cut the stand. Stemwood + bark harvested. All slash, understorey and litter retained with minimum disturbance.

SC (Standing Crop) – Standing crop left intact.

The study included three additional treatments:

SL_p Clear-cut the stand and harvest the stemwood. All residue (bark, slash, litter and understorey) incorporated in the soil with a heavy harrow.

SL_b Clear-cut the stand and harvest the stemwood. All residue distributed on the soil, and burnt.

CP Clear-cut the stand and harvest the stemwood. All residue retained on the soil. Cut stumps allowed to sprout (coppice).

The stand was clear-cut on 11 July 1995 and treatments were applied by 2 August 1995. Treatments BL_0, BL_1, BL_2, SL_p and SL_b were completed after

Table 2. Chemical characteristics of the soil.

Depth	pH	S.O.M.	P	K	Ca	Mg	H	Al	BS	T	V	m
(cm)	$CaCl_2$	($g\ dm^{-3}$)	($mg\ dm^{-3}$)				($cmol_c\ dm^{-3}$)				(%)	
0-10	3.7	25.0	4.0	0.04	0.4	0.1	6.0	1.7	0.5	2.2	24	76
10-20	3.8	17.0	4.3	0.03	0,5	0.1	5.5	1.5	0.6	2.1	29	71
20-30	3.8	16.0	3.0	0.03	0.2	0.1	3.8	1.5	0.3	1.8	19	82
30-50	3.9	8.0	3.0	0.02	0.1	0.1	3.0	1.3	0.2	1.5	12	88
50-100	4.0	2.5	2.0	0.02	0.1	0.0	2.5	1.2	0.1	1.3	11	89

BS = Base sum (K+Ca+Mg); T = CEC at pH 7.0; V = Base saturation (BS/T)x100; m = Aluminium saturation (Al/(Al + BS))x100.

clearcutting and seedlings for the new plantation were planted on 26 September 1995 at a spacing of 3.0 x 2.0 m. Seedlings were raised in a commercial nursery from seed of *E. grandis* (Coffs Harbour provenance).

The seedlings were planted in furrows 30 cm deep. They were fertilised at planting with 15, 13 and 12 kg ha^{-1} of N, P and K respectively, and a basal dressing of 250 kg ha^{-1} of KCl was applied on 8 May 1996. Two manual weedings were undertaken, the first 3 months after planting (27/12/95) and the second 4 months later.

Experimental Design

The plots were established in a randomised complete block design, with 7 treatments and 4 replicates. Each plot consisted of 121 trees, in 11 rows with 11 trees per row. The total trial occupied 1.75 ha.

Monitoring Macro- and Micro-Climatic Conditions

Meteorological data including rainfall, maximum, average and minimum temperatures and relative humidity were collected in a meteorological station 5 km from the experimental area.

The maximum and minimum temperatures of the soil were measured weekly at 2.5 cm soil depth in all treatments. The soil and residue moisture contents were estimated during soil-core sampling for evaluation of N mineralisation.

Estimation of Biomass and Nutrient Content

Tree growth was measured in all SC plots as height, diameter at breast height (DBH), basal area, volume of wood and site index. To estimate the biomass and nutrient uptake, 5 trees were cut per plot (from treatment SC), each tree representing a particular size class distributed across all treatments.

Litter on the soil surface was collected by using a metal ring, 30 cm diameter, with a sharp edge to cut through the litter layer; five samples were gathered per plot.

Litterfall (leaf, branches, etc.) were collected in three litter collectors installed in all the plots of the treatment SC. This collector was basket-shaped (0.25 m^2) and made of nylon mesh. The litterfall samples were collected monthly in the first twelve months and afterwards for two months.

Litter Decomposition

Litter decomposition was measured using the litter-mesh bag technique. Leaves (20 g dry weight per bag) were placed in nylon mesh (1 mm mesh and 20 x 20 cm in size). Twenty samples were placed in the plot (SC), and sequentially removed at intervals of two months. Three subsamples were used for dry-weight determination and chemical analysis.

N Mineralisation, Leaching and Uptake

Dynamics of nitrogen mineralisation were measured in treatments SC, BL_0, BL_1, SL_p and SL_b, using methodology described by Raison *et al.* (1987). Soil cores were contained *in situ* in 6 PVC tubes (40 cm long and 5 cm diameter). Soil was incubated (± 50 days), sequentially sampled and mineral nitrogen measured. The technique allows estimation of mineralisation, leaching and uptake. The soil cores were divided at the following depths: 0-5, 5-15 and 15-30 cm.

For obtaining the extracts, 10 g of fresh soil and litter was shaken with 50 ml of KCl (2M) for one hour (Bremner 1965). The extracts were centrifuged to 2000 rpm for 15 minutes; and 20 ml of aliquots collected and treated with 1 ml of the microbiologic activity inhibitor. The concentration of NH_4^+ and NO_3 was measured in the aliquot. Soil and litter subsamples were dried at 105ºC for 24 hours to determine moisture content.

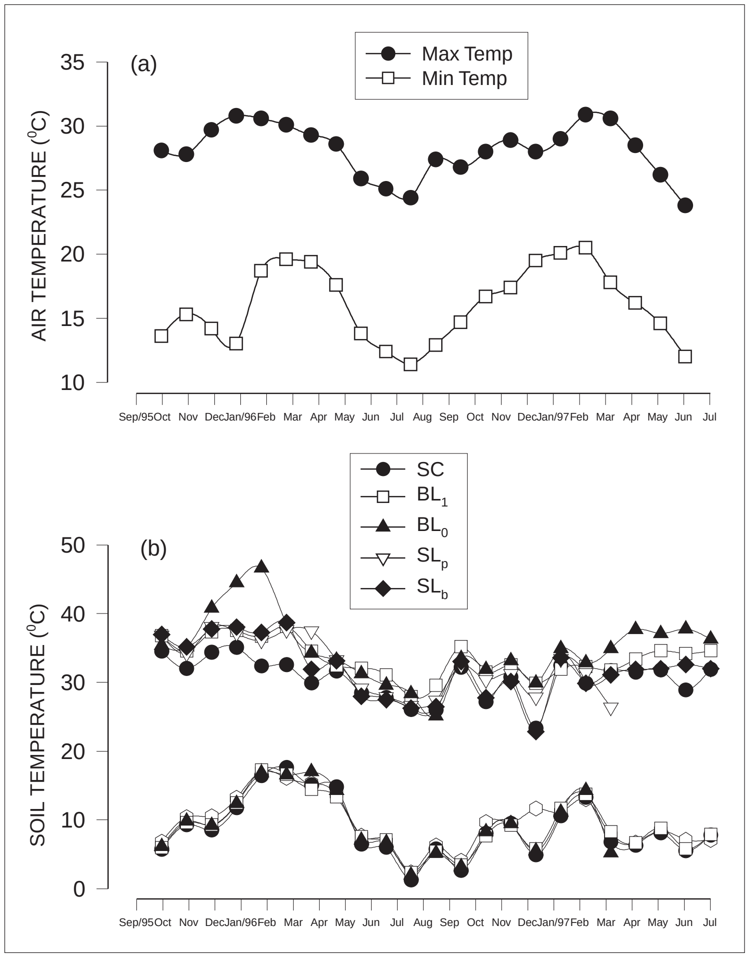
Studies on the Root System (fine and coarse roots)

The root system was sampled in the SC treatment.

Fine roots (≤3 mm diameter) were sampled with a steel tube (4.0 cm in diameter and 1.3 m long). An area bounded by four medium-sized trees (DBH) was selected in each replicate of SC. Cores were taken to obtain samples from 0-10, 10-20, 20-30, 30-50, 50-100 and 100-150 cm in the soil. Roots that were present in the litter were also collected. The samples were kept in plastic bags and taken to the laboratory and stored under low temperature (<4°C) until processed. To remove soil particles, the samples were sieved with a set of sieves (2 and 0.5 mm). Due to the sandy nature of the soil it was not necessary to use agents for dispersion. After washing, roots were preserved in a solution of 10% ethyl alcohol. Only live roots with diameter ≤3 mm were assessed in this study. They were separated into diameter classes >1 mm and ≤1 mm. Root length was estimated by the SIARCS software (Integrated System for Root Analysis), developed by EMBRAPA/CNPDIA (Brazilian Research Institute) using the method of Jorge *et al.* (1993). Initially, the roots were cut into segments of approximately 5 cm, and distributed in a glass tray 15 x 21 cm and 1 cm deep, and covered with a thin layer of water. The tray was placed on a scanner with resolution of 1200 dpi, which digitised the images of the roots and transferred them automatically to a file in the computer. The image data were then processed to obtain the root length.

Roots were sampled separately to assess root mass (roots >3 mm) and chemical composition. An area represented by 3 medium-sized trees (DBH) was selected in three replications of treatment SC. Trenches (6.0 m^2) were dug near the trees, and blocks of soil taken. After careful removal of the roots from the soil, they were weighed fresh. Approximately 1 kg of roots was dried at 65°C and used for the estimates of dry weight and chemical composition.

Figure 1. a) Range of maximum and minimum air temperature and, b) Soil at 2,5 cm of depth in treatments. The measurement started 2 months after clearcutting the stand.



Results and Discussion

Effects of Site Cultivation on Temperature and Soil Moisture

During the eight months after installation of the experiment (September 1995 to April 1996), the maximum soil temperature fluctuated between 29.9 and 46.6ºC and the minimum between 5.3 and 17.6ºC (Fig. 1). The least fluctuations were observed in the standing crop treatment and the highest in treatment where residues were removed (treatment BL_0), showing the importance of soil cover, either as trees or slash, on soil temperature. On an average, between September 1995 and April 1996, the removal of the litter (BL_0) resulted in an increase of 2.5ºC in the mean maximum temperature of the soil when compared with that in the treatment where the residues were retained (BL_1) (Fig. 1). The mean maximum temperatures of the soil under the intact forest (SC) were always 1 to 2ºC less than in other treatments. The management of the slash residues had greater influence on the maximum temperatures of the soil than on the minimum temperatures. Similar results were obtained by Smethurst and Nambiar (1990), in a study on the effects of slash and litter on N dynamics and growth of *Pinus radiata* in sandy soils in the southeast of Australia.

The largest fluctuations and differences in mean maximum temperature among treatments were observed in the eight initial months (Fig. 1). Subsequently, the mean of the maximum and minimum temperatures decreased. These effects are associated with crown growth that reduced exposure of the soil. As seen in Figure 1, there is a clear parallel between the air temperature and the soil temperature.

The soil moisture oscillated between 2% and 14% (w/w) in the 0-30 cm layer between September 1995 and March 1997 (Fig. 2); the differences among treatments being most pronounced in the initial months. Then the median moisture content of the soil decreased (variation = 2% to 6% w/w) with little difference between treatments. The reduction in moisture content is directly related to the demands for water by trees for growth, and the effect of treatments on the moisture content was overtaken by the presence of tree crowns.

In the slash treatment BL_1 soil retained more water than in other treatments, demonstrating the effect of slash in reducing evaporation. Low moisture contents were observed in the treatments where the soil was exposed (BL_0 and SL_b).

Figure 2. Soil moisture content from 2 months after harvest.

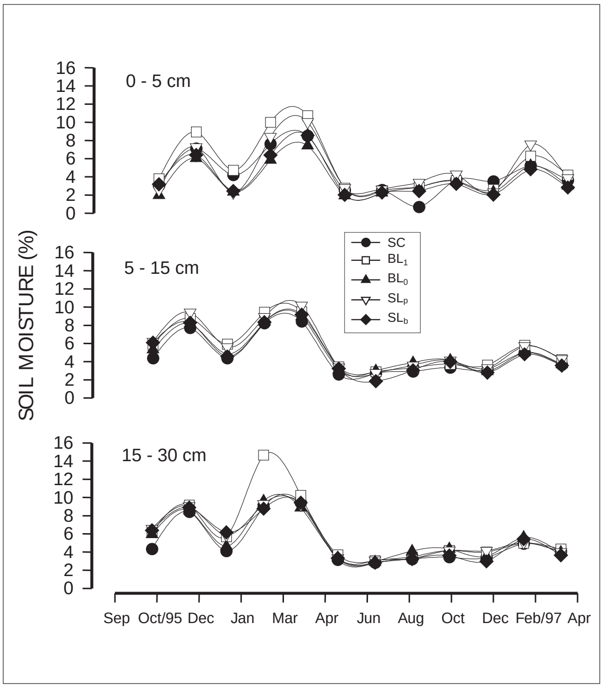


Table 3. Growth attributes of the intact stand of *Eucalyptus grandis* at age 7 years (treatment SC).

Site index (m)	27.7
Mean height – all trees (m)	17.0
Mean height – dominant (m)	27.7
Diameter (DBH) (cm)	13.0
Basal area (m^2 ha^{-1})	25.1
Stem volume over bark (m^3 ha^{-1})	314.9
Stem volume under bark (m^3 ha^{-1})	280.0

Effect of Site Cultivation on Growth and Uptake of Nutrients

Initial stand growth data are given in Table 3. Effects of treatments on height at 6 and 15 months after planting are given in Table 4. At 6 months of age, the trees that sprouted from stumps (coppice) were the tallest (CP). This rapid early growth of coppice of *E. grandis*, compared to that of planted seedlings, is commonly observed in general plantations, probably because of the reserves of carbohydrate and nutrients in stumps and access to a large soil volume through an established root system. The 'tree residue burnt' treatment (SL_b) had the second greatest height, which was also significantly larger than the averages obtained for the other treatments. This is probably due to the release of a large pool of nutrients through ash and faster mineralisation. There was no significant difference between treatments BL_1, BL_2 and SL_p (minimum cultivation, retention of the litter, incorporation of all the residues, respectively) at the first assessment. Similarly there was no significant difference between BL_0 and BL_2 (removal of all the residues and maintenance of just the litter, respectively).

At 15 months of age, tree height in treatment SL_b differed statistically (P=0.01) from BL_1, BL_2 and SL_p. The height differences among these treatments show a clear reduction with time (age 6 to 15 months). Over this time, the trees of the treatment BL_1 and SL_p were equal in growth to those of the treatment where coppice was retained (treatment CP). Treatment BL_0 had the smallest average height growth.

The amounts of biomass and nutrients accumulated in the different components of the stand (SC) are shown in Table 5. The biomass in the residue (leaves, branches, bark and litter), 38.9 t ha^{-1}, represents 28% of the total aboveground biomass. It contained 57%, 61%, 51%, 76% and 76% of N, P, K, Ca and Mg of the aboveground nutrient stocks, respectively. In the bark and litter more than 40% of the stock of those nutrients is present as well as of the micronutrients, Zn, Cu and Fe. These results show the importance of leaving residues on the soil after wood harvesting.

Table 4. Mean height growth of the trees at 6 and 15 months of age.

Treatment	Height (1)		Survival (1)	
	6 months	15 months	6 months	15 months
	(m)		(%)	
SL_b	3.4 b	7.5 a	2.0 a	3.6 a
CP	4.4 a	7.4 a	4.1 a	4.6 a
SL_p	2.9 c	6.1 b	0.5 a	2.6 a
BL_1	2.7 c	5.8 bc	0.0 a	1.0 a
BL_2	2.5 cd	5.5 c	2.6 a	2.6 a
BL_0	2.3 d	4.6 d	1.0 a	2.0 a

(1) Means within columns followed with the same letters are not significantly different using Tukey's test at P= 0.05.

Table 5. Biomass and nutrient content of the different components of *Eucalyptus grandis* stand 7 years old (SC).

Component	Biomass ($t\ ha^{-1}$)	N	P	K	Ca	Mg	S	Fe	Cu	Mn	Zn	Na
		($kg\ ha^{-1}$)										
Leaf	3.2	57.3	5.1	20.9	25.0	8.6	2.5	0.38	0.04	2.31	0.03	8.5
Branch	3.1	15.5	2.5	8.1	17.7	3.1	1.1	0.21	0.06	2.20	0.02	6.5
Bark	8.9	35.7	11.8	47.4	95.0	14.9	3.2	0.36	0.09	4.45	0.05	24.9
Wood	125.1	223.9	18.8	106.3	110.1	16.3	26.3	4.79	0.62	7.29	0.17	16.3
Root (>3mm)	20.6	75.2	2.7	28.2	21.0	6.4	3.1	4.22	0.14	1.17	0.12	7.9
Root (≤3mm)	3.6	22.4	1.2	1.0	11.9	3.1	-	-	-	-	-	-
Litter	23.7	187.2	9.5	35.5	208.6	23.7	-	-	-	-	-	-
TOTAL	188.2	617.2	51.6	247.4	489.3	76.1	36.2	9.96	0.95	17.42	0.39	64.1

Harvesting of wood would cause an export of about 224 kg ha^{-1} of N, 19 kg ha^{-1} of P, 106 kg ha^{-1} of K and 110 kg ha^{-1} of Ca. These quantities represent 43% of N, 39% of P, 49% of K and 24% of Ca contained in aboveground tree biomass.

Table 6 shows the nutrient content of the several tree components of treatments BL_0, BL_1, SL_p and SL_b at 13 months of age.

The total uptake of N, P, K, Ca and Mg varied, from approximately 46 to 62 kg ha^{-1}, 6 to 9 kg ha^{-1}, 49 to 70 kg ha^{-1}, 22 to 68 kg ha^{-1} and 8 to 14 kg ha^{-1}, respectively.

In general, the treatments SL_p and SL_b were superior to the other treatments in the uptake of N, Ca and Mg. These treatments were relatively equivalent to treatment BL_1 in the uptake of P and K (Table 6). The largest uptake of nutrients in the treatments SL_p and SL_b is associated

Table 6. Aboveground biomass and nutrient content of trees at 13 months of age.

Component / Treatment	Biomass ($t\ ha^{-1}$)	N	P	K	Ca	Mg
		($kg\ ha^{-1}$)				
Leaf						
BL_0	1.50 (0.39)	26.6 (7.0)	2.0 (0.4)	16.0 (1.2)	8.6 (3.1)	4.5 (2.4)
BL_1	1.48 (0.23)	25.0 (4.5)	2.6 (0.9)	18.9 (2.5)	10.9 (3.2)	5.5 (0.8)
SL_p	2.10 (0.28)	35.9 (7.3)	3.1 (0.6)	21.0 (2.0)	22.8 (8.7)	7.3 (2.6)
SL_b	1.78 (0.53)	34.5 (4.1)	3.1 (0.3)	19.3 (3.2)	14.2 (2.9)	5.7 (0.9)
Branch						
BL_0	1.89 (0.84)	7.0 (3.2)	1.1 (0.3)	7.7 (2.8)	6.3 (3.7)	1.5 (1.4)
BL_1	1.60 (0.19)	6.2 (0.9)	1.9 (0.6)	12.3 (1.7)	10.2 (2.4)	1.8 (0.4)
SL_p	2.45 (0.32)	6.5 (2.0)	1.3 (0.7)	12.8 (3.8)	25.3 (7.3)	2.8 (0.8)
SL_b	3.31 (0.52)	9.6 (3.9)	2.8 (1.1)	14.4 (3.5)	26.3 (8.1)	3.8 (2.2)
Bark						
BL_0	0.39 (0.16)	1.5 (0.7)	0.3 (0.2)	3.1 (1.1)	4.5 (2.7)	1.0 (0.8)
BL_1	0.59 (0.15)	2.1 (0.6)	0.3 (0.1)	4.0 (1.5)	10.1 (3.1)	1.6 (0.4)
SL_p	0.69 (0.09)	2.7 (0.2)	0.4 (0.1)	4.0 (0.5)	14.8 (3.2)	1.5 (0.1)
SL_b	0.88 (0.13)	3.3 (0.1)	0.5 (0.0)	5.9 (0.5)	13.0 (6.7)	2.4 (0.2)
Wood						
BL_0	4.75 (1.28)	10.4 (2.1)	2.3 (0.1)	22.5 (5.8)	2.9 (1.0)	1.4 (0.9)
BL_1	6.66 (1.10)	12.4 (0.6)	4.3 (1.6)	21.4 (1.6)	3.2 (0.3)	1.3 (0.2)
SL_p	7.18 (0.95)	14.2 (2.9)	4.1 (1.4)	31.9 (5.1)	5.0 (1.3)	2.4 (0.3)
SL_b	8.60 (1.01)	14.6 (0.7)	2.8 (0.3)	22.5 (6.1)	6.5 (4.0)	1.6 (0.7)
TOTAL						
BL_0	8.53	45.5	5.7	49.3	22.3	8.4
BL_1	10.33	45.7	9.1	56.6	34.4	10.2
SL_p	12.42	59.3	8.9	69.7	67.9	14.0
SL_b	14.57	62.0	9.2	62.1	60.0	13.5

Values in parentheses are standard error of mean.

with the highest growth rates observed in these treatments (Table 6), and with the largest supply of nutrients provided by the faster mineralisation of soil organic matter and residues deposited on the soil, through incorporation and/or burning, respectively.

Nutrient cycling

The annual rate of litter deposition in the intact stand was 7.7 t ha^{-1} (59% of leaves and 41% of branches). In the spring and winter the largest amount of litterfall was observed and the smallest amount in the autumn (Table 7). The annual deposition of nutrients through the fall were 42 kg ha^{-1} of N, 2.3 kg ha^{-1} of P, 20 kg ha^{-1} of K, 47 kg ha^{-1} of Ca and 14 kg ha^{-1} of Mg. Those values accounted for 10% of N, 6% of P, 10% of K, 17% of Ca and 27% of Mg accumulated in the trees (Table 7).

Table 8 compares mass and nutrient content of litter accumulated under an intact stand and 6 months later in the BL_2 stand which had not commenced litterfall by that time. The standing pool of litter dropped from 23.7 t ha^{-1} in treatment SC to 15.6 t ha^{-1} (treatment BL_2), a reduction of 8 t ha^{-1} or a decomposition rate of 34%. This also shows that the amount of residue on the soil would decrease quickly after the removal of the forest. This occurs because of the absence of litterfall and accelerated decomposition, aided by increased temperature of the residue. It was also found that the concentration of nutrients in litter did not change after 6 months of decomposition (Table 8). The loss in mass of litter indicates that 34% of the mass had decomposed. The estimated release of nutrients was 75 kg ha^{-1} of N, 5 kg ha^{-1} of P, 11 kg ha^{-1} of K, 73 kg ha^{-1} of Ca and 8 kg ha^{-1} of Mg, which is a significant amount that may be reabsorbed by the new crop. Data in Table 5, for a stand 7 years old, verify that the fraction of total nutrients (aboveground and belowground) accumulated in the litter is 30% for N, 18% for P, 14% for K, 43% for Ca and 31% for Mg.

The pattern of litter decomposition (and rate) is shown in Figure 3. The decomposition rates followed the exponential model proposed by Shanks and Olson (1961). For a period of 6 months, the litter decomposition rate estimated by the model was identical to that obtained by the measured data (Table 8). Using the model, it is estimated that 50% loss in weight would occur in 10 months and 80% loss would occur in 23 months. In other words, over 2 years, almost all litter is likely to have decomposed. However, the pattern and rate of decomposition of woody components of the slash are not yet established.

Table 7. Biomass and nutrient content of litterfall during different seasons (SC).

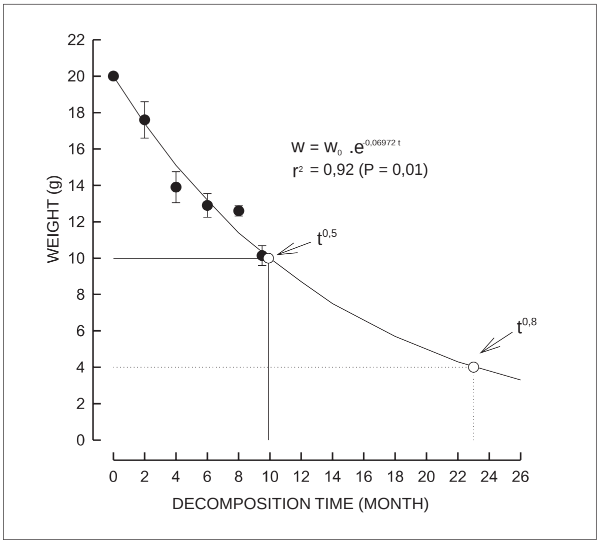
	Spring		Summer		Autumn		Winter	
	Leaf	Branch	Leaf	Branch	Leaf	Branch	Leaf	Branch
	(kg ha^{-1})							
Biomass	1437	1130	1075	812	797	431	1326	790
N	7.1	6.3	6.3	2.7	6.0	1.5	9.7	2.5
P	0.4	0.4	0.3	0.1	0.3	0.1	0.5	0.2
K	2.8	3.0	4.0	2.2	2.6	0.8	4.1	0.6
Ca	8.4	7.9	10.0	5.9	4.2	1.3	6.9	2.1
Mg	3.1	2.0	2.1	0.7	2.0	0.3	2.7	0.7

Table 8. Biomass, nutrient concentration and nutrient content in the accumulated litter of an eucalypt stand (SC) and 6 months after clearcutting of a stand (BL_2).

Treatment	Biomass	Nutrient concentration					Nutrient content				
		N	P	K	Ca	Mg	N	P	K	Ca	Mg
	(t ha^{-1})	(g kg^{-1})					(kg ha^{-1})				
SC	23.7 (1.8)	7.9	0.4	1.5	8.8	1.0	187.20	9.48	35.55	208.56	23.70
BL_2	15.6 (1.9)	7.2	0.3	1.6	8.7	1.0	112.03	4.67	24.89	135.37	15.56

Values in parentheses are mean standard error.

Figure 3. Pattern and rate of decomposition of eucalypt leaves incubated in the field.



Conclusions

The large fluctuations in soil temperature and moisture content observed in the surface soil (2-5 cm depth) where the residues were burnt or removed were reduced when slash was retained on the soil surface. These effects would impact on biological activity of the soil.

Removal of slash litter had an adverse effect on tree growth 15 months after replanting. In general, slash and litter retention had a positive effect on growth. Slash burning stimulated growth, probably because of the release of a high concentration of nutrients in a short period.

The mass of residue (leaf, branch, bark and litter) was 38.9 t ha^{-1}, i.e. 24% of the total aboveground biomass. Those components contained 57%, 61%, 51%, 76% and 76% of N, P, K, Ca and Mg respectively of the aboveground nutrient stock. With the wood harvesting, 43% of N, 39% of P, 49% of K and 24% of Ca of the aboveground nutrient stock may be exported from the site.

The annual rate of litter deposition in the intact stand was 7.7 t ha^{-1} (59% of leaves and 41% of branches). Annually, 42 kg ha^{-1} of N, 2.3 kg ha^{-1} of P, 20 kg ha^{-1} of K, 47 kg ha^{-1} of Ca and 14 kg ha^{-1} of Mg were returned through litterfall. Those values represent 10% of N, 6% of P, 10% of K, 17% of Ca and 27% of Mg accumulated in the trees.

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References

Bremner, J.M. 1965 Organic nitrogen in soils. *In:* Bartholomew, W.V. and Clark, F.E. (eds.) Soil nitrogen. Agronomy 10: 93-149.

Jorge, L.A.C., Resende, P.C.S., Posadas Durand, A., Freitas Junior, E. and Crestana, S. 1993 Comparação de técnicas de análises de imagens digitais na determinação do comprimento de raízes. *In:* Resumos da X Reunião Brasileira de Manejo e Conservação do Solo e da Água, 314-315.

Raison, R.J., Connell, M.J. and Khanna, P.K. 1987 Methodology for studying fluxes of soil mineral-N *in situ*. Soil Biology and Biochemistry 19: 521-530.

Shanks, R.E. and Olson, J.S. 1961 First-year breakdown of leaf litter in southern Appalachian forests. Science 134: 194-195.

Smethurst, P.M. and Nambiar, E.K.S. 1990 Effects of slash and litter management on fluxes of nitrogen and tree growth in young *Pinus radiata* plantation. Canadian Journal Forest Research 20: 1500-1507.

2. *Eucalyptus* Plantations in the Equatorial Zone, on the Coastal Plains of the Congo

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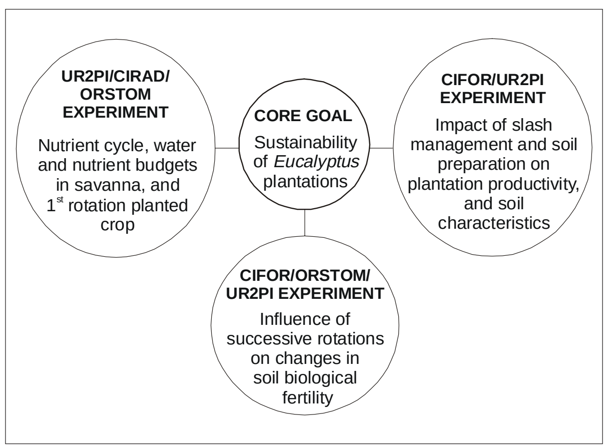
Summary
43 000 hectares of eucalyptus clonal plantations have been created around Pointe-Noire. Soils in the area are sandy and have limited nutrients, making them prone to degradation. Ensuring sustained productivity of these plantations without adverse impact on the soil is a research priority. Two trials of replanting and silviculture at the early stage of stand development are underway. Experiment 1 compares six kinds of treatments and their effects on the kind and amount of residue that remains after clear felling. Experiment 2 involves six blocks in which three litter treatments are crossed with three site preparation treatments. Accurate site and stand characterization prior to clear felling has been carried out for both experiments. The results of Experiment 1 are not yet available. Initial results in Experiment 2 at 11 months after planting show improved tree growth because of quicker release of nutrients into the soil when litter is burnt. Similarly, young trees respond better to subsoiling with three tines. However, in both cases these positive effects are no longer significant after 21 months.

Introduction

Since 1978, 43 000 ha of clonal plantations have been established in the Pointe-Noire region. These plantations, owned by ECO SA (Eucalyptus du Congo Société Anonyme), are based on two natural hybrids (*Eucalyptus PF1* and *E. tereticornis* × *E. grandis).* These hybrids are well suited to the conditions and, given weeding and fertilisation, they perform well (20-25 m^3 ha^{-1} yr^{-1}). The plantations consist of 18 000 ha of planted crops, 21 000 ha of coppice and 4000 ha of replanted sites.

However, little is known about sustainability of the management, i.e. long-term production and maintenance of the environment. The nutrient requirements of these plantations at various stages of development and the impact of intensive cropping on soil fertility are not known. This question is particularly relevant as the soils are sandy, acidic and have small reserves of available nutrients. The sustainability of the plantations has therefore been identified as a priority for research by UR2PI, an association created with the Congo, CIRAD, and ECO SA for research and development. Thus, complementary studies focusing on this goal have been conducted since 1997 (Fig. 1).

Figure 1. Representation of the coordinated research programme on plantation sustainability.



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One of the main tasks is to identify silvicultural practices and harvesting methods for sustainable management of the replanted sites. Plantations should systematically follow coppice, as well as planted crops, at the end of each rotation.

This silviculture must take into account the intra-stand heterogeneity. In logged areas, three types of inter-rows can be identified:

- slash inter-rows (with abundant litter) well stocked with leaves, bark, branches and twigs;
- log inter-rows (with a substantial amount of litter) used to store debarked wood; and
- haulage inter-rows (used by machines collecting the crop) contain a small amount of litter and have compacted soil as a result of the passage of heavy vehicles.

Studies in South Africa have shown that soil compaction resulting from the passage of heavy harvesting machines can have adverse consequences on soil structure (soil porosity) and greatly reduce soil water reserves. The soil compaction can have a marked impact on tree growth (Smith 1995, 1996; Ellis 1996).

On soils as poor as those around Pointe-Noire, it is imperative that litter is conserved throughout rotations to assist replenishment of available nutrients and soil organic matter (Trouvé *et al.* 1991, 1994; Bernhard-Reversat 1993, 1996; Martin *et al.* 1996). However, abundant litter and slash increase the fire risk and lead to the total destruction of young trees and to depletion of soil nutrients. In addition, the presence of slash is a real problem for site preparation (i.e. tillage, subsoiling). To overcome these difficulties, ECO SA sometimes uses controlled fires in areas which are to be replanted. The intensity and duration of fires affect their impact:

- they induce organic matter depletion which is damaging for nutrient reserves, soil physical properties and soil biological activity (Wells *et al.* 1979; Woodmansee and Wallach 1981; Trabaud 1991);
- they can lead to volatilisation of elements (particularly carbon and nitrogen); and
- they bare the soil surface, assisting the incorporation of ash in the soil and contributing to faster nutrient recycling, and thus 'starting' fertilisation (Monnier 1981; Gutelman 1989).

In order to improve plantation techniques, a trial was set up in 1995 to analyse the combined effects of litter management and soil preparation on *Eucalyptus* production and on soil physico-chemical properties. This trial is complementary to the CIFOR/UR2PI experiment.

Location and Site Description

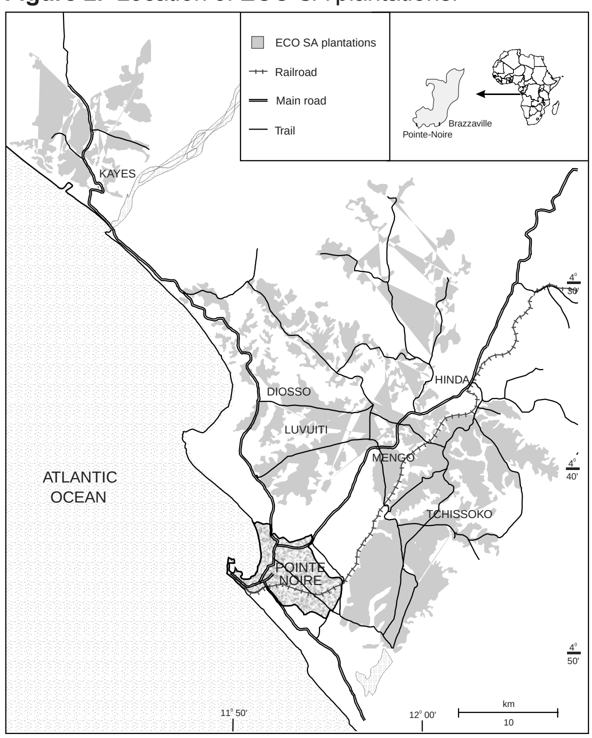
The main characteristics of the sites are given in Table 1.

Table 1. Main characteristics of the trial site.

Parameter	Value
Latitude	4°48'S
Longitude	11°54'E
Altitude	90-110 m
Mean annual precipitations	1200 mm
Mean annual temperature	25°C
Mean annual minimun temperature	22°C
Mean annual maximum temperature	27°C
Mean monthly potential evapotranspiration	93 mm
Mean relative humidity	85%
Annual sunshine	1500 h

The commercial *Eucalyptus* plantations of the Congo are set up on coastal plains around Pointe-Noire (Fig. 2). The relief is provided by hills and plateaux with an elevation varying between 40 and 180 m, separated by valleys.

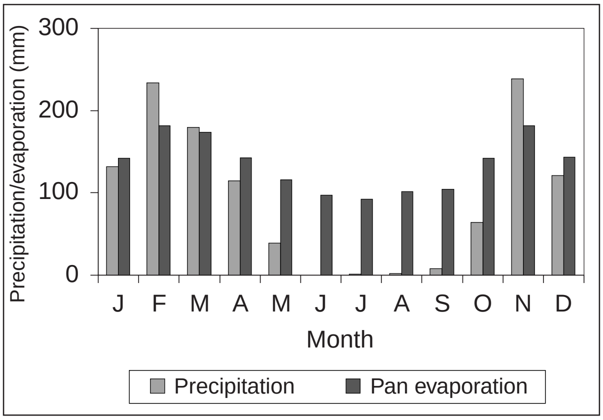
Figure 2. Location of ECO SA plantations.



CIRAD-Forêt juillet 1997.

The climate is sub-equatorial with a rainy season from October to May (90% of the annual precipitation) and a dry season from June to September (Fig. 3).

Figure 3. Seasonal variation in precipitation and evaporation at Pointe-Noire.



The native vegetation was savanna dominated by *Loudetia* sp. with scattered *Anona arenaria* shrubs. Rainforest covered the valleys and some hills but plantations were exclusively established on savanna.

Soil

The geological substrate is a thick sedimentary formation of continental origin of the Plio-Pleistocene period. This series is underlaid by a dolomitic sandstone clay series from the Cretaceous period, surmounted by a sandy to sandy-clay series of horizons varying between 80 and 300 m.

The soils are acrisol 3, characterised by homogeneous sandy to sandy-clay texture (the sand content is more than 90%), limited available nutrients, characterised by very low levels of exchangeable cations, organic matter and small cation exchange capacity and are highly erodible.

The properties of the soil on trial sites are consistent with these general characteristics (Tables 2 and 3). On the site of the Experiment 2 there is no significant difference between the different types of inter-rows.

Water Balance

Observations carried out between October 1996 and September 1997 are summarized in Table 4.

Table 2. Properties of soil at Experiment 1 site (Kondi).

Property		Soil horizon				
		A_{11}	A_{12}	B_1	B_2	B_2
Depth		0 - 5 cm	5 - 50 cm	50 - 70 cm	70 - 280 cm	280-600 cm
Color		Dark gray	Light gray	Yellow brown	Yellow	Ochre
Munsell Chart		10YR 3/3	10YR 3/6 to 4/6	7.5YR 4/6 to 10YR5/8	7.5YR 6/8 to 5/8	5YR 5/8
Texture		Sandy	Sandy	Sandy	Sandy	Sandy to sandy clay
Structure		Spheroidal granular	Spheroidal granular	Blocklike Subangular blocky	Blocklike Subangular blocky	Blocklike Subangular blocky
Porosity		Very porous	Porous	Porous	Slightly porous	Very slightly porous
Compacity		Light	Slight compact	Slight compact	Compact	Very compact
Clay (%)		7.9	6.6	9.9	10.6	11.4
Silt (%)		2.1	2.1	2.2	2.4	2.7
Sand (%)		90.0	91.3	87.9	87.0	85.9
pH H_2O		4.38	4.51	4.95	4.81	4.88
pH KCl		4.00	4.26	4.46	4.57	4.47
Total C (%)		0.85	0.47	0.23	0.1	0.05
Total N (%)		0.063	0.039	0.025	0.019	0.016
C/N		13.5	12.1	9.2	5.3	3.1
Exchange complex (cmolc kg^{-1} of soil)	Ca	0.07	0.02	0.01	0.01	0.01
	Mg	0.11	0.02	0.01	0.01	0.01
	K	0.03	0.01	0.01	0.01	0.01
	Na	0.03	0.02	0.01	0.01	0.02
	S	0.24	0.07	0.04	0.04	0.05
	CEC	3.73	2.12	1.60	1.10	1.11
S/T (%)		6.43	3.30	2.50	3.87	4.50

Table 3. Main initial soil characteristics at Experiment 2 site (Tchissoko). Mean values on the three inter-rows.

Level	pH		Total C	Total N	C/N	Exchangeable cations (cmolc kg^{-1} of soil)						S/CEC
(cm)	H_2O	KCl	(%)			Ca^{++}	Mg^{++}	K^+	Na^+	S	CEC	(%)
0-10	4.39	3.78	0.95	0.050	19	0.07	0.04	0.03	0.01	0.15	3.96	3.8
10-20	4.48	4.03	0.46	0.031	14.8	0.04	0.04	0.03	0.01	0.12	2.86	4.2

CEC: cation exchange capacity; S: Sum of base cations.

Table 4. Water balance observations at the trial site.

	Plantation Area	Adjacent Savanna
Throughfall[a]	90%	93%
Net interception[a]	10%	7%
For a gross precipitation (p = 360 mm)[a]		
Mean seasonal daily evapotranspiration[a]	4.68 mm	2.29 mm
Mean seasonal daily evapotranspiration[b]	1.24 mm	1.58 mm
Total seasonal evapotranspiration[a]	992 mm	634 mm
Total seasonal evapotranspiration[b]	158 mm	187 mm
Total annual evapotranspiration during its period of observation	1150 mm is equal to 97% of m.a.p 1950-1977	821 mm is equal to 69.7% of m.a.p 1950-1977

[a] during rainy season; [b] during dry season.
m.a.p: mean annual precipitation.

Stand characteristics of the area under plantation were as follows: a planted crop of *E. PF1*, clone 1-41, 5 years old, 532 stems ha^{-1}.

It should be noticed that 1996-1997 was a rain deficit period 459 mm. Mean annual precipitation between 1950-1997 was 1029 mm. In those conditions the soil water content in September 1997, at the end of the dry season was 15 mm less that that of September 1996.

Experimental design and layout

Experiment 1

Before planting the original savanna was burned, and two months later regrowth was treated with glyphosate. The soil was ripped along planting lines. The stand was planted in April 1990 at a spacing of 4.0 x 4.7 m (532 stems ha^{-1}). The planting material used was *E. PF1* clone 1-41, which is most extensively used in the plantations (on around 7000 ha).

Two hundred grams of NPK fertiliser (13-13-21) were applied near the base of each tree, two weeks after planting. Thus, the amount of fertiliser applied was 13.8 kg ha^{-1} of N, 13.8 kg ha^{-1} of P and 22.3 kg ha^{-1} of K. A further 200 kg ha^{-1} NPK (13-13-21) - 26.0 kg ha^{-1} of N, 26.0 kg ha^{-1} of P and 42.0 kg ha^{-1} of K - was applied after 3 years. The stand was periodically weeded using glyphosate. At harvesting in December 1997, the stand had a mean height of 26.1 m, a standing basal area of 12.9 m^2 ha^{-1} and a standing volume of 129 m^3 ha^{-1}. The stumps were weakened with a 40% glyphosate solution.

The plots were relatively clean except those in the second block which was strongly invaded by *Chromolaena odorata*. In total, we found 15 herbaceous and 8 woody species from 13 families; *Poaceae* (five species) and *Cyperaceae* (four species) were best represented. Herbaceous weeds have a height of less than 2 m, whereas the woody species can reach 4 m. The overall cover is small: 5 % on average.

Trial establishment lasted two months. Planting was done in March 1998. The spacing was of 2.7 m, on the previous rows, by 4.7 m (800 stems ha^{-1}). The *E. PF1* clone 1-41 was used again. One hundred and fifty grams of NPK (13-13-21) were applied at the bottom of each tree, two weeks after planting (15.6 kg ha^{-1} of N, 15.6 kg ha^{-1} of P and 25.2 kg ha^{-1} of K). No more fertiliser will be applied. Weeding will be carried out chemically using glyphosate.

Design and Layout

The experimental design is a complete randomised block design with four replications. Blocks 1 and 2 are in compartment T90-28 on flat land whereas blocks 3 and 4 are in adjacent compartment T90-29 on a slope of about 5%.

Unit plot has a gross area of 0.26 ha and an inner plot of 0.11 ha (88 trees) with two border rows (112 trees). In all treatments the inner plot includes the same number of slash inter-rows, log inter-rows and haulage inter-rows; respectively two, four and two for blocks 1 and 2, and two, four and one for blocks 3 and 4.

Treatments

BL_0 All aboveground organic residue including crop trees, any understorey and litter (leaves, decomposed or not, branches, bark, fine roots) is removed from the plot.

BL_1 Whole-tree harvest. All aboveground components of the commercial trees (diameter at breast height >11 cm) are removed. The rest of the vegetation is cut and spread on the ground except in one inter-row every four inter-rows (for vehicular traffic).

BL_2 Stemwood + bark harvested. Stand is felled and the tops and branches are cut and spread on the ground (cf BL_1). Only the commercial-sized boles (top-end over-bark diameter >2 cm) and associated bark is removed. All other organic residue is left undisturbed.

BL_3 Double slash. All the trees are logged as in the BL_2 treatment. The residue of the treatment and these from BL_1 are distributed on the ground (cf BL_1).

BL_4 Stemwood harvested. Stand is felled and the tops and branches are cut and spread on the ground (cf BL_1). Only the commercial-sized boles (top-end over-bark diameter >2 cm), de-barked, are removed. All other organic residue is left undisturbed. This treatment corresponds to one of the two ECO SA site management practices.

BL_5 BL_4 + burning of organic residue. This treatment corresponds to the second ECO SA site management practice.

Measurements

Litter

Samples of litter were taken within a frame 50 cm square. For each inter-row type, two inter-rows and two sites in each inter-row were randomly selected. In each of these twelve sampling sites, five points have been chosen in a square delimited by four trees: a sample was taken between two trees on the four sides and a fifth sample was taken from the centre of the square. A total of 600 samples of litter were taken from the trial. Each sample was oven-dried and weighed individually before pooling for chemical analysis (120 pooled samples in total). The analytical determinations concerned the major nutrients N, P, K, Ca and Mg. Samples were calcined and the ash dissolved in HCl; N was determined by the Kjeldhal procedure, P by colorimetry and K, Ca and Mg by atomic absorption spectrophotometry.

Litter decomposition will be assessed as follows: nets (50 cm square) will be put over the original litter to prevent the input of new material, for each treatment of block 1 and 3. For each inter-row type, two inter-rows and two sites in each inter-row will be randomly chosen. For each of these twelve sites, six locations will be retained on each sampling occasion, corresponding to a bi-monthly sampling during a year.

Litterfall will be collected monthly in BL_0, BL_3 and BL_4 using traps 50 cm square. For each of these treatments and each of the blocks 1 and 3, ten litter traps will be randomly placed within rows and inter-rows: six pooled samples will therefore be made up.

Soils

Soil samples were taken at the site of litter sampling at the following depths: 0-10 cm, 10-20 cm, 20-50 cm, 50-70 cm and 70-100 cm. The five samples of each level were mixed to provide a pooled sample (600 soil samples in total).The sampling depths were chosen after a pedological examination. Analyses were carried out on the pH water and KCl solution (at a ratio of 2:5), exchangeable cations and cation exchange capacity (method of ammonium acetate at pH 7), organic matter (total carbon measured by the Walkey and Black method, and total nitrogen by the Kjeldjahl method), total phosphorus (digestion by perchloric acid and colorimetric measurement) and particle size using the Robinson pipette method. Samples will be taken again at the same places at ages 1, 3 and 7 years.

Nitrogen mineralisation will be quantified by *in situ* measurements during the first year for BL_0, BL_3, BL_4 and BL_5 (method of Raison *et al.* 1987).

Biomass and nutrient content

Aerial biomass and nutrient content of the trees was quantified before the establishment of the trial. Twelve trees were sampled in different basal area classes (two trees in each class). Regression equations relating biomass and nutrient content of each tree component to the girth at breast height were developed using the model:

$Y = a + b\,C_{1.30m}$, or

$Y = a + b\,C_{1.30m}^3$ or

$Y = a + b\,C_{1.30m}^4$

where Y is the biomass or the nutrient content of the tree component and $C_{1.30m}$ the girth at breast height.

The regressions were weighted by $1/C_{1.30m}^2$, in order to satisfy the hypothesis of the homoscedasticity of the residues (SAS Institute 1988). These equations were then applied to the inventory of the stand to evaluate the biomass and nutrient content for each compartment on a per-hectare basis.

Nutrient content of the stands will be assessed by sampling 12 trees from BL_0, BL_3 and BL_4 at age 1, 3 and 7 years. The trees will be taken from the buffer zones. These values and those of the nutrient content in litterfall will permit an assessment of the tree nutrient uptake.

Tree growth

Trees of the inner plot will be measured for height and girth every three months during the first year, every six months the second year and then every year, up to age 7, the time of clearfelling.

Experiment 2

The stand was originally planted with *E. PF1* clone 1-60 in October 1981. The whole area was ploughed with a disc harrow and then ripped along each planting row. Tree spacing was 4.0 x 6.0 m (417 stems ha^{-1}). One hundred grams of NPK (13-13-21) were applied in the planting hole (5.4 kg ha^{-1} of N, 5.4 kg ha^{-1} of P and 8.8 kg ha^{-1} of K). Weeding was carried out mechanically with a disc harrow between the rows and manually in the rows. Five passes were necessary during the first three years. The first harvest was in August 1988. During the second rotation, weeding was carried out mechanically. No fertiliser was applied. The second harvest was in November 1994. At the end of this first coppice rotation, the low yield (10 m^3 ha^{-1} yr^{-1}) dictated that the plot had to be replanted. The stumps were weakened with a 10% triclopyr (Garlon®) solution.

After logging (March 1995) the establishment of the trial took 6 months. In April 1995 the herbaceous stratum was treated with glyphosate. In July and August 1995 the treatments including burning, ploughing with a disc harrow or ripping were set up. Planting was done in October 1995 at a density of 800 stems ha^{-1}.

The blocks were monoclonal, like the stands in commercial plantations. Two clones of *E. PF1* (1-87 and 1-131), three clones of *E. tereticornis* × *grandis* (2-6, 2-45 and L2-123) and one clone of *E. urophylla* × *grandis* (18-52) were used.

Design and Layout

The experimental design is a criss-cross of six blocks where three litter treatments are crossed with three site preparation treatments. The gross experimental unit is 0.42 ha and the inner plot 0.13 ha with four border rows.

Treatments

The litter treatments are:

C undisturbed litter
D litter lightly buried with a disc harrow
B controlled burning of the litter

The treatments for soil preparation are:

NS no subsoiling
1T subsoiling using one tine
3T subsoiling using 3 tines

For 1T the line of subsoiling passes along the new planting row which is 1.25 m from the previous planting line. For 3T the subsoiling is at the middle of the old 6 m inter-row; no tine passes on the new planting row. Only the area surrounded by the trees is broken down. The depth of the subsoiling is 30-40 cm using 1 tine and 40-60 cm using 3 tines.

Measurements

To reduce the cost of analyses, the study dealt only with the NS treatments (3 plots per block).

The litter samples were taken within a frame 50 cm square. For each type of inter-row and each treatment, four sampling points were randomly selected. Each sample was dried and weighed individually before being mixed together for chemical analysis (54 pooled samples in total).

At the same places, soil samples were taken using a cylinder (10 cm height and about 300 cm^3 in volume) from 0-10 cm and 10-20 cm soil depth. The four samples were then mixed to provide a representative sample (54 pooled samples for each level). Thirty-six other soil samples were taken following the same principle for the treatment NS x B, immediately after burning. Samples were again taken one year after planting in order to characterise the impact of different treatments on soil fertility. Soil samples will be taken again at ages 3 and 7 to characterise the dynamics of the impact of different treatments on soil fertility.

The litter and soil were analysed as for Experiment 1.

In order to follow the dynamics of tree growth, height and girth were measured at 3, 6, 11, 21 and 29 months. The same variables will be measured every year from age 3 to 7 years.

Results

Experiment 1

Biomass and Nutrient Content

Aboveground biomass and nutrient content of the trees are given in Table 5. They are significantly different

Table 5. Biomass and nutrient content of the aboveground components of the initial trees (Experiment 1) at clearfelling (8 years old).

Compartments	Biomass	Nutrient content (kg ha^{-1})				
	(t ha^{-1})	N	P	K	Ca	Mg
Wood (diameter >2 cm o.b.)	96.33	158.2	22.2	57.1	27.7	16.5
Bark (diameter > 2 cm o.b.)	5.92	31.0	10.9	23.1	25.7	16.4
Leaves	2.64	65.1	4.3	14.6	7.4	6.0
Living branches + top stem	9.36	39.5	7.4	15.9	7.9	5.8
Died branches	3.41	22.1	3.1	8.1	5.0	3.1
Total stand	117.66	315.8	47.8	118.7	73.7	47.8

between compartment T90-28 (blocks 1 and 2) and compartment T90-29 (blocks 3 and 4): the quantities are greater in the first compartment. The average biomass of the initial stand is about 118 t ha^{-1}; in this stand we can notice high levels of nitrogen (316 kg ha^{-1}) and potassium (119 kg ha^{-1}), whereas Laclau (1997) has obtained in another compartment and for the same clone 1-41 amounts of 203 kg ha^{-1} N and 70 kg ha^{-1} P. This phenomenon could be linked to luxury consumption of these nutrients after re-fertilisation, three years after planting.

Experiment 2

Soil and Litter Characteristics

Initially soil characteristics were improved by the treatments in which litter was burnt, except for a small decrease in organic matter and nitrogen content (Table 6).

Five months after the coppice harvesting, there were significant differences between the amount of litter observed on the *slash inter-rows* (20 t ha^{-1}) and the *haulage inter-rows* (barely 10 t ha^{-1}). With about 15 t ha^{-1} litter the *log inter-rows* were not significantly different from the two other types of row. The organic layer was poor in phosphorus (8 kg ha^{-1}), potassium (6 kg ha^{-1}) and magnesium (14 kg ha^{-1}) whereas nitrogen (123 kg ha^{-1}) and calcium (49 kg ha^{-1}) were relatively abundant.

The nutrients released by litter decomposition would be the source of an increase, one year after planting, of mineral and organic content of soils in all treatments except those including litter burning, for which the values remain relatively stable. These changes are evident only in the upper layer (0-10 cm), the deeper level exhibiting no change (Table 7).

Table 6. Soil characteristics before burning (BB) and after burning (AB). Experiment 2.

Level	pH		Total C	Total N	C/N	Exchangeable cations (cmolc kg^{-1} of soil)						S/CEC
(cm)	H_2O	KCl	(%)			Ca^{++}	Mg^{++}	K^+	Na^+	S	CEC	(%)
0-10 (BB)	4.39	3.78	0.95	0.050	19	0.07	0.04	0.03	0.01	0.15	3.96	3.8
0-10 (AB)	4.59	4.12	0.91	0.045	20	0.11	0.10	0.09	0.01	0.31	3.77	8.2
10-20 (BB)	4.48	4.03	0.46	0.031	14.8	0.04	0.04	0.03	0.01	0.12	2.86	4.2
10-20 (AB)	4.50	4.10	0.45	0.031	14.5	0.02	0.03	0.05	0.01	0.11	2.54	4.3

CEC: cation exchange capacity; S: Sum of base cations.

Table 7. Soil characteristics of the litter treatments (0-10 cm) one year after replanting. Experiment 2.

Treatment ⇩	PH		Total C	Total N	C/N	Exchangeable cations (cmolc kg^{-1} of soil)						S/CEC
	H_2O	KCl	(%)			Ca^{++}	Mg^{++}	K^+	Na^+	S	CEC	(%)
B	4.44	3.87	0.94	0.052	18	0.17	0.14	0.03	0.02	0.36	3.64	9.9
D	4.35	3.70	1.16	0.058	20	0.14	0.15	0.03	0.02	0.34	4.03	8.4
C	4.36	3.67	1.45	0.066	22	0.16	0.17	0.04	0.01	0.38	4.21	9.0

B: Litter burning; D: Litter buried; C: Litter conserved intact; S: Sum of base cations; CEC: cation exchange capacity.

Tree Growth

Litter treatments

Litter burning induced better tree growth during the first year (Table 8), but this effect disappeared during the second year when differences between treatments are no longer significant.

Soil preparation treatments

Significant differences between 3T and no subsoiling existed at 11 months, but not at 21 months (Table 9).

Combined treatments

At 21 months the best growth was still observed when litter burning was combined with 3T (Table 10).

Table 10. Mean height and circumference at breast height of combined treatments. Experiment 2; values at 21 months.

Treatment	Height (m)	Circumference $_{1.30m}$ (cm)
Litter burning/3 tines	10.2	26.3
Disc harrow/ no subsoiling	10.1	25.7
Litter burning/1 tine	10.1	25.8
No burning/3 tines	10.1	25.9
Disc harrow/3 tines	10.0	25.8
Disc harrow/1 tine	9.9	25.1
No burning/1 tine	9.8	25.1
Litter burning/ no subsoiling	9.8	25.1
No burning/ no subsoiling	9.6	24.7

Table 8. Mean height and circumference at breast height of the litter treatments. Experiment 2; values at 11 and 21 months.

	11 months			21 months		
Treatment ⇨	B	D	C	B	D	C
Height (m)	6.42	6.14	5.81	10.01	10.00	9.79
	a	*ab*	*b*			
Circumference $_{1.30\,m}$ (cm)	17.93	16.82	15.78	25.18	25.14	24.64
	a	*ab*	*b*			

B: Litter burning; D: Litter buried; C: Litter conserved intact.
Different letters are used when significant differences appear at 5% threshold.

Table 9. Mean height and circumference at breast height in the site preparation treatments. Experiment 2; values at 11 and 21 months.

	11 months			21 months		
Treatment ⇨	3T	1T	NS	3T	1T	NS
Height (m)	6.40	6.07	5.89	10.08	9.90	9.83
	a	*b*	*b*			
Circumference $_{1.30\,m}$ (cm)	17.63	16.60	16.30	25.41	24.84	24.72
	a	*b*	*b*			

3T: Subsoiling using three tines; 1T: Subsoiling using one tine; NS: No subsoiling.
Different letters are used when significant differences appear at 5% threshold.

Discussion

Burning Effects

The quicker release of nutrients induced by controlled burning of litter initially speeds up tree growth, but this effect is very brief since after 21 months differences between litter treatments are no longer significant.

Soil Decompaction

A positive effect of 3T is still noticed at 21 months, but it is no longer significant. Further study of soil compaction is necessary to clarify the actual effect of this factor.

Conclusion

For Experiment 1, few results are available yet. In Experiment 2, the role of slash treatment and soil preparation is emerging. These results are already very interesting for the management of replanted sites.

More generally the CIFOR experiment will give relevant information which will be included in the general study of sustainability of the plantations, carried out by UR2PI. By the year 2000, commercial plantation managers will have an objective basis for the choice of technical treatment of the plantation, including site preparation, fertiliser or lime application, and use of cover crops.

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References

Bernhard-Reversat, F. 1993 Dynamics of litter and organic matter at the soil-litter interface in fast-growing tree plantations on sandy ferrallitic soils (Congo). Acta-Oecologica 14: 179-195.

Bernhard-Reversat, F. 1996 Nitrogen cycling in tree plantations grown on a poor sandy savanna soil in Congo. Applied Soil Ecology 4: 161-172.

Bishop, K. and Dambrine, E. 1995 Localization of tree water uptake in Scots pine and Norway spruce with hydrological markers. Canadian Journal of Forest Research 25: 286-297.

Ellis, F. 1996 Soil properties that restrict plant growth and root development: part 2. Wood SA/Timber Times 21(7): 6-7.

Ezzaom, A. 1997 Intérêt de la mesure du flux d'éléments issu de l'altération des minéraux des sols dans le calcul des bilans minéraux d'un écosystème forestier. Le cas des plantations de Douglas dans le Beaujolais. Thèse de Doctorat, Université Henri-Poincaré-Nancy I, 198 p.

Fichter, J., Dambrine, E., Turpault, M.P. and Ranger, J. 1998 Base cation supply in spruce and beech ecosystems of the Strengbach catchment (Vosges Mountains, N-E France). Water, Air, and Soil Pollution 104: 125-148.

Gutelman, M. 1989 L'agriculture itinérante sur brûlis. La Recherche 216: 1464-1474.

Laclau, J.P. 1997 Dynamique d'incorporation des éléments minéraux majeurs (N, P, K, Ca, Mg) dans une futaie d'*Eucalyptus* au Congo. Mémoire de Diplôme d'Études Approfondies (DEA), Institut National Agronomique Paris-Grignon, CIRAD-Forêt, 30 p.

Martin, A., Gallardo, J.F. and Santa Regina, I. 1996 Aboveground litter production and bioelement potential return in an evergreen oak (*Quercus rotundifolia*) woodland near Salamanca (Spain). Annales des Sciences Forestières 53: 811-818.

Monnier, Y. 1981 La poussière et la cendre. Paysages, dynamiques de formations végétales et stratégies des sociétés en Afrique de l'Ouest. ACCT, Paris, 250 p.

Raison, R.J., Connell, M.J. and Khanna, P.K. 1987 Methodology for studying fluxes of soil mineral-N in situ. Soil Biology and Biochemistry 19: 521-530.

Ranger, J. 1995 Le cycle biogéochimique des éléments nutritifs dans les écosystèmes forestiers. INRA, 108 p.

Ranger, J. and Bonneau, M. 1984 Effets prévisibles de l'intensification de la production et des récoltes sur la fertilité des sols de forêt. Le cycle biologique en forêt. Revue Forestière Francaise XXXVI: 93-112.

SAS Institute. 1988 SAS/STAT user's guide. Release 6.03 edition. SAS Institute Inc., Cary, NC, 1028 p.

Smith, C.W. 1995 Soil compaction. ICFR Annual Research Report 1995. 70-105.

Smith, C.W. 1996 Soil compaction. ICFR Annual Research Report 1996. 43-48.

Sverdrup, H. and Warvfinge, P. 1993 Calculating field weathering rates using a mechanistic geochemical model PROFILE. Applied Geochemistry 8: 273-283.

Trabaud, L. 1991 Le feu est-il un facteur de changement pour les systèmes écologiques du bassin méditerranéen. Sécheresse 3(2): 163-174.

Trouvé, C., Mariotti, A., Schwartz, D. and Guillet, B. 1991 Étude par traçage naturel en ^{13}C de la dynamique du renouvellement des matières organiques des sols de savane après plantation de pins et d'*Eucalyptus* au Congo. Cahiers ORSTOM, série Pédologie, 26(4): 357-364.

Trouvé, C., Mariotti, A., Schwartz, D. and Guillet, B. 1994. Soil organic carbon dynamics under *Eucalyptus* and *Pinus* planted on savanna in the Congo. Soil Biology and Biochemistry 26: 287-295.

Wells, C.G., Campbell, R.E., De Bano, L.F., Lewis, C.E., Fredriksen, R.L., Franklin, E.C., Froelich, R.C. and Dunn, P.H. 1979 Effects of fire on soil. USDA Forest Service, General Technical Report WO-7, 34 p.

Woodmansee, R.G. and Wallach, L.S. 1981 Effects of fire regimes on biogeochemical cycles. Ecological Bulletin 33: 649-669.

3. Eucalypt and Pine Plantations in South Africa

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Abstract

This document describes some of the key constraints on productivity of plantation forests in the southern African context. The remainder is devoted to an experimental plan and a series of trials that had been proposed in 1998, to be carried out in collaboration with the CIFOR network project on 'Site Management and Productivity in Tropical Plantations'. The principal focus of the trials is on nutrient cycling processes in young stands and how these are affected by various intensive silvicultural operations such as harvesting, fertilisation and slash management. Three potential trial sites are described in terms of location, physiographic, edaphic and climatic features. A detailed experimental plan is given for the first trial to be established (located in the Midlands in the Province of KwaZulu-Natal in South Africa). The plan covers details of the treatments to be imposed and proposed methods for implementation, and relevant measurements.

Background

In South Africa plantation forestry is based predominantly on short- to medium-rotation crops which are intensively managed. Central and North American pines are the major softwoods grown commercially in South Africa (*Pinus patula, P. taeda, P. elliottii* and *P. radiata*). The first three species are planted in the summer rainfall zone and their average productivity is 15 m^3 ha^{-1} yr^{-1}. Hardwood production is dominated by eucalypts (mainly *E. grandis* and its hybrids), although *Acacia mearnsii* is also planted as a dual-purpose crop (for timber as well as for extracts from the bark). The average productivity of eucalypt stands is 21 m^3 ha^{-1} yr^{-1} (range 15-55 m^3 ha^{-1} yr^{-1}), and that of *A. mearnsii* is 12 m^3 ha^{-1} yr^{-1}. The major plantation forestry areas are located in the summer rainfall region of the country. Middle- to high-altitude sites are dominated by highly weathered acrisols and ferralsols derived primarily from granite, shale, dolerite and sandstone. The subtropical coastal area of KwaZulu-Natal (KZN) consists almost entirely of arenosols derived from recent aeolian sands. Most silvicultural inputs are made at the time of establishment of the first or subsequent crops. Several silvicultural practices, notably site preparation, fertilisation, vegetation management and plantation residue management have been tested to varying degrees in applied experiments over the last half century at the Institute for Commercial Forestry Research (ICFR) and in other institutions in southern Africa. Although current silvicultural practice is based on results from these trials, the key processes involved in maximising nutrient and water supply to plantation crops are not fully understood. Consequently, the formulation of robust yet site-specific recommendations regarding silvicultural regimes is difficult at this stage. Furthermore, long-term impacts of some silvicultural practices cannot be predicted with confidence.

Constraints on Productivity in Southern African Plantations that are Directly or Indirectly Linked to Forest Nutrition

Effect of Site Factors on the Supply of Nutrients and Water to Stands

Several water balance models have been developed in South Africa (Roberts 1994; Schulze 1995) and it could be said that the soil moisture supply, as affected by climatic and soil (site) factors, is relatively well understood. Tree water use is reasonably well understood, yet uncertainties remain regarding the patterns of tree water use under increasing water stress. A modest start has been made to understand the effect of site and climatic factors on the nutrient supply potential to tree crops, but generally

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speaking there is a lack of field data regarding nutrient supply processes in southern African forestry. Too many published results rely heavily on results obtained under agricultural conditions or revert to speculation with regard to nutrient supply processes. This restricts the formulation of fertiliser and other silvicultural recommendations to a coarse, broad scale with resulting losses in productivity. The basic nutrient supply processes need to be studied and understood in the forestry context across a range of sites on the subcontinent.

Effects of Intensive Silvicultural Operations on Nutrient Supply in Plantations

The nutrient and water dynamics of younger versus older stands are considered separately for the following reason: it is hypothesised that the opportunity to optimise productivity on water-limited sites (other than by irrigation which is not a broad-scale option in a water-scarce country) lies with intensive, early silviculture, i.e. to shorten the time period to obtain full site capture by trees, at which stage the soil water supply becomes limiting. There is increasing evidence from Brazil to support this statement, e.g. data of Bellote *et al.* (1980) and Reis *et al.* (1987); both cited in Gonçalves *et al.* (1997). Sites that are not limited by water supply can benefit from early intensive silviculture, but they benefit most from improved nutrition later in the rotation (Gonçalves *et al.* 1997). The majority of sites in South Africa fall in the water-limited category. The study described in this document will focus on young stands.

The nutrient supply and, to a lesser degree, water availability to trees can be modified significantly through specific combinations of silvicultural operations, e.g. soil tillage, fertilisation and harvesting processes, as well as slash and vegetation management operations. These operations are interlinked and changes in one operation, e.g. degree of soil cultivation, may significantly alter the optimal recommendation for another operation, e.g. fertilisation at planting (Herbert 1996). Little *et al.* (1996) showed that the management of plantation residue (including slash burning practices) has a pronounced effect on the weed species composition and the development of the weedy biomass, as well as moisture and temperature levels in the topsoil, resulting in varying levels of competition with tree crops. It appears that topsoil disturbance (as caused by harvesting operations) may have an effect on the rate of nutrient mineralisation (Smith and du Toit 1998). It is clear that changes in nutrient supply processes will take place when harvesting, slash and vegetation management practices are altered. The first and most practical step to compensate for such changes is to modify the nutrient content and composition of fertiliser mixtures. However, optimum productivity can be realised through the integration of several silvicultural options that would ensure optimum (sustainable) levels of nutrient supply. A thorough understanding of the modifying effect of silvicultural operations on nutrient supply processes is a prerequisite to extrapolate such results. Considerable variation in rainfall and temperature (both in space and time) occurs on the eastern seaboard of South Africa, resulting in large variations in available soil water. Responses to silvicultural treatments need to be understood in the context of the climatic conditions (and hence soil water status) prevailing at the time.

Diagnosis and Treatment of Micronutrient Deficiencies

Micronutrient nutrition has not received much attention in South Africa to date. Few deficiencies have been recorded (Lange 1969; Schönau 1981), most of which were localised in extent. The expansion of plantation forestry to previously unplanted areas has brought about an increase in micronutrient deficiencies. This problem is not included in the scope of this proposed study.

Objectives

The study described in this paper focuses on the effect of intensive silviculture on nutrient supply to young stands.

Primary Objectives

1. In the short term, to understand and quantify the following processes across a range of silvicultural management options (harvesting, slash management and fertilisation):
   - Variations in the rate of macronutrient release through decomposition of litter and harvesting residues.
   - Variations in N and P supplying capacity of the soil.
   - Variations in the rate of nutrient uptake by trees.

   In the longer term we also intend to study the effect of treatments on nutrient cycling including litterfall.
2. A considerable amount of variation in the abovementioned processes is expected to be attributable to soil water availability and micro-climatic effects. These mechanisms will be studied in detail to improve the reliability of extrapolation to other sites.

3. To understand and quantify changes in the nutrient capital of the site as brought about by the silvicultural operations mentioned above in the medium to long term (over several crop cycles), so as to model the effects on nutritional sustainability.

Secondary Objectives

Self-contained experiments, using smaller plots and aimed at the formulation of recommendations pertaining to one silvicultural operation at a time, will be established in the same compartment (see treatment structure at KZN Midlands trial). This creates the opportunity to also monitor some of the processes in these additional treatments so as to (a) place the variation obtained from the core treatments in context, and (b) provide an appropriate estimate for such processes in other systems for which no data are available.

Description of Trials and Site Selection

Forestry plantation areas in South Africa are marked by striking variations in soil and climatic conditions. In addition, several species are commercially planted, as most species are fairly site-specific. Three trial sites are proposed (Table 1) that would be fairly representative of the major site types and tree species in the forestry areas described in the introduction.

Table 1. Details of sites proposed for the CIFOR network project.

Variable	Trial No. 1	Trial No. 2	Trial No. 3
Region	KwaZulu-Natal Midlands	KwaZulu-Natal Coastal plain	Mpumalanga escarpment
Species	*Eucalyptus grandis* improved seedlings	*Eucalyptus grandis* improved seedlings	*Pinus patula* improved seedlings
Latitude	29^o south	*ca.* 28^o south	*ca.* 25^o south
Longitude	30^o east	*ca.* 32^o east	*ca.* 31^o east
Altitude (m asl)	1260	*ca.* 1200	*ca.* 50
Mean annual rainfall (mm)	940	*ca.* 1200	*ca.* 1200
Mean annual temperature (^{o}C)	*ca.* 15.5	*ca.* 21	*ca.* 17
Geology	Shale	Recent aeolian sands	Granite or shale
Soil texture	Clays	Sands	Sandy clays or sandy clay loams
Soil organic C (%)	6-7 (high)	*ca.* 0.5 (very low)	*ca.* 3 (moderate)

Climatic data in Figures 1 and 2 were taken from a long-term meteorological station and they provide a general idea of the climate prevailing in the subregion of the KZN Midlands. Rainfall and temperature values listed for the actual study site have been estimated from several other data sources close to the site.

Figure 1. Mean monthly minimum, maximum and extreme minimum temperatures from the closest temperature recording station to the KZN Midlands site. (Mean values calculated from 83 years of data). The study site is expected to have slightly lower temperatures as it is situated at a higher altitude than this station (1260 m vs. 1076 m asl).

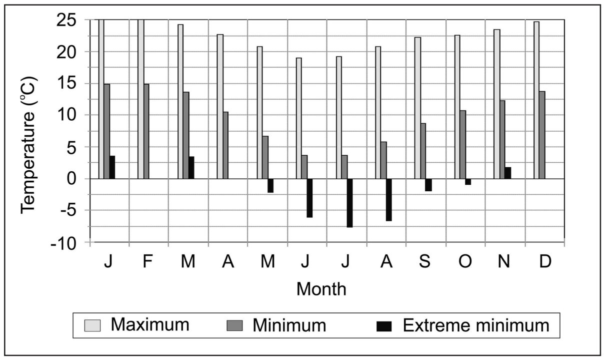
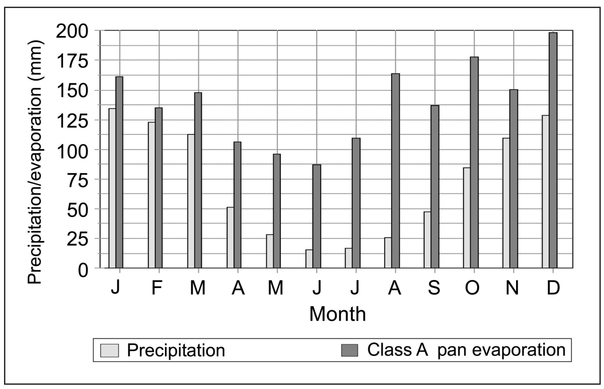


Figure 2. Mean monthly values for precipitation and Class A pan-evaporation near the KZN Midlands site.



The details on treatment structure and measurements pertain to the KZN Midlands trial site, due to be established in November 1998. The finer details of the Zululand and Mpumalanga trials will be finalised closer to the time of establishment. All trials will incorporate at least three of the four core treatments to facilitate comparison with other experiments internationally. The Zululand and Mpumalanga trials will also contain some of the optional treatments listed for the Midlands trial.

Treatment Structure (KZN Midlands trial)

Core treatments

BL_0	Stem, bark, harvesting residue and litter layer removed after clearfelling
BL_1	Conventional harvesting (CH) stemwood alone removed
BL_3	CH; litter, bark and harvesting residue from BL_0 added

Optional treatments

BL_{1+B}	CH; litter and harvesting residue burnt before re-establishment
BL_{1+F}	CH; trees fertilised at planting
BL_{1+D}	CH; topsoil disturbed though mechanical timber extraction
BL_{1+C}	CH; earmarked for base cation application (lime + gypsum) in 2nd rotation
BL_{1+X}	CH; Additional treatment for use in future rotations

Additional areas adjacent to trial

Additional treatment plots will be used to obtain benchmark measures of nutrient dynamics, soil water status, and where relevant, soil physical measurements. These treatments are not replicated unless otherwise specified.

SC	Mature standing crop
GR	Virgin grassland
CO	Compacted area
RO	Area where *Acacia mearnsii* crop will be rotated with *E. grandis* in the second rotation
WE	Replicated trial with various weed control intensities (using smaller plot sizes)

Methods Proposed for Implementing Treatments in the KZN Midlands Trial

Clearfelling of Existing Stand – all core and optional treatments

Harvesting in all treatment plots will be carried out by manually felling and debranching the trees with chainsaws. Stems will be cut into 24 m lengths and stacked manually at the access road and then transported in forwarders. Extraction routes (3 m wide) will be laid out 8 tree rows apart to avoid measurement plots. Trees in all treatments will be debarked on site. Where appropriate, slash will be broadcast on site.

Relocation of Litter and Harvesting Residue

Before clearfelling, the litter layer will be raked up manually in treatment BL_0 and redistributed on treatment BL_3. After clearfelling, trees will be debranched and debarked. Branches (with leaves attached), tree tops and bark will be removed from treatment BL_0 and redistributed on treatment BL_3 by hand.

Site Disturbance - treatment BL_{1+D}

This treatment is based on the considerable disturbance which takes place during commercial harvesting operations. Disturbance may include soil compaction, rutting, surface smearing and incorporation of trash and surface litter into the topsoil. This will be achieved by extracting short length timber from these plots and adjacent plots with 3-wheeled logger-bunchers. Comparing growth data together with nutrient and water fluxes of these treatments will provide an insight into the reasons for growth differences between treatments, thus contextualising responses in the core treatments to current harvesting practices on subtropical forestry soils (acrisols/ferralsols).

Compaction - additional treatment (Code CO)

In order to minimise disturbance within treatment plots, forwarding operations will take place on the edges of the measured (inner) plots. Vehicular traffic from the log extraction operation will be channelled into two corridors on the perimeter of the experiment. These corridors can be used as optional treatments of value to the CIFOR objectives as well as a harvesting impact project of the ICFR. This treatment would be a high-impact compaction rather than a site disturbance treatment.

Site Preparation for Planting - all core and optional treatments

Seedlings will be raised from improved *E. grandis* seed using a containerised nursery system. When planting, slash and litter will be cleared in a circle of radius 50 cm around the planting position to ensure proper quality planting and to facilitate subsequent weeding operations. A shallow pit will be prepared with a hoe, and seedlings will be planted with 2 l of water. A preventative pest control treatment will be applied across the entire trial to ensure that pest-induced mortality at establishment does not confound results (especially as slash loads will vary considerably across treatments). The entire trial will thus be treated with a drench application of deltamethrin at the recommended application rate of 0.025 g active ingredient per seedling.

Weed Control - all core and optional treatments

A full pre-plant cover spray with glyphosate at 4 l ha^{-1} will be applied to ensure that plots are free of competing vegetation at time of planting and to increase the time before the next weeding operation. Subsequent operations: manual ring weeding will be carried out on weed regrowth in the previously cleared circle around each tree. A cone-shaped tree guard will be placed over each tree to enable full cover spray with herbicide as above. Operations will be repeated as required until canopy closure.

Fertilisation - treatment BL_{1+F}

Several experiments on the highly weathered acrisols/ ferralsols of the middle and high-altitude soils in the summer rainfall area of South Africa have shown that eucalypts respond very strongly to fertilisation with N and P at time of planting. Trees will be fertilised with mono-ammonium phosphate (MAP; 11% N and 22% P) at a rate of 90 g per tree, resulting in the application of 10 g N and 20 g P per plant (17 kg N and 33 kg P per ha). A low basal dressing of micronutrients will be applied to avoid possible deficiencies. Fertiliser will be applied one week after planting and it will be localized rather than broadcast to prevent excessive P fixation. Fertiliser will be placed in two slots, approximately 15 cm from the planted seedling and covered lightly with soil.

Design and Layout

The existing stand was planted to a rectangular spacing of 2.44 x 2.44 m (1680 stems ha^{-1}). This spacing will be adhered to because it is in step with results obtained from spacing trials on optimum stand density. The total plot size will be 44 x 39 m (18 x 16 trees) and the inner (measured) plot size will consist of 19.5 x 14.6 m (8 x 6 trees). Total plot area = 1715 m^2, inner plot = 286 m^2.

The core and optional treatments (total of eight) will be randomised in each of four replications. Additional treatments will be located in nearby blocks to minimise shading and competition effects on the remainder of the treatments. Total trial size is approximately 8 ha, with 6 ha devoted to the core plus optional treatments.

Measurements Proposed for the KZN Midlands Trial

Biomass and Nutrient Pools in the Pre-Harvest Stand

All trees in the future measurement plots will be measured for diameter at breast height (DBH). Paired DBH and height measurements will be taken on selected trees. Height will be regressed on DBH so that the height of the remaining trees can be estimated. Standing basal area and volume will be calculated per plot for use as a covariate in analyses. The population will be stratified into six classes based on diameter. Six sample trees out of each class will be felled to determine aboveground biomass components. Diameter will be measured under bark at breast height as well as at 2.5 m intervals along the stem to determine stem taper. The understorey will be divided into morphologically similar classes of plants (woody weeds, tufted grasses, creeping grasses and annual herbs). Subsamples of all aboveground biomass components of trees, as well as weed classes and litter will be oven dried, weighed and analysed for nutrient content to determine nutrient pool sizes, using standard methods (Smith *et al.* 1986).

Belowground biomass. The possibility of estimating mass of tree stumps plus major roots will be investigated by regressing stump plus principal root mass against stem volume for a small number of sample trees outside the experiment (Miller *et al.* 1980). Fine root biomass and root length density will be estimated by core sampling (Vogt *et al.* 1981).

Stand Development and Nutrient Uptake

Diameter at ground level and height will be measured at monthly intervals for the first summer from a subsample of trees in all plots. Diameter at breast height will be measured as soon as trees are sufficiently tall. Measurement intensity will decrease to three monthly intervals after the first growing season.

The biomass and nutrient content of sample trees will be determined at 3, 6, 9, 12, 15, 18, 24 and 36 months and annually thereafter. Eight sample trees will be harvested from each treatment at each sampling (two trees per plot). They will be selected to represent the diameter distribution of the specific treatments. Trees harvested during the first year of growth will be separated by biomass components. From the second year onwards, the components will be separated and analysed as foliage, branches, stemwood and bark. Wet mass will be determined in the field. Subsamples will be oven dried, weighed and analysed for nutrient content. The biomass and root length density of fine roots in the topsoil horizon will be estimated using a core sampling technique at quarterly intervals.

Leaf area will be determined quarterly by scanning subsamples of leaves from six trees per treatment for the first six months. As soon as the canopy closes, leaf area (determined by scanning) will be replaced by light interception measurements that can be correlated to measured leaf area. The rate of litterfall will be monitored quarterly using two litter traps per plot as soon as leaf fall commences. Nutrient content of the litter will be assessed at each collection to quantify the flow of nutrients including translocation. Nutrient content of mature leaves will be collected and analysed on a quarterly basis (first as part of the destructive sampling procedure described above and later as a separate foliar sampling exercise).

Forest Floor, Decomposition and Mineralisation Rates

The size of the nutrient pool in the forest floor will be determined before clearfelling of the pre-harvest stand. Relocation or burning of plantation residue (BL_0, BL_1 and BL_{1+B}) ensures that the initial size of the litter layer will differ substantially between treatments. Litter plus harvesting residue load will be determined at the onset of the experiment for all treatments. Subsequent litter decomposition in selected treatments will be studied using a litter bag technique somewhat similar to that of O'Connell (1987). Bags of litter plus harvesting residue with a known mass will be placed in each monitored treatment (12 per plot). Two bags will be collected per plot at each of six collection events over a period of about 18 months. Bags will be weighed and the contents will be analysed for macronutrient contents. Soil N mineralisation rates will be estimated on a quarterly basis (Raison *et al.* 1987) for the first two years. Resin-available P will be measured with a similar frequency. Both of these measurements will be carried out in selected treatments only.

Soil Physical and Chemical Measurements

Soil physical and chemical properties will be surveyed on a 100 m grid across the site. Soil texture, the potential rate of N mineralisation and a range of total and labile nutrients will be determined at the outset. The following properties will then be monitored annually in the topsoil: soil organic carbon (total and labile fraction), total N and P, soil pH and exchangeable base cation fractions, 1M KCl extractable acidity and effective cation exchange capacity (sum of extractable acidity and exchangeable base cations).

Before harvesting, soil cores will be taken across the site to determine soil bulk density and the relationship between soil matric potential and water content (water retentivity curves). These measurements will enable comparison of changes in soil physical properties following treatment. At the same time penetrometer soil strength (PSS) will be measured across the whole trial. PSS will be measured again on the treatments receiving wheeled traffic after harvesting and on the same plots plus standing crop and a designated control (e.g. treatment BL_1) every three years.

After harvesting bulk density and water retentivity curves will again be measured on plots where soil water balance is being monitored. These will be used to establish changes that have taken place since harvesting and to enable interpretation of the soil water content measurements.

Soil Water Measurements

Soil water content will be measured on all core treatments using a neutron moisture meter (NMM) and within selected treatments using time domain reflectometry (TDR) sensors. Three NMM access tubes, replicated twice, will be installed within each treatment. TDR sensors will be placed at various depths within the soil profile in selected treatments only. NMM measurements will be taken on a weekly basis with TDR data being collected continuously every two hours during the wet season and daily in the winter months. Soil water data will be used in the interpretation of changes in soil processes (e.g. rate of N mineralisation) between treatments. Furthermore, with the use of appropriate soil water balance models (*cf* section on modelling) these data, together with rainfall and evapotranspiration, will be used to estimate the water balance within each treatment. Such information, with data on tree growth and tree water potential, will provide an insight into growth differences.

Climatic Data

An automatic weather station (AWS) has been erected relatively close to the trial to measure solar irradiance, air temperature, relative humidity, wind speed, wind direction and rainfall. These data will be used in the Penman-Montieth equation to calculate the reference evaporation (E_r), and so potential evaporation (PET). Actual evaporation (AET) will also be calculated using data from the AWS. Using the AET/PET ratio, *inter alia,* it is hoped to develop tree water stress indices as an aid in identifying soil water stress conditions.

In addition, a tipping bucket raingauge will be installed on site. By comparing the data to those collected at the AWS, a rainfall correction factor will be calculated. In selected treatments, air temperature and relative humidity will be monitored at ground level using data loggers while soil temperature will be recorded at various depths in the topsoil using thermocouples.

Modelling

Various simple water balance models will be tested to determine which will be most representative for the site. Information emanating from this trial could also be used to calibrate growth models such as 3PG (Landsberg and Waring 1997). It has been demonstrated that early intensive silviculture has a pronounced effect on stand productivity in short-rotation plantation forestry. This trial can provide basic information that could be used to more accurately model the effects of silvicultural operations of varying intensity on early growth.

Implementation of Treatments and Time Schedule

The first trial in the group of three (KZN Midlands) will be established during spring/summer 1998. Time schedule details pertain to this site only. Trials in Mpumalanga and coastal Zululand will commence during the period 1999 - 2001.

Time Schedule

June - October 1998	Installation of soil moisture probes, initial soil sampling and recording of biomass measurements before harvesting. Clear felling of current crop. Relocation of litter and harvesting residues.
November 1998	Burn selected plots. Establish new crop and fertilise
December 1998 and 1999	Period of very intensive measurement following establishment phase
October 1999	Implement weed control treatments in adjacent block
October 1999	Implement treatments and establish Mpumalanga trial
2001	Implement treatments and establish Zululand trial
ca. 2007	Harvest and re-establish the KZN Midlands trial for the second rotation. Additional fertilisation treatments (BL_{1+C}; BL_{1+X}) as well as the crop rotation treatment (CO) will now be activated.

References

Gonçalves, J.L.M., Barros, N.F., Nambiar, E.K.S. and Novais, R.F. 1997 Soil and stand management for short-rotation plantations. *In:* Nambiar, E.K.S. and Brown, A.G. (eds.) Management of soil, nutrients and water in tropical plantations. ACIAR Monograph No. 43, 379-417.

Herbert, M.A. 1996 Fertilizers and eucalypt plantations in South Africa. *In*: Attiwill, P.M. and Adams, M.A. (eds.) Nutrition of eucalypts. CSIRO, Melbourne, 303-325.

Landsberg, J.J. and Waring, R.H. 1997 A generalised model of forest productivity using simplified concepts of radiation-use efficiency, carbon balance and partitioning. Forest Ecology and Management 95: 209-228.

Lange, P.W. 1969 A manganese deficiency in *Pinus radiata* at Klein Gouna, Knysna. Forestry in South Africa 10: 47-61.

Little, K.M., Eccles, N., Oscroft, D., Viero, P. and Eastwood, T. 1996 Growth of eucalypts on slash managed and burned sites in Zululand. Institute for Commercial Forestry Research Bulletin 3/96. Scottsville, South Africa, 38 p.

Miller, H.G., Miller, J.D. and Cooper, J.M. 1980 Biomass and nutrient accumulation at different growth rates in thinned plantations of Corsican pine. Forestry 53: 23-39.

O'Connell, A.M. 1987 Litter dynamics in karri (*Eucalyptus diversicolor*) forests of south-western Australia. Jounal of Ecology 75: 781-796.

Raison, R.J., Connell, M.J. and Khanna, P.K. 1987 Methodology for studying fluxes of soil mineral-N *in situ*. Soil Biology and Biochemistry 19: 521-530.

Roberts, P.J.T. 1994 Stochastic silviculture - Part 2: A description of the conceptual structure of models WETNES, DEATH and TREGRO. Institute for Commercial Forestry Research Bulletin 4/94. Scottsville, South Africa, 17 p.

Schönau, A.P.G. 1981 The effects of fertilizing on the foliar nutrient concentrations in *Eucalyptus grandis*. Fertilizer Research 2: 73-87.

Schulze, R.E. 1995 Hydrology and agrohydrology: A text to accompany the *ACRU* 3.00 agrohydrological modelling system. Water Research Commission Report TT69/95. *ACRU* Report 43.

Smith, C.T., McCormack, M.L.(Jr), Hornbeck, J.W. and Martin, C.W. 1986 Nutrient and biomass removals from a red spruce - balsam fir whole-tree harvest. Canadian Journal of Forest Research 16: 381-388.

Smith, C.W. and du Toit, B. 1998. The combined effect of harvesting operations and fertilization on the growth of *E. grandis x camaldulensis* on a sandy Fernwood soil in Zululand: early results. *In:* ICFR Newsletter February 1998 (ed. L. MacLennan), Scottsville, South Africa, 15-19.

Vogt, K.A., Edmonds, R.L. and Grier, C.C. 1981 Seasonal changes in biomass and vertical distribution of mycorrhizal and fibrous-textured conifer fine roots in 23- and 180-year old subalpine *Abies amabilis* stands. Canadian Journal of Forest Research 11: 223-229.

4. Plantation of *Eucalyptus urophylla* S.T. Blake in Guangdong Province, China

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Abstract

The productivity of eucalypt plantations in southern China is low and may decline over successive rotations. This study focuses on the effects of harvest residue management, intercropping, fertilisation and regeneration on productivity of a second-rotation plantation of *Eucalyptus urophylla* S.T.Blake. The first rotation produced 44 t ha^{-1} of aboveground tree biomass in seven years. Of this, 87% was in the bark and stemwood removed at harvest. An additional 5.8 t ha^{-1} of biomass was in the understorey and litter. Retention of residue at the site (from 1.4 to 17.5 t ha^{-1}) increased tree height from 2.5 to 3.3 m at age 15 months. Applications of fertiliser increased the height at 15 months from 1.2 m (without fertiliser) to 4.1 m at the highest rate. Retaining litter alone without fertiliser had little effect on growth of planted trees. Fertiliser application to coppice trees also had little effect on growth.

Introduction

In southern China there are about 1 000 000 ha of eucalypt plantations, most of which have been established since the 1980s. Because centuries of past land uses have degraded the soils, productivity is very low (5-10 $m^3 ha^{-1}yr^{-1}$) and highly variable (3 to 30 $m^3 ha^{-1}yr^{-1}$) (Bai and Gan 1996). Meeting the strong demand for pulpwood in a rapidly expanding economy with current eucalypt plantations is a challenge. Both genetic improvement and fertiliser application are required to sustain or improve productivity. Genetic improvement will increase potential productivity, but actual productivity gains depend on sustainable or improved soil fertility as well. Usually, high-yielding species or clones need high soil fertility to prevent growth from stagnating in mid-rotation (at 3-4 years of age). Therefore, sustaining or improving soil fertility is essential to sustain or improve productivity of eucalypt plantations in southern China.

Without proper management, the productivity of eucalypt plantations may decrease over successive rotations because of soil degradation and nutrient imbalance (Xu 1997). Management activities may decrease plantation productivity if performed improperly, but can be modified to maintain or increase production (Folster and Khanna 1997). These include:

(1) Inappropriate site preparation which causes serious soil erosion. Appropriate site preparation and minimum disturbance of understorey and topsoil will reduce soil erosion in eucalypt plantations.

(2) Poor management of understorey, topsoil, surface litter and soil moisture during the rotation lowers soil organic matter. Harvesting all tree components (leaves, branches, stem, roots), litter and understorey as fuel at the end of the rotation depletes nutrients and lowers soil organic carbon (C) (Xu 1996). Retention of nutrients and organic C by proper management during and at the end of the rotation will increase organic matter in the topsoil and on the plantation floor, and improve soil properties and soil nutrient-supplying ability.

(3) Removal of biomass during harvest also removes nutrients from an already depleted soil. Application of the correct type and amount of fertilisers at proper times will increase productivity of eucalypt plantations as well as the quantity and quality of litterfall, which will be returned to the soil (Wang and Zhou 1996; Xu 1997).

The goal of this subproject is to develop options for site management that will sustain or improve productivity of eucalypt plantations over successive rotations. The objective is to better understand the relationship between site management practices and productivity of eucalypt plantations over succession rotations in southern China by studying:

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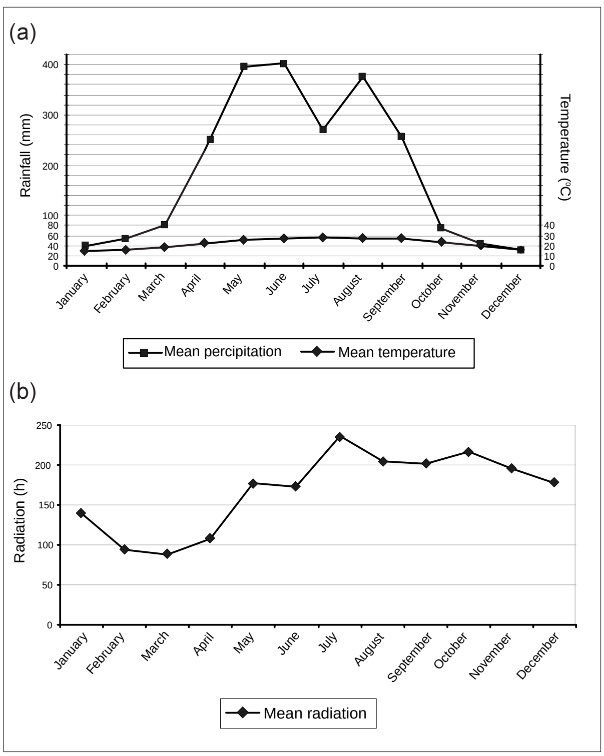
(1) impact of different harvest levels and intercropping on soil physical and chemical properties, tree growth, biomass accumulation and nutrient cycling;
(2) impact of replanting options and fertilisation on soil physical and chemical properties, tree growth, biomass accumulation and nutrient cycling;
(3) impact of site management options on processes influencing of soil fertility; and
(4) long-term change in productivity of eucalypt plantations over successive rotations.

Material and Methods

Site Description

The experimental site is located in Yangxi county, Guangdong province, 5 km from Zhilong town (2°143'N, 111°35'E). The main features of the climate are average annual rainfall 2178 mm (Fig. 1), maximum rainfall in a day 242 mm, annual mean temperature 22.0°C, maximum temperature 37°C, minimum temperature 2.1°C, mean temperature of the coldest month 15°C, mean temperature of the hottest month 28°C, and annual mean humidity 81%. The experimental site is 20-50 m asl on a small hill with a slope of about 5 degrees.

Figure 1. Climatic conditions in Yangxi. Averages at a meteorological station 33 km from the plantation site;1953 to 1979.



The soil is lateritic red soil (Utilsol) over granite. The soil profile is over 2 m deep with less than 20 cm A horizon. The bulk density of the soil is quite high and about 60% of the topsoil (0-40 cm) is white granite sand (Table 1). Because it is degraded land and soil erosion was quite serious after cultivation for the first rotation, the fraction of white granite sand in the topsoil is higher than that in the subsoil. Organic C in the topsoil is very low. However, the relatively higher organic C in the 0-10 cm layer compared to the 10-20 cm layer indicates that litter from the first-rotation plantation may have contributed some organic C to the topsoil. Both total and available nutrient concentrations in the soil are low compared with undisturbed forest soils in southern China.

Table 1. Selected soil properties, averaged from 20 plots.

Property	Depth (cm)		
	0-10	10-20	20-40
Bulk density (g cm^{-3})	1.46	1.43	1.54
Granite sand concentration (% dw)	61.9	59.5	55.0
pH	4.37	4.42	4.44
Organic C (g kg^{-1})	8.33	6.45	4.36
Total N (g kg^{-1})	0.70	0.55	0.54
Total P (g kg^{-1})	0.12	0.11	0.11
Total K (g kg^{-1})	2.97	2.98	3.05
Available N (mg kg^{-1})	45.4	36.3	35.5
Available P (mg kg^{-1})	0.75	0.40	0.45
Exchangeable K (mg kg^{-1})	9.85	7.18	7.34
Exchangeable Ca (mmol kg^{-1})	0.21	0.12	0.15
Exchangeable Mg (mmol kg^{-1})	0.41	0.22	0.27
Exchangeable acidity (mmol kg^{-1})	26.6	24.3	24.8

However, this site is typical for eucalypt plantations planted on degraded soils in the region. As a result, nutrient and water availability is limited in the topsoil during the dry season, and *Eucalyptus urophylla* cannot grow well without soil cultivation and fertilisation. Soil erosion on the site after site preparation and tree planting often exceed 10 t ha^{-1} yr^{-1}. In the dry season (October to March), water stress in the soil limits tree growth because of the shallow root system of *E. urophylla*.

In 1991, the site was cleared of the original vegetation (shrubs with a few trees of *Pinus massoniana*) and cultivated to establish a plantation of *E. urophylla*. Spacing for the plantation was 2 x 3 m. At planting, 100 g of a NPK complete fertiliser (10.0% N; 4.4% P; 8.3% K) was applied per tree as base manure. In 1992, the application was repeated.

Soil and Plant Analysis

Because the soil was cultivated, the A horizon has been mixed with the upper part of the B horizon. Bulk density and chemical analyses were made on soil samples collected after plots were established but before any treatments were applied. Five points in each plot were sampled and the soil separated into 3 layers (0-10, 10-20 and 20-40 cm). Methods for soil analysis were:

- total N, by K_2CrO_3 and H_2SO_4 digestion;
- available N, by NaOH (1.8 mol) solonozation and diffusion;
- total P, by ignition followed by colorimetric molybdate blue (Murphy and Riley 1962);
- available P, by Mehlich-1 extractant (0.05 mol L^{-1} HCl and 0.025 mol L^{-1} H_2SO_4 extractable P);
- total K, ignition method (same as total P) and determined by flame photometer;
- exchangeable K, by 1 mol L^{-1} NH_4OAc extraction and determined by flame photometer;
- exchangeable Ca and Mg, by NH_4OAc extraction and determined by atomic absorption;
- pH, in 1:2.5 water solution; and
- organic C, by K_2CrO_3 digestion and heating.

Methods for plant analysis are:

- N by H_2SO_4 ($ZnSO_4$, $FeSO_4$) digestion and Kjeldahl;
- P by HNO_3 and $HClO_4$ digestion and colorimetry;
- K by HNO_3 and $HClO_4$ digestion and flame photometer; and
- Ca and Mg, by HNO_3 and $HClO_4$ digestion and atomic absorption.

Experimental Design and Layout

The subproject consists of two adjacent experiments having separate but complementary objectives and treatment designs.

Experiment 1: Impacts of different intensities of harvest and intercropping with acacia

The impacts of different harvest levels and intercropping are measured when a first-rotation plantation of *E. urophylla* is harvested and a second crop established. The experimental design is a randomised complete block with five treatments and four blocks. The treatments are:

BL_0 All aboveground organic residue is removed from the plot (tree components, understorey and litter).

BL_1 Whole-tree harvest (aboveground tree components removed from plot and distributed on BL_3).

BL_2 Stem and bark harvest (branches and foliage distributed evenly on the plot) (Stem only harvest).

BL_3 Double slash (foliage and branches from trees harvested from plot plus the slash from BL_1 are distributed evenly over the plot).

BL_4 Stem and bark harvest + intercropping with *Acacia holosericea*

Each of the 20 plots is 360 m^2 in area with 60 trees (6 x 10) spaced at 2 x 3 m. Before tree harvest, the trees and understorey were sampled for biomass and nutrient concentrations. Twenty trees from different diameter classes and blocks were selected for biomass investigation and eight of these trees were selected for measurement of nutrient concentrations. Each tree was divided into leaves, branches, stembark and stemwood.

The equation:

$$Y=a+bX$$

where Y = biomass (oven-dried basis)
X = diameter at breast height
a and b = constants

was fitted for each tree component. These equations were used to predict biomass of each plot from the tree diameters.

Five 1 m^2 sample areas were set up in each plot for understorey and litter biomass determinations. The samples were divided into shrub, grass, other herbs, branch litter and leaf litter, and bulked by block, oven-dried, weighed and saved for nutrient analysis.

The designated harvest level was applied to each plot as it was harvested in March 1997. Planting holes (40 x 40 x 30 cm) were prepared at the same spacing as in the former plantation (2 x 3 m), and 50 g urea (46% N), 40 g KCl (40% K) and 150 g superphosphate (6.4% P) were placed in each hole. On 8 April 1997, seedlings grown from seeds collected from the same plantation were planted and coppice from first-rotation stumps was removed every 2-3 months.

Experiment 2: Impacts of different regeneration methods and fertilisation

The experimental design is split plot with three treatments, two subtreatments and four blocks. The main treatments are three nitrogen levels:

N_0 no additional fertilisation

N_1 low level fertilisation – kg ha^{-1} – N 76.7, P 16.0 and K 53.4) and

N_2 high level fertilisation – kg ha^{-1} – N 153.3, P 32.0 and K 106.7)

The two subtreatments are:

MT_0 coppice

MT_1 seedling planting

Seedlings grown from seed collected in the plantation were planted on 8 April 1997. The coppice subtreatment was thinned to two coppice stems per tree on 15 July 1997. The harvesting level on all of these plots was stem-only removal. An additional two subplots were added in each block to compare the effects of different harvest levels when no fertiliser is added. The two subtreatments are BL_0 (all above ground organic residue removed from the plot) and BL_3 (double slash). There are 72 trees in each plot (6 x 12) and 36 trees in each subplot. The spacing is 2 x 3 m. The area of each plot is 432 m^2. Soil sampling, biomass estimation and nutrient contents of different tree components are the same as Experiment 1 except that only three soil, litter and understorey samples were collected from each plot. The soil characteristics, biomass levels and nutrient concentrations were similar to those found in Experiment 1 and are not reported in this paper. As in Experiment 1, the predesignated harvest level was applied to each plot in March 1997. Planting holes (40 x 40 x 30 cm) were prepared on the planted subplots while the coppice plots were left undisturbed. The planted and coppice subplots in the N_0 treatments received no fertilisation. The planted subplots designated as N_1 received 25 g urea (46% N), 40 g KCl (40% K) and 150 g superphosphate (6.4% P) in the hole as base application before planting, and an additional 25 g urea was applied 3 months after planting. In coppice subplots, the entire 50 g urea, 40 g KCl and 150 g superphosphate was applied 3 months after cutting. Both the planted and coppice plots received an additional 50 g urea and 40 g KCl one year after planting. The N_2 fertiliser treatments received 50 g urea, 40 g KCl and 150 g superphosphate as base application and another 50 g urea and 40 g KCl applied 3 months after planting. The N_2 coppice plots received 100 g urea, 80 g KCl and 150 g superphosphate 3 months after cutting. On both planted and coppice subplots, an additional 100 g urea, 80 g KCl and 150 g superphosphate was applied one year after planting.

Results

Experiment 1: Impacts of Different Intensities of Harvest

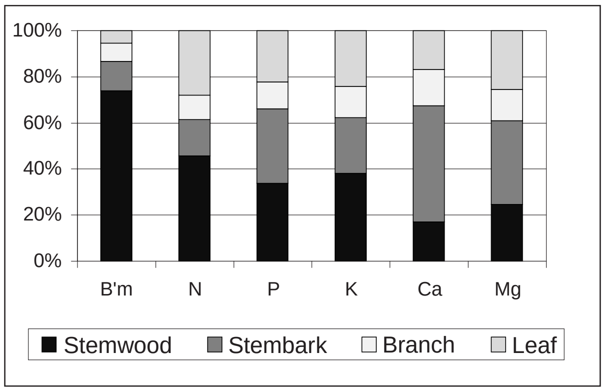
Aboveground tree biomass distribution and nutrient accumulation in previous plantation

The aboveground tree biomass of the harvested plantation was 44.0 t ha^{-1}. The biomass of stemwood, stembark, branches and leaves was 32.6, 5.6, 3.4 and 2.4 t ha^{-1} respectively. The biomass varied between plots: for branches from 3.0 to 4.0 t ha^{-1} and for leaves from 2.1 to 2.9 t ha^{-1}.

Nutrient concentrations in the different components varied with size of individual trees, so average nutrient concentration was used for nutrient content estimation. Total aboveground tree content of N, P, K, Ca and Mg is 106, 8.0, 48, 55 and 16 kg ha^{-1} respectively.

The stem + bark biomass accounts for 87% of the total aboveground biomass (Fig. 2), while the nutrient content in the stem + bark is much lower. More than 60% of the nutrients accumulated in the aboveground tree biomass will be lost in the case of stem + bark harvest, a major loss in terms of nutrient budget in the ecosystem of short-rotation plantations. Returning bark to the site (debark on the site) would be more important for Ca, Mg and P than for N and K. The content of N, P, K, Ca and Mg in branches and leaves is 38%, 34%, 38%, 33% and 39% of total content in aboveground biomass respectively.

Figure 2. Biomass and nutrient distribution in different tree components.



Understorey and litter biomass and nutrient content

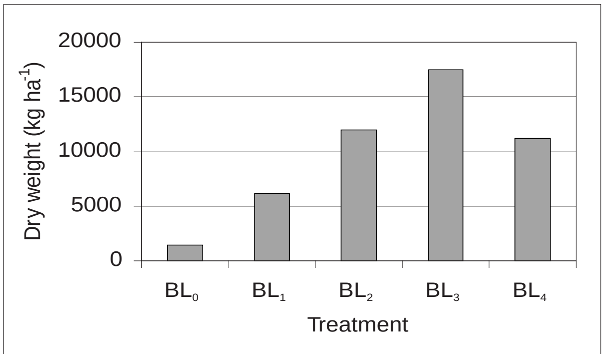
Within the experimental plots, the dry weight of grass, shrubs, leaf litter, branch litter and half-decomposed litter was 530, 334, 2634, 913 and 1397 kg ha^{-1} respectively. This is much lower than in plantations of *E. grandis x E. urophylla* and *Acacia mangium* on better sites around the area (Xu 1996b and unpublished). The decomposition loss of the litter of *E. urophylla* is 50- 60% per year and the litter remaining after decomposition for one year is similar to half- decomposed litter. Nutrient content in the understorey and forest floor was estimated by multiplying the biomass by the nutrient concentration for each block.

Average N, P, K, Ca and Mg accumulations by understorey and litter in the experimental plots are 49, 2.1, 8.1, 23 and 7.8 kg ha^{-1} respectively. Because half-decomposed litter was difficult to remove, it was left on the forest floor in the BL_0 treatment.

Dry weight and nutrient content of harvest residue, understorey and litter in each plot after experimental layout

The 'retention of slash after harvesting' treatments consistently increase in biomass (Fig. 3). The average dry weight of half-decomposed litter left on site in BL_0 plots was 1.4 t ha^{-1}. The amount of biomass left was 6.2 t ha^{-1} in BL_1, 12.0 t ha^{-1} in BL_2 and 11.2 t ha^{-1} in BL_4. Dry weight of harvest residue, understorey and litter on BL_3 plots was 17.5 t ha^{-1}, of which 3.6 t ha^{-1} of branches and 2.6 t ha^{-1} of leaves came from 'double slash' (Fig. 3).

Figure 3. Dry weight of harvest residue, understorey and litter in different treatments.



The amount of nutrients left on the site was also strongly influenced by the application of the treatments (Table 2), with BL_2 and BL_4 being almost the same as for biomass. Retaining double slash (BL_3) increased N, P, K, Ca and Mg content in harvest residue, understorey and litter substantially. When most organic matter was removed (BL_0) only a small amount of N, P, K, Ca and Mg remained in the half-decomposed litter. The amount of branches and leaves left from the harvest is very important to the conservation of K, N, P and Ca on the site.

Table 2. Nutrient content in harvest residue, understorey and litter.

Elements	BL_0	BL_1	BL_2	BL_3	BL_4
			(kg ha^{-1})		
N	16	53	94	134	92
P	0.67	2.28	5.14	7.78	4.97
K	2.1	8.7	28.2	46.4	27.4
Ca	7.3	25.4	42.7	61.0	41.6
Mg	2.2	8.5	14.6	20.8	14.3

There was no difference in NO_3-N and available K concentrations in topsoil (mixed sample from 0-30 cm) in soil samples collected from the plots in May, August and October. There were however some differences in the concentration of available P (Fig. 4) and in NH_4-N (Fig. 5). The highest concentration of available P about 2 months after harvest was in BL_0 where all organic matter was removed. However, by 5 and 7 months after harvest, the highest concentration of available P was in BL_3. The concentration of NH_4-N did not follow a pattern in the May and August samplings, but by October BL_3 was the best, followed by BL_2 (see Fig. 5).

Figure 4. Available P in the soil.

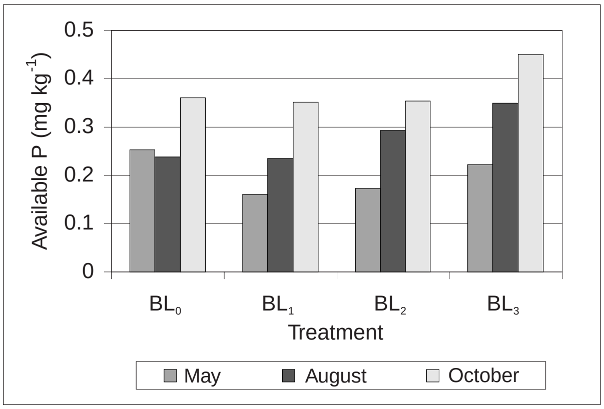
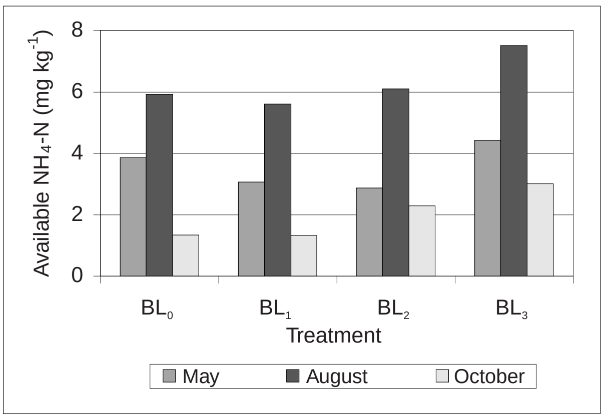


Figure 5. Available NH_4-N in the soil.

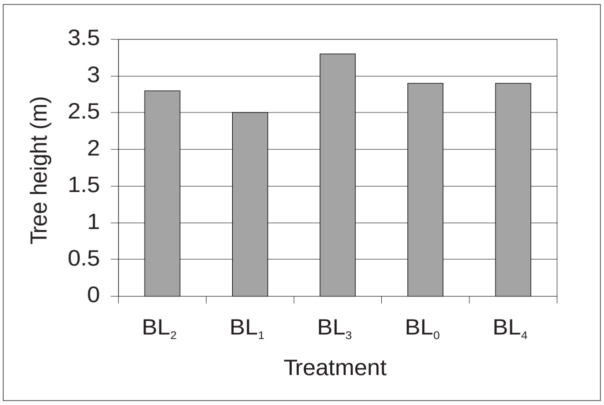


Early tree growth

The mean height of trees was 0.5 m and diameter 0.76 cm three months after planting. The height had increased to 1.6 m and the diameter to 2.7 cm eight months after planting. Neither the harvesting level treatments or the intercropping had a statistically significant effect on height and diameter of the trees.

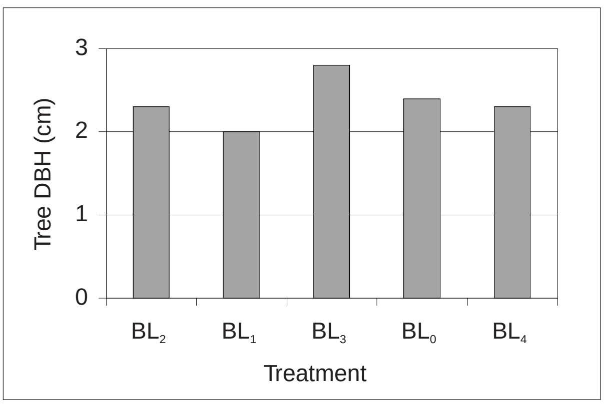
At age 15 months, the trees were tallest on the double slash (BL_3) plots (Fig. 6), averaging 3.4 m. Trees on the whole-tree harvest treatment (BL_1) were the shortest, averaging 2.5 m. There were no differences between the height of other treatments.

Figure 6. Tree height at 15 months.



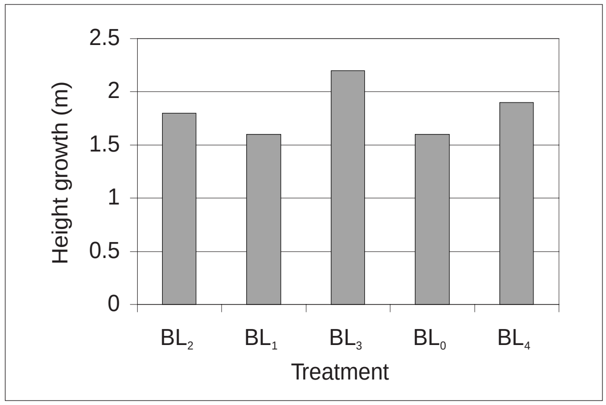
DBH at age 15 months followed a pattern similar to tree height, with trees on the double slash (BL_3) plots being the largest (Fig. 7). Trees on whole-tree harvested (BL_1) plots were the smallest among the five treatments. Differences between the other three treatments were not statistically significant.

Figure 7. Tree diameter at breast height at 15 months.



Treatments affected height growth more clearly in the first half of 1998, or 9 to 15 months after planting. Tree height growth in BL_0 and BL_1 were about the same and less than BL_2 and BL_4. The increase in tree height was superior on the plots receiving double slash (Fig. 8). The slowing of height growth on the treatments with the greatest residue removals (BL_0 and BL_1) indicates that trees had depleted the nutrients from fertiliser applied at planting. As the amount of harvest residue left increased, decomposition was able to provide available nutrients for tree growth. At the same time, the organic material left on the soil surface may have improved water supply to trees in the dry season.

Figure 8. Tree height growth from 9 months to 15 months of age.

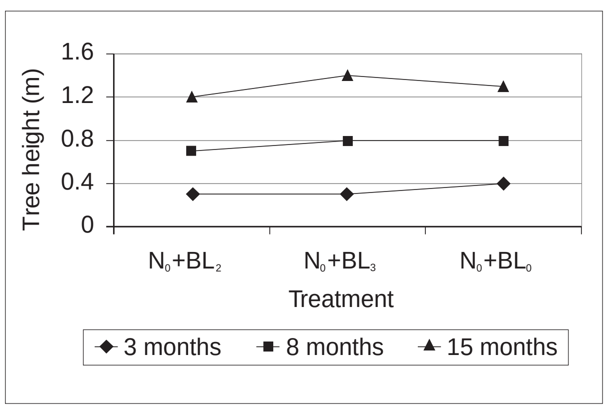


Experiment 2: Impacts of Different Regeneration Methods and Fertilisation

Effect of residue retention without fertiliser on tree growth

The three residue management treatments ('double slash', 'all aboveground organic residue cleaned' and 'stem and bark only' harvest) without fertilisation did not affect tree height significantly (Fig. 9). Trees in all three treatments did not grow well and are about 1 m shorter than fertilised trees in Experiment 1. Because of nutrient deficiency, poor root development restricted the ability of the trees to take up nutrients that were available from decomposition of harvest residue. Thus, in early stages of plantation establishment, base (initial) fertilisation is more important than logging residue management on degraded lands.

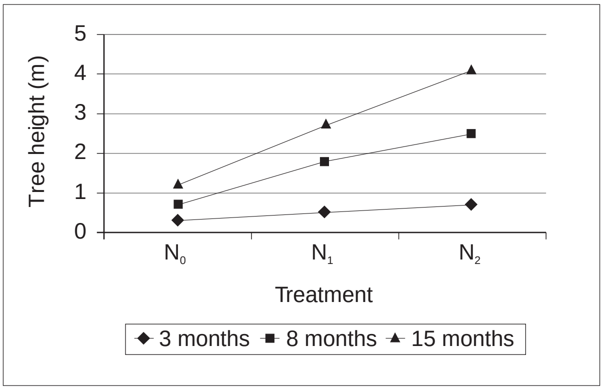
Figure 9. Tree height of harvest residue treatments at 3, 8 and 15 months of age.



Effect of fertilisation on tree growth

Fertilisation increased growth of trees dramatically. The effect of the fertilisation increased with age (Fig. 10). At age 15 months, the average tree height at the high level of fertilisation was nearly four times more than the average tree height with no fertilisation. Thus, even though the first rotation was fertilised, more fertiliser is essential for the second rotation of plantation eucalypts on degraded lands.

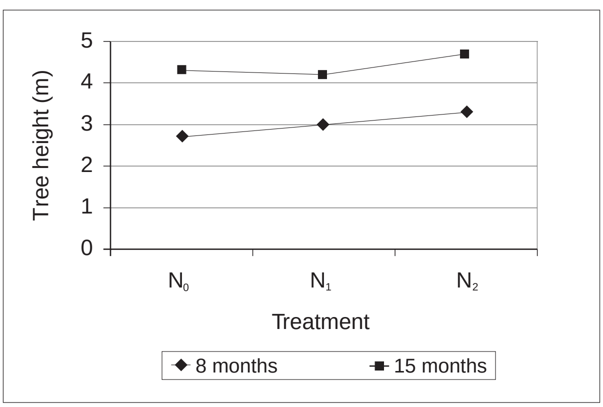
Figure 10. Tree height in relation to age and applied fertiliser.



Effect of fertilisation on coppice tree growth

Fifteen months after harvest, fertilisation had little impact on growth of the coppice (Fig. 11). Compared with the large effect on planted trees, this minor effect of fertiliser on coppice growth indicates that an existing root system is very important for nutrient uptake from the soil. This may help us to understand why trees in the treatment 'double slash without fertilisation' were not much better than trees in the treatment 'all above ground organic materials cleaned'. Nutrient deficiency restricted development of the root system and this poor root system restricted uptake of available nutrients. The basic application of fertiliser was into planting holes where it was readily accessible to young trees.

Figure 11. Coppice tree height in relation to age and applied fertiliser.



At 15 months, it is difficult to predict whether final production from coppice or from planting will be greatest but, at this early stage, growth of planted trees was much lower than that of coppice trees in the 'no' and 'low' fertilisation treatments. In the 'high' fertilisation treatment, planted trees were a little smaller than coppice trees. This indicates that fertilisation had a much greater effect on growth of planted trees than on that of coppice trees.

Discussion

Harvest residue management has a large effect on the amount of organic materials on the soil surface of eucalypt plantations. The poorest treatment was 'whole-tree harvest' followed by the 'removal of all aboveground organic materials'. The removal of some of the litter on the cleaned plots may have increased early tree growth by speeding decomposition of the remaining half-decomposed litter. But from 8 to 15 months of age, tree growth of this treatment is the lowest and it is probable that it will continue to be lower in the future. In contrast, the 'double slash' treatment (BL_3) increased tree growth the most in Experiment 1. This shows that retention of organic material by managing the harvest residue is very valuable in increasing tree growth. Also, the levels of available P and N were also higher in the 'double slash' treatment compared to those in other treatments. The decomposing residues will probably increase the soil organic matter content and available nutrient supply by speeding litter decomposition on degraded lands. This organic material on the soil surface may improve water supply to trees in the dry season. Up to 15 months after planting, intercropping with acacia had not affected the growth of the eucalypt trees.

Fertilisation dramatically improved the growth of planted trees. The more fertiliser applied, the greater the tree growth, indicating even higher rates or more applications of fertilisers may further improve growth. Without fertilisation, root system development was evidently restricted so trees could not take up available nutrients released from litter decomposition even in the case of 'double slash'.

Without fertilisation, coppice trees grew faster than replanted trees for the first 15 months. With high levels of fertilisation, the difference between coppice and planted trees was not significant. Fertilisation had little effect on growth of coppice trees because the existing root system of coppice trees may have helped them absorb enough nutrients for early growth.

References

Bai, J.Y. and Gan, S.M. 1996 *Eucalyptus* plantations in China. *In:* Report Submitted to the Regional Expert Consultation on *Eucalyptus* (Vol II). FAO Regional Office for Asia and Pacific, Bangkok, Thailand, 23-32.

Folster, H. and Khanna, P.K. 1997 Dynamics of nutrient supply in plantation soils. *In:* Brown, A.G. and Nambiar, E.K.S. (eds.) Management of soil, nutrients and water in tropical plantation forests. ACIAR, Canberra, Australia, 339-371.

Xu, D.P. 1996 Soil degradation, a key factor restraining productivity of tropical tree plantations in south China. *In:* Proceedings of IUFRO Conference on Effects of Environmental Factors on Tree and Stand Growth. Dresden, Germany.

Xu, D.P. 1997 An approach to nutrient balance in tropical and south subtropical short rotation plantations. *In:* Yang Chengdong (ed.) Forest soil. Science and Technology Publishing House, Beijing, China.

Xu, D.P., He, Q.X. and Yang, Z.J. 1996 Aboveground primary productivity and nutrient cycling of the plantation of *Eucalyptus grandis ′ E. urophylla*. *In:* Proceedings of the Conference on Tropical Forestry in 21st Century. Bangkok, Thailand.

Xu, D.P., Zeng, Y.T and Li, W.X. 1994 Aboveground biomass and nutrient cycling of young plantation of *Eucalyptus urophylla*. Forest Research 8(2): 600-605.

Xu, D.P., Yang, M.Q. and Zeng, Y.T. 1994 Aboveground primary productivity and nutrient cycling of young plantation of *Acacia mangium*. Guangdong Forest Science and Technology No. 4, 24-29.

Wang H.R. and Zhou W.L. 1996 Fertilizer and eucalypt plantations in China. *In:* Attiwill, P.M. and Adams, M.A. (eds.) Nutrition of eucalypts. CSIRO, Melbourne, Australia, 389-397.

5. *Acacia mangium* Plantations in PT Musi Hutan Persada, South Sumatera, Indonesia

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Abstract

PT Musi Hutan Persada, a forestry company growing wood for pulp in South Sumatra, Indonesia, manages about 200 000 ha of forest plantations, 90% of which consists of *Acacia mangium*. Most of the plantations are in an area with high rainfall and on red-yellow Podzolic soil with inherently poor fertility and low pH. Inter-rotation site productivity and management has been identified by the company as one of the crucial issues for sustaining the long-term productivity of its plantations.

This paper describes the study plan for inter-rotation site productivity and management of *A. mangium* plantations in PT Musi Hutan Persada. The experiment is testing the on-site effect of different treatments of organic matter or aboveground biomass management. Information from some earlier work indicates that most *A. mangium* biomass and three major nutrients (N, P and K) is in the wood, and harvesting will remove around 200 kg N, 45 kg P and 240 kg K per hectare. Litter production of an 8-year-old stand was about 13.0 t ha^{-1} and about 70% of its mass will be lost in one year.

Introduction

PT Musi Hutan Persada (PT MHP) is a joint venture plantation company between the Barito Pacific Group and a state-owned company, Inhutani V (formerly Inhutani II). The company was set up to establish a plantation forest to provide raw material for the pulp and chip industries.

The Government of Indonesia has granted PT MHP a concession area of 300 000 ha in South Sumatera Province. The company started its operation early in 1990, and by the end of 1996 around 200 000 ha of plantation, mainly of *Acacia mangium,* have been established. Each annual planting has been large, involving big capital investment, extensive human resources and millions of seedlings.

The plantation will be harvested to feed pulp and chip mills. The pulp mill will need around 2.5 million m^3 of solid roundwood to produce 450 000 tons of bleached kraft pulp every year. The chip mill will require 1.2 million m^3 of solid roundwood every year. The harvesting operation will take only merchantable sized logs, including bark, to both mills. Non-commercial residues such as leaves, branches and stemwood smaller than 7 cm in diameter will be left at the site. The operations of felling, extracting and transporting the wood to the mills will be extensive.

The concern to sustain plantation productivity in order to be able to supply the mills continuously is enormous. Declining yield over successive rotations is not yet well documented but it has been a major consideration for plantation forest businesses over many years. Great efforts have to be made to adopt sound ecological and economic approaches to avoid such a decline and sustain the industry.

A comprehensive study of residue management after harvesting has been planned in collaboration with CIFOR. The objectives are to assess the effect of different slash management regimes on the growth of the replanted stand and on soil properties (both physical and chemical) and to make recommendations to the company on how to manage the slash to sustain site productivity.

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Location and Site Description

The overall concession area is geographically located at 103°10'-104°25'E longitude and 03°05'-04°28'S latitude. The concession area is divided into three main blocks, i.e. Subanjeriji Forest Block, Benakat Forest Block and Martapura Forest Block. The experiment will be set up in Subanjeriji Forest Block where the mature stand will be felled operationally during 1998.

The plantation has been established on previously alang-alang (*Imperata cylindrica*) grasslands, scrublands and unproductive logged-over secondary forest areas. Both the alang-alang grasslands and scrublands were formed by shifting cultivation practices with repeated fire. Fire has been either wildfire or fire from land preparation for farming. The logged-over areas were formed by traditional logging activities in the natural forests long ago, leaving only unproductive forests.

The annual rainfall in the plantation area is 2000-3000 mm. October to April are wet (rainy) months and May to September is the dry season, but even during the dry season some light rains may be expected. During our service with the company since January 1991, we have experienced three periods of prolonged drought (in connection with the occurrence of El Niño in the Pacific Ocean) – in 1991, 1994 and 1997. The average daily temperature is 29°C, with around 12 hours of daylight.

Soil

The soil of the area originates from sedimentary rocks consisting of tuff, sandy tuff, sandstone and claystone. The topography is mostly flat to undulating (0-8%), although parts are quite rolling (8-15%).

The concession area is mostly dominated by red-yellow Podzolic soil. According to Fanning and Fanning (1989), red-yellow Podzolics correspond with Udults of the Soil Taxonomy. This soil is inherently low in fertility and characterised by low pH and low base saturation, having an argilic or kandic horizon or a fragipan with thick clay skins. Intensive leaching of cations has led to acidification. The soil is advanced in its development with a solum depth of more than 150 cm.

Setiawan (1993) took soil samples from several age classes of *Acacia mangium* stands in Subanjeriji (parts of our plantation). The results of the analysis are presented in Table 1.

Organic C ranged from low to high, calcium and magnesium were all low, nitrogen and potassium were low to medium, cation exchange capacity (CEC) was low and acidity very high. Phosphorus ranged from medium to high.

Stand Description

The land preparation methods applied included fully mechanical preparation for grasslands (clearing and ploughing), and semi-mechanical (windrowing) and manual preparation (slashing, felling and stacking) for the scrublands and logged-over areas (before 1995 the debris was burnt too). Some spots were also sprayed with herbicides to control weeds before planting.

Planting was done by manual labourers during the rainy season. Planting holes were dug in the soil using hoes and the seedlings were planted immediately. Fertilisers were applied at planting time. Triple superphosphate (TSP) at 70 g per tree was applied in every

Table 1. Soil chemical properties under stands of *Acacia mangium* of different ages in Subanjeriji - South Sumatera Indonesia (Setiawan 1993).

Age	Depth	Organic C	N	Available P	Exchangeable cations (me/100 g)			pH	CEC
(years)	(cm)	(%)		(ppm)	K	Ca	Mg		(me/100 g)
2	0-50	1.75	0.14	21.00	0.13	0.77	0.18	4.8	7.0
	50-100	1.25	0.09	12.25	0.08	0.81	0.08	5.4	8.5
5	0-50	2.58	0.21	15.75	0.17	0.61	0.15	4.5	12.5
	50-100	1.31	0.12	14.70	0.11	0.46	0.06	4.9	9.0
8	0-50	2.76	0.22	17.50	0.15	0.56	0.26	4.6	9.5
	50-100	1.48	0.11	10.50	0.09	0.52	0.15	5.0	7.0
11	0-50	3.46	0.25	8.75	0.19	0.84	0.39	4.7	10.0
	50-100	1.77	0.12	3.50	0.08	0.46	0.06	5.0	6.0

planting hole, and urea at 30 g per tree was applied around the seedling on the soil surface. Weed control during the first two years was done both manually by slashing and sometimes a combination of manual slashing with herbicide application. Pruning and singling are recommended to be done earlier than 6 months after planting. Singling is preferably done much earlier. The spacing varied from 3 x 2 m to 4 x 4 m, but 4 x 2 m and 4 x 3 m are the standard spacings now used.

The *A. mangium* stand used for this trial is of mature age (7 years) that will be harvested in operational logging during 1998. The stand is of Subanjeriji (Inhutani) seed source and of representative growth rate and site conditions.

A. mangium is the main species planted in PT MHP's plantations. This species has been found to be superior to other species. It is easy to work with both in the nursery and in the field, relatively free from serious pests and diseases, fast growing and, of course, suitable for the intended industries.

At the beginning of its plantation programme, PT MHP used seed from an unimproved source, i.e. Inhutani seed source in Subanjeriji. Historically this seed source originated from the Cairns region of Queensland (Daintree, Mossmann, Cassowary Creek and Jullaten). The seed was from only very few parent trees giving a very narrow genetic base. Some provenance trials of this species show that this Inhutani seed source is inferior in terms of growth to other provenances in South Sumatera (Hardiyanto *et al*. 1997) The most productive provenance, from Papua New Guinea, produced 162% of the volume of the Inhutani seed source at 28 months.

Therefore since the beginning of its operation the company has conducted a solid tree improvement programme, broadening the genetic (breeding) base by introducing many more provenances and developing short- and long-term seed procurement and clonal propagation. So far the mean annual increment in total volume (MAI) of unimproved *A. mangium* in our commercial plantation is around 33 m^3 ha^{-1} yr^{-1} at the age of 6 years. With improved genetic material and better silvicultural regimes the average MAI will hopefully be increased to around 45 m^3 ha^{-1} yr^{-1} in the coming second rotation. With an increased growth rate, the company can either harvest the stand at the same age as the first rotation but with higher yield, or shorten the rotation age by 1 to 2 years with the same volume yield. At the same time the company is looking at other promising species such as *A. auriculiformis*, *A. crassicarpa*, *Eucalyptus pellita* and *acacia* hybrids (*A. mangium x A. auriculiformis*) as a back-up for *A. mangium.* Nevertheless we believe that *A. mangium* will remain our major species until there is good reason to change it.

Experimental Design and Method

The trial uses a randomised complete block design, with five core and two optional treatments with five replications. The plots are of 48 x 48 m in size with 32 x 32 m as the core area. Each plot will have 8 rows and 16 planting spots within each row. The total area that may be needed is around 15-20 ha, considering that not all parts of the site will be useable for the trial.

The core treatments tested in this trial are:

BL_0 All biomass, litter and understorey are removed from the plot (site).

BL_1 Whole-tree harvest. Take out all the trees including non-commercial parts. Understorey and litter are left where they are.

BL_2 Merchantable tree harvest. Take only stems of commercial size including bark. Non-commercial parts, litter and understorey are evenly distributed within the plot.

BL_3 Merchantable tree harvest. The same as BL_2 but non-commercial residues from plot BL_1 are brought in and distributed evenly, adding to the slash already present (thus doubling the amount of slash).

C Leave standing crop undisturbed to give some idea about the condition of the site without harvesting.

BL_0 to BL_3 will use a standard harvesting method (Method No. 1) but the method has not been chosen yet.

Two optional treatments employed in this trial are:

MHP_1 Based on BL_2 but with alternative harvesting method (Method No. 2).

MHP_2 Based on BL_2 but with alternative harvesting method (Method No. 3).

These two different harvesting methods (MHP_1 and MHP_2) are to give some comparison of the degree of soil compaction resulting from different traffic regimes for heavy machinery. The effect of soil compaction on the growth of the replanted stand is of great importance since it will determine the productivity of the following rotation.

Litter, standing biomass and soil properties (both chemical and physical) in the mature stand are measured to establish the initial condition of the stand before felling. Soil chemical properties analysed are organic C, N-total and anaerobic N, total and available P, exchangeable K, Ca, Mg, Al and pH. Bulk density, infiltration rate and moisture content are measured before and after felling to study changes in the physical condition of the soil resulting from harvesting and extraction activities. Biomass growth, nutrient status and litter decomposition rate will be measured after treatments are applied.

The time schedule for the trial is presented in Table 2.

Table 2. Time schedule for site productivity and management trial in PT MHP - Indonesia.

Activity	Planned time
Treatment confirmation	November - December 1997
Site selection	November - December 1997
Preliminary survey and sampling	January - February 1998
Site preparation	April - July 1998
Treatment application	April - July 1998
Initial measurement after harvesting (bulk density, infiltration rate, moisture content, etc.	August 1998
Planting	November – December 1998
Growth measurement	December 1999
Maintenance (weeding, singling, pruning)	January - December 1999

Discussion

We have not obtained results from this experiment because it is still at the planning stage. We can however present as preliminary information data collected by Ihwanudin (1994) in Subanjeriji plantation on nutrient distribution in an *A. mangium* stand 9 years old, litter production under an 8-year-old stand (Rachmawaty 1993), and litter decomposition rate under an 8-year-old stand (Setiawan 1993).

The data in Table 3 show that the highest percentage of biomass and the three major nutrients is in the wood. This fraction would be even higher if the accompanying bark is included. Stemwood and bark comprise 81% (118.0 t ha^{-1}) of the total standing biomass in the stand. Branches and twigs comprise 16% (23.4 t ha^{-1}), leaves 2.7% (3.96 t ha^{-1}) and fruit 0.65% (0.96 t ha^{-1}) of the total standing biomass. The total amount of N, P and K in the standing trees is also shown in the table. N is most abundant (296 kg ha^{-1}), followed by K (295 kg ha^{-1}) and P (60 kg ha^{-1}) respectively. Litter and understorey bring the total amount of nutrients to 349 kg ha^{-1} for N, 65 kg ha^{-1} for P and 319 kg ha^{-1} for K respectively.

Table 3. Nutrient distribution in a 9-year-old *Acacia mangium* stand in Subanjeriji, South Sumatera, Indonesia (revised from Ihwanudin 1994).

Stand component	Biomass	Nutrient content (kg ha^{-1})		
	(t ha^{-1})	N	P	K
Leaves	3.96 (2.7)*	22.76 (7.69)	2.81 (4.69)	11.24 (3.81)
Fruit	0.96 (0.65)	5.92 (1.99)	1.58 (2.64)	6.84 (2.32)
Branches + twigs	23.44 (16.01)	64.20 (21.68)	9.08 (15.14)	36.68 (12.42)
Wood	105.12 (71.82)	161.89 (54.67)	38.90 (64.88)	216.55 (73.35)
Bark	12.88 (8.80)	41.35 (13.96)	7.60 (12.68)	23.91 (8.10)
TOTAL	146.36	296.13	59.96	295.23
Litter (all components)	10.08	43.69	3.18	15.72
Understorey	2.40	9.29	2.07	8.47
GRAND TOTAL	158.83	349.11	65.21	319.42

*Numbers in brackets are percentage of the total of standing trees

Rachmawaty (1993) studied litterfall on standing crop under an 8-year-old *A. mangium* plantation in Subanjeriji. The data are shown in Table 4. It was found that litterfall production could reach 12.98 t ha^{-1} yr^{-1}, of which leaves were 63%, reproductive parts (flower stalks, dry pods, seeds) 21%, branches and twigs 16%, and bark was only 0.04%. The litter will eventually contribute nutrients to the soil through the process of decomposition. The amount of litter (all components) found by Rachmawaty (1993) was greater than that found by Ihwanudin (1994) as shown in Table 3.

Table 4. Mean dry weight of litter under an 8-year-old *Acacia mangium* stand in Subanjeriji (revised from Rachmawaty 1993).

Litter component	Litterfall		Fraction of total
	(g m^{-2} $week^{-1}$)	(t ha^{-1} yr^{-1})	(%)
Leaves	15.70	8.18	62.98
Reproductive parts	5.33	2.78	21.38
Branches + twigs	3.89	2.03	15.60
Bark	0.01	0.005	0.04
TOTAL	24.93	12.995	100.00

Setiawan (1993) studied the decomposition rate of *A. mangium* litter under an 8-year-old stand in Subanjeriji (Table 5). An exponential regression equation indicates that the proportion by weight of the litter standing crop was 61% after 4.5 months and 27% after 12 months. Leaves decomposed most rapidly, followed by of reproductive parts and twigs respectively.

Table 5. Decomposition of *Acacia mangium* litter under an 8-year-old stand in Subanjeriji (from Setiawan 1993).

Litter component	Remaining weight (%)	
	4.5 months	12 months
Leaves	61.07	26.84
Reproductive parts	64.53	31.09
Twigs	67.79	35.46

Harvesting operations that take only merchantable parts of the trees, i.e. stemwood including bark, will remove 81% of the total standing biomass (118.0 t ha^{-1} out of 146 t ha^{-1}). This export will also remove nutrients that have been gathered from the soil and stored in the stemwood and bark.

All slash that is left behind, litter that has accumulated and some that has decomposed, and understorey that remains *in situ* will play an important role in the nutrient budget of the site. In contrast, whole-tree harvesting combined (for instance) with skidding will take all biomass and nutrients contained in the trees off the site.

Soil chemical properties might have been improved by the enrichment of soil with organic matter throughout the rotation. Decomposing litter would have released nutrients back to the soil, contributing to an increasing content of some nutrients. As shown in Table 5, after 12 months the proportion by weight of litter remaining was 27% for leaves, 31% for reproductive parts (flower stalks, empty dry pods, seed, etc), and 35% for twigs. Therefore at least around 73% of the nutrients in leaf litter, 69% of those in reproductive parts and 64% of those in twigs that were produced per year would have been returned to the soil. The negative effects of full exposure of the site after clear felling are possibly soil erosion due to disturbance of the soil surface and nutrient leaching along with surface runoff.

A harvesting operation will, of course, to some extent affect the balance of the nutrient budget in the stand ecosystem. Consequently, biomass and litter management during harvesting operations will determine the amount of organic matter on the site that will be available for the next rotation.

A harvesting system that will give the optimum yield of wood but at the same time minimise site disturbances will have to be chosen. Producing around 3.7 million m^3 of solid wood per year or around 12 000 m^3 per day is a subtantial operation. The stands have to be felled, the logs have to be bucked, extracted and transported to the mills. Once the mills start the delivery of wood must be maintained. The plantation sites will inevitably be affected, in some way, by the whole operation. Furthermore, the possibility of increasing plantation yield by using improved genetic material and better silvicultural regimes will also have additional consequences. Greater volume (MAI) and reduced rotation age will expose sites to more frequent disturbance, which will in turn accelerate site deterioration unless extra care is strictly implemented.

The inter-rotation management regime (harvesting, slash management and site preparation for the next rotation) is crucial in sustaining long-term productivity of the plantation. Whatever system is applied may affect the physical, biological and chemical conditions of the site, which in turn may affect stand productivity. There must be a compromise between the economic benefits of the selected harvesting and land preparation systems and the impacts resulting from such operations.

Conclusions

This research in collaboration with CIFOR is vitally important to demonstrate, to all parties involved, the extent to which harvesting and biomass management will affect site productivity. Information from this experiment will provide a basis for decisions regarding harvesting and subsequent biomass and litter management, and understanding the likely effects of the chosen harvesting system on future site productivity.

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References

Fanning, D.F. and Fanning, M.C.B. 1989 Soil morphology, genesis and classification. John Wiley and Sons, New York, 395 p.

Hardiyanto, E.B., Siregar, S.T.H., Chandralika and Syarifudin 1997 Hasil uji provenans *A. mangium* umur 28 bulan di Setuntung. Technical Notes R&D. Vol. 7 No. 5 (internal publication), PT Musi Hutan Persada, South Sumatera, Indonesia, 7 p.

Ihwanudin, A. 1994 Ketersediaan unsur hara N, P, K di hutan tanaman *A. mangium* Willd., areal HTI Subanjeriji, Muara Enim, Sumatera Selatan (BSc Thesis). Fakultas Kehutanan Institut Pertanian Bogor, Bogor, 84 p.

Rachmawaty, V.A. 1993 Pengukuran produktivitas serasah *Acacia mangium* Willd. di hutan tanaman industri Subanjeriji, Sumatera Selatan (BSc Thesis). Fakultas Kehutanan Institut Pertanian Bogor, Bogor, 93 p.

Setiawan, I. 1993 Studi proses dekomposisi *A. mangium* Willd., di hutan tanaman industri Subanjeriji, Sumatera Selatan (BSc Thesis). Fakultas Kehutanan Institut Pertanian Bogor, Bogor, 98 p.

6. Eucalypt Plantations in Monsoonal Tropics - Kerala, India

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Abstract

In Kerala, large-scale planting of eucalypts commenced in the 1960s. Most of these plantations were raised either by clearing natural forests or on natural grasslands. The principal species grown are *Eucalyptus tereticornis* and *E. grandis*. Though the productivity of the plantations was initially satisfactory, it has been declining in the last several years. Deterioration of soil fertility due to adverse management practices is the main reason for poor productivity. As the area under plantations cannot be extended, increasing productivity of the existing plantations is the only option to cater for the needs of the paper and pulp industries in the State. In order to explore various management options to optimise and sustain eucalypt growth over successive rotations, a comprehensive long-term research project was initiated in July 1997 as a collaborative venture between the Kerala Forest Research Institute and CSIRO Forestry and Forest Products (Australia). A series of inter-rotation experiments has been initiated at four sites in the State using *E. tereticornis* (two low-altitude sites) and *E. grandis* (two high-altitude sites). The experiments include harvest residue management, use of inter-row legumes, nutrient application, weed management and nutrient and water conservation through soil trenching. In addition, experiments are also being conducted in established stands paired with natural forests to assess long-term changes following replacement of natural forests with eucalypts. It is hoped that the results of this project will assist understanding of the positive influence of various management practices on eucalypt growth. We aim to use the results to develop a package of practices for increasing and maintaining plantation productivity.

Introduction

Eucalypts are one of the most widely planted trees in forestry programmes in India due to their high adaptability and fast growth, and the increasing demand for wood. The total area under eucalypts in India is 4.8 million ha (Davidson 1995), corresponding to 25% of the area under forest plantations in the country. Major uses are as pulpwood, firewood and poles. In Kerala State, large-scale planting of eucalypts commenced in the 1960s. Initially they were grown on marginal and degraded lands. However, when the demand for eucalypt wood increased, the area of plantations was increased by clearing natural forests, or by planting in native grassland at higher altitudes. Clearfelling of natural forests was prohibited by the Government of India in 1982. Thereafter, new plantations could be established only after harvesting existing plantations. Currently, eucalypts occupy about 40 000 ha in the State. The main species grown are *Eucalyptus grandis* Hill ex Maiden (16 000 ha, mainly in high ranges) and *E. tereticornis* Sm. (24 000 ha, in low-altitude areas).

Current management practices for eucalypts include:

- harvesting of existing plantations at age 7 years;
- manual weeding of undergrowth;
- burning of slash; and
- preparation of planting rows, pitting and planting.

Normal spacing is 2 x 2 m (2500 stems ha^{-1}). Coppice-based production is common; replanting is normally done after three rotations (one seedling and two coppice crops). Coppice from old stumps is periodically removed to

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encourage seedling growth in replanted areas. Neither fertiliser application nor weed control is conducted on a regular basis. These management practices can have adverse impacts because:

- removal and burning of harvest residue and weeds result in nutrient loss, leaching and adverse changes in soil;
- topsoil and ash are eroded by rain;
- repeated planting at the same site leads to site deterioration as there is no input of organic or inorganic nutrients to replenish the soil; and
- if weeds are not controlled regularly they compete with trees for nutrients and water.

Productivity of Eucalypt Plantations in Kerala

The productivity of eucalypt plantations in Kerala is estimated to be 5-10 m^3 ha^{-1} yr^{-1}. This is significantly lower than results from Brazil, Australia and other eucalypt-growing countries. Although the Government is committed to provide pulpwood for industries in the State, their requirements are seldom met due to poor productivity of the existing plantations. This, coupled with the limited land base available for plantation eucalypts, has resulted in high priority being given to increasing the productivity of existing plantations.

Studies in eucalypt plantations in the State have indicated that deterioration of soil fertility, due to successive rotations of the crop, is one of the reasons for poor productivity. Balagopalan and Jose (1983) showed that the soil organic carbon content (at 0-15 cm depth) in a second-rotation coppice (2R) *E. tereticornis* plantation at Kollathirumedu was lower (15 g kg^{-1}) than in a first-rotation (1R) plantation (26 g kg^{-1}). There was an increase in soil acidity in 2R (pH 5.1) compared to 1R (pH 5.9) and the C:N ratio was lower in 2R (10.1) than 1R (14.5). Moreover, total as well as different forms of nitrogen also declined in the 2R plantation (1.80 g kg^{-1} in 1R and 1.34 g kg^{-1} in 2R).

Balagopalan (1992) compared the physico-chemical properties of soils in the upper 15 cm layer in the first rotation (seedling), second rotation (coppice) and third rotation (coppice) of an *E. tereticornis* plantation in Trivandrum as described in Table 1. The adverse changes in soils can be ascribed to bad management practices. For example, prolonged exposure of mineral soil (especially after harvesting the trees) leads to enhanced leaching of bases resulting in high acidity.

Table 1. Soil properties between 0 and 15 cm of depth in a *E.tereticornis* plantation in Trivandrum.

Parameter	1st Rotation	2nd Rotation	3rd Rotation
	(seedling)	(coppice)	
Bulk density (g cm^{-3})	1.21	1.36	1.57
Gravel (%)	19	30	41
Sand (%)	75	82	84
Organic carbon (g kg^{-1})	19.70	14.90	11.99
pH	5.8	5.4	5.0

Faster mineralisation of organic matter resulting from detrimental silvicultural practices may have also contributed to poor nutrient status of soils. According to Nair *et al*. (1986), the deficiency of available copper, phosphorus and zinc in the soil was the main reason for failure of *E. grandis* plantations at Kulamavu. Likewise, studies by Singh *et al.* (1988) revealed that stunted growth and high mortality of *E. grandis* at Kottayam was due to the poor soil nutrient status (P_20_5 – 0.015 g kg^{-1} and N 0.91 g kg^{-1}). They also observed that compaction of the surface layer of soil and its skeletal makeup contributed to poor growth of trees. Balagopalan and Jose (1986), who compared the distribution of organic carbon and different forms of N in soils of a 7-year-old eucalypt plantation and a semi-evergreen forest, observed that plantation activities enhanced erodability, and decreased C content, total as well as different forms of N, and cation exchange capacity of the soil, and increased oxidation. Ghosh *et al.* (1989) have also reported that cropping of *E. tereticornis* considerably reduced the available nutrient status of soil after three years of cultivation at Trivandrum. Reductions were from 8.3 to 5.2 g kg^{-1} for C, from 288 to 222 kg ha^{-1} for N, from 20 to 13 kg ha^{-1} for P and from 86 to 66 kg ha^{-1} for K.

Foliar analysis of *E. tereticornis* and *E. grandis* plantations at Kondazhi and Muthanga respectively indicated that the soils are poor in N and P. The low concentration of N and P in both soil and plant material suggests that the growth of eucalypts can be increased by soil nutrient management (Sankar *et al.* 1988). Fungal diseases and water stress have also been identified as factors limiting growth of eucalypts in Kerala (Sharma *et al.* 1985; Kallarackal and Somen 1997). It is evident from these studies that poor nutrient status of soils and improper management practices are the main reasons for low productivity of eucalypt plantations. Methodologies need be developed to understand and correct nutritional constraints to growth and to optimise conservation and use of site resources for improving and maintaining productivity.

Project Aim

A comprehensive long-term research project was initiated in July 1997 as a collaborative venture between Kerala Forest Research Institute, the Commonwealth Scientific and Industrial Research Organization Australia (CSIRO) and the Australian Centre for International Agricultural Research (ACIAR). Other collaborators in the programme include the University of Western Australia, the University of New South Wales, Griffith University, Bunnings Treefarms in Australia and Hindustan Newsprint Ltd, Kerala Forest Department and Kerala Forest Development Corporation in India. The primary aim of the project is to explore management options to optimise and sustain tree growth over successive rotations.

In Kerala, research on important eucalypt species, *viz. E. tereticornis* and *E. grandis*, is conducted at four different locations. Parallel studies are conducted in Western Australia using *E. globulus*. In both the projects, experiments have been initiated to investigate aspects of harvest residue management, nutrient application and use of legumes under crops to increase soil fertility and devise practical methods of soil and water conservation (O'Connell and Grove, this volume). The primary objectives of the study are to:

- quantify soil nutrient status, site productivity, nutrient stores and nutrient cycling in eucalypt plantations (pre-harvest);
- determine nutritional requirements for growth of trees;
- assess influence of growing inter-row legumes, weed control and soil and water conservation through silvicultural practices on growth of trees;
- evaluate differences in tree water status, water use and nutrient uptake in response to applied silvicultural treatments; and
- develop appropriate methodologies to manipulate soil organic matter, soil and tree nutrients and water status to maintain high productivity.

Location and Site Description

Climate

Kerala State, located between 8.2 and 12.8°N latitude, has a tropical, warm, humid monsoonal climate. There are two main monsoons, the South-West (SW) and the North-East (NE). The SW monsoon starts in early June and extends until November. The NE monsoon is relatively dry with occasional rains and lasts from December to February. The summer season is from March to May. The average annual rainfall is 3000 mm (range 2200-3600 mm) spread over 120 rain days. Mean atmospheric temperature is 27°C (range 20-42°C). Relatively humidity ranges between 64% (February-March) and 93% (June-July). Solar radiation varies from 3.5 to 27 MJ m^{-2} day^{-1}, and potential annual evapo-transpiration from 1400 to 1700 mm.

Eucalypt plantations in Kerala are located in two broad geographic regions. At lower elevations (<1000 m asl) on the undulating coastal plains *E. tereticornis* dominates and accounts for 60% of the area under eucalypts. At higher ranges (1000-2000 m asl) *E. grandis* is the principal species which covers the rest of the area. Our research is focused on these two species with two *E. tereticornis* sites at lower elevations and two *E. grandis* sites at higher elevations (Table 2).

Table 2. Location, geographical position and other parameters of study sites.

Location and Species	Latitude and longitude	Altitude (m)	Slope (°)	Rainfall (mm)
Kayampoovam *E. tereticornis*	N 10°41' E 76°23'	120	10	2700
Punnala *E. tereticornis*	N 09°06' E 76°54'	150	5	2000
Suryanelli *E. grandis*	N 10°02' E 77°10'	1280	4	3000
Vattavada *E. grandis*	N 10°08' E 77°15'	1800	15	1800

Kayampoovam (Thrissur District)

The site was originally a degraded moist deciduous forest where *E. tereticornis* was planted in 1977. The trees were first harvested in 1991. The first coppice growth (2R) was harvested in March 1998. The site is characterised by moderate rainfall (less summer rain), low humidity, high evaporation and high wind velocity.

Punnala (Kollam District)

The site was originally a degraded moist deciduous forest before planting with eucalypts in 1977. The trees were first harvested in 1991. The first coppice growth (2R) was harvested in April 1998. The site has high humidity, high evaporation and low wind velocity.

Suryanelli (Idukki District)

The site was a grassland before planting with eucalypts in 1978. The trees were clearfelled in 1991 after three rotations (1 seedling and 2 coppice). The site was replanted in 1991 and this seedling crop was harvested in May 1998.

Vattavada (Idukki District)

The site was planted with eucalypts in 1958 after clearing natural semi-evergreen (shola) forest. The trees were clearfelled in 1991 after three rotations of the crop and replanted in the same year. The first crop (seedling) was harvested in June-July 1998.

Soils

Kayampoovam

The site is part of a hill facing east-west with rolling to sloping terrain. There are occasional rocky outcrops. The parent material of the soil is colluvium over saprolite. The rock is granite and the gravel content is high. The soils are well structured and are sandy loam to sandy light clay in texture. Undergrowth is dominated by *Chromalaena* and *Glycosmis*. Soil physico-chemical characteristics of a eucalypt plantation close to the experimental site are given in Table 3.

Table 3. Soil properties at Kayampoovam.

Parameter	Soil depth (cm)		
	0-20	20-40	40-60
Bulk density (g cm^{-3})	1.3	-	-
Gravel (%)	27	27	28
Sand (%)	76	71	71
Silt (%)	10	11	7
Clay (%)	14	18	22
pH	5.7	5.8	5.8
EB (c mol kg^{-1})	35	31	30
EA (c mol kg^{-1})	107	129	121
CEC (c mol kg^{-1})	142	160	151
OC (g kg^{-1})	5.9	4.5	4.0
Total N (g kg^{-1})	0.80	0.61	0.40
Available P (g kg^{-1})	0.15	0.12	0.08
K (g kg^{-1})	14.1	8.3	4.7
Ca (g kg^{-1})	12.2	6.4	3.1
Mg (g kg^{-1})	7.1	4.2	3.0

Punnala

The site is part of a hill extending east-west from the main chain of the Western Ghat mountains. The terrain is sloping and outcrops of boulders of granite are visible. The parent material is colluvium over saprock. The soil is well structured, with crumb to angular blocky structure. The texture varies from sandy loam on the surface to clay loam on the subsoil. Undergrowth is dominated by *Lantana* and *Chromalaena*.

Suryanelli

This site is at the top of a plateau forming a second chain of hills on the Western Ghats. The soil parent material is recent colluvium without any evidence of granatoid fabrics. The soil structure varies from crumb to blocky. The content of gravel is negligible and the texture ranges from clay to silty clay loam. The undergrowth is mainly *Lantana* and *Chrysopogon*.

Vattavada

The site is located in rolling to sloping terrain joining a valley between two ridges at the boundary of Tamil Nadu and Kerala States. This geographical isolation is the reason for low rainfall in the area (Table 2). The deep soils are formed on recent colluvium as a result of land movement and slides. The gravel content is low. Soil structures are at times weak while it is generally crumb to blocky. Soil texture is light clay. The undergrowth is predominantly *Ageratum.*

Details on soils from all the four sites are taken from Gilkes *et al.* (1998 unpublished).

Productivity of harvested stands

The yield of wood from harvested stands at the four experimental sites was:

Location	Yield (m^3 ha^{-1} yr^{-1})
Kayampoovam	11.6
Punnala	6.1
Suryanelli	9.0
Vattavada	31.3

The high productivity of the site at Vattavada is because of the higher number of trees per unit area (3900 stems ha^{-1}), although the average rainfall is lower than at other sites (Table 2).

Experimental Details

Five experiments were conducted at each site:

Experiment 1: Organic matter manipulation

Rationale

Although it is known that retention of harvest residues in plantations will enhance nutrient status of soils, information on this aspect is scarce on eucalypt plantations in Kerala. As the existing practice is to burn the slash, it was considered worthwhile to demonstrate the influence of slash retention and impact of burning on soil fertility status in plantations.

Treatments

- No slash – All slash material removed (**BL_0**)
- Single slash – Harvest residues retained and spread evenly on each plot (**BL_1**)
- Double slash – Slash added from no-slash treatment (**BL_2**)
- Leaf slash only – All wood residues removed (simulates firewood removal) and leaves retained
- Burn plus starter fertiliser – All residues burnt (current practice) with starter fertiliser (17:17:17 N, P, K @ 100 g $tree^{-1}$)
- Burn only – All residues burnt (no starter fertiliser added)

Experiment 2: Inter-row legumes

Rationale

A positive influence of leguminous cover crops on short-rotation trees has been demonstrated through studies conducted in Australia and elsewhere. Legumes can enhance nitrogen content of soil. The project aims to examine this potential for improving growth of eucalypts.

Treatment

Three legumes are grown at each site, a plot without legumes provides a control. *Peuraria phaseoloides, Stylosanthes hamata* and *Mucuna bracteata* are grown as an intercrop in *E. tereticornis* plantations. *Desmodium intoratum, D. uncinatum* and *Phaseolus* sp. are grown as an intercrop in *E. grandis*.

Experiment 3: Soil trenching

Rationale

Water stress has been identified as one of the factors limiting growth of eucalypts in Kerala (Kallarackal and Somen 1997). In certain cases, this is because of the hilly terrain in which eucalypts are planted. During a heavy monsoon, the surface runoff in these areas can be between 40% and 90% (James and Mohan 1996) which means that not much water is available for recharging the soil or watertable. It is expected that soil trenching will reduce water stress and help to conserve soil and nutrients and thus enhance productivity.

Treatment

Contour and staggered trenches at each site, except for Kayampoovam for want of a suitable area. The trenches are located on the contour at different spacings depending on the topography of the site.

Experiment 4: Vegetation management

Rationale

Weed control is seldom practised in eucalypt plantations in Kerala especially after the initial three years of establishment. This may be one of the factors contributing to poor performance of eucalypts. The present study is expected to provide useful data in this regard.

Treatment

- Weeds retained (but weed growth around tree base removed)
- Strip weed control (1 m wide along rows)
- Total weed control

Experiment 5: Nutrient additions

Rationale

Low nutrient status of the soils, especially after successive harvests of the crop, is considered to be one of the main reasons for low productivity. Our experiments will clarify the influence of nutrient addition on growth of eucalypts.

Treatment

- P rate experiment — 5 levels of added P (0, 12, 40, 120 and 250 kg P ha^{-1}) plus basal major and minor nutrients
- N rate experiment — 5 levels of N (0, 24, 80, 250 and 500 kg N ha^{-1}) plus basal major and minor nutrients.

Experimental Design

Experiments using randomised complete block design with four replicates are being conducted at four locations with two sets of replicate sites, i.e. 1) two low-altitude sites with *E. tereticornis* and 2) two high-elevation sites based on *E. grandis*. Plot size is 20 x 20 m at all sites except Kayampoovam where it is 18 x 18 m. Plant spacing is 2 x 2 m with 100 seedlings per plot (81 seedlings at Kayampoovam).

Sampling and Measurement of Biomass and Nutrient Content of the Standing Crop

Diameter at breast height (DBH) of all eucalypt trees at the site was measured. Six trees were felled and total height and diameter at different levels (0.3, 0.5, 1, 1.3, 2, 3, 4, 5, 6, 7 m height) were determined. Branches were divided into 3 categories based on diameter (>3 cm, 1-3 cm and <1 cm). Fresh weight of bole, bark, branches and leaves was determined at the site. Subsamples of all fractions were collected, weighed and transferred to the laboratory for finding dry weight. Sawdust of bark and bole was collected for nutrient analysis. All samples were dried at 70ºC, ground and analysed for nutrient content (N, P, K, Ca and Mg).

Results

The biomass and nutrient content of different components of eucalypt trees at Kayampoovam are given in Table 4. The total biomass is estimated to be 64 t ha^{-1}. Wood contributed 74% of the biomass followed by bark (12%), branches (11%) and leaves (3%). In a similar study, Negi and Sharma (1985) recorded the biomass of *E. tereticornis* trees belonging to different age groups in Tamil Nadu. Seven-year-old trees produced biomass ranging from 69 to 116 t ha^{-1}. Results of the present study are also in agreement with reports by George (1984), who estimated biomass of 10-year-old *E. tereticornis* at Dehra Dun.

- Site preparation and planting with eucalypt seedlings were completed during June-August 1998. All experiments are in place.
- An experiment has been commenced to determine the rate of decay of slash residue (branches, leaves and bark) and the contribution of these components to nutrient cycling in replanted eucalypt plantations (litter bag method).
- An experiment has been initiated to assess residence time of different harvest residues in replanted eucalypt plantations (quadrat method).
- In cooperation with CSIRO, a project planning and initiation workshop was held in April 1998.
- Three months after planting growth was measured and trees sampled for analysis of nutrients.
- Physiological measurements including leaf water potential, stomatal conductance, photosynthesis and leaf area index are in progress.

Table 4. Biomass and nutrient content of different components of 7-year-old *E. tereticornis* at Kayampoovam.

Components	Biomass	Nutrient content (kg ha^{-1})				
	(t ha^{-1})	N	P	K	Ca	Mg
Leaf	2.12	38.92	2.41	23.02	20.74	5.15
Branch <1 cm	1.84	10.28	2.16	16.45	32.96	2.59
1-3cm	3.57	16.20	4.26	22.10	69.01	5.61
>3 cm	1.76	6.14	1.82	7.35	24.44	2.44
Bark	7.85	32.47	10.99	70.74	170.77	16.42
Wood	46.83	74.60	20.71	90.25	91.17	12.90
Total	63.97	178.61	42.35	229.91	409.09	45.11

Data on the nutrient content of different components show that the major portion of N, P and K is accumulated in the wood (bole) (N 42%, P 49%, K 39%). Bark contained more calcium (42%) and magnesium (30%) compared to other components. Thus, harvest of wood removed 75 kg ha^{-1} of N, 21 kg ha^{-1} of P and 90 kg ha^{-1} of K from the site. Further, if burning of slash is carried out and small branches extracted for firewood, it would result in the loss of most of the nutrients from the site. These results indicate that retention of slash is crucial for maintenance of site fertility.

Status of the Project

- Pre-harvest characteristics (physical, biological, chemical) of the four experimental sites have been determined.
- Sites properly maintained; soil temperature, soil moisture, relative humidity maximum and minimum temperature and rainfall monitored at periodic intervals. Weather stations are being established at two sites.

Poor nutrient status of soils and adverse management practices are the main reasons for low productivity of eucalypts in Kerala. Although use of high quality (disease resistant) seedlings and the addition of nutrients to the soil may show some promise in terms of growth, these are inadequate to maintain high productivity in the long term. As burning and removal of slash are known to affect soil N and C status, priority should be given to retaining slash at the site. Removal of bark can lead to the loss of large amounts of calcium (Table 4). Slash retention, use of inter-row legumes and other silvicultural practices like weed control and soil trenching are options for maintaining site fertility and water availability to trees. The results of this project will help us to understand the influence of some of these practices on eucalypt growth and develop appropriate management practices.

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References

Balagopalan, M. 1992 Impact on soils of growing eucalypts in Kerala. *In:* Unni, P.N. (ed.) Proceedings of workshop on environmental problems in Kerala. Centre for Water Resources Development and Management, India, 12-21.

Balagopalan, M. and Jose, A.I. 1983 Changes in organic carbon and different forms of nitrogen under first and second rotation (coppiced) eucalypt plantations. Agricultural Research Journal of Kerala 21: 57-62.

Balagopalan, M. and Jose A.I. 1986 Distribution of organic carbon and different forms of nitrogen in a natural forest and adjacent eucalypt plantations at Arippa, Kerala, India. *In:* Sharma, J.K. *et al.* (eds.) Eucalypts in India: past, present and future. Kerala Forest Research Institute, India, 112-119.

Davidson, J. 1995 Ecological aspects of eucalypt plantations. *In:* Proceedings of the Regional Expert Consultation of Eucalyptus. FAO Regional Office for Asia and the Pacific, Bangkok, 35-72.

George, M. 1984 Nutrient removal from *Eucalyptus* plantations by harvesting wood. Indian Forester 110: 61-67.

Ghosh, S.P., Mohankumar, B., Kabeerathumma, S. and Nair, G.M. 1989 Productivity, soil fertility and erosion control under cassava-based forestry systems. Agroforestry Systems 8: 67-82.

James, E.J. and Mohan, R. 1986 Regional monthly rainfall run-off model for the Chaliyar basin – Malabar Coast. *In:* Proceedings of the 53rd Annual R&D Session, Centre for Water Resources Development and Management, India.

Kallarackal, J. and Somen, C.K. 1997 Water use of *Eucalyptus tereticornis* stands of differing density in Southern India. Tree Physiology 17: 195-203.

Nair, J.M., Deo, A.D., Nair, T.J.C., Kumar, D. and Ramaswamy, V. 1986 Reclamation of grasslands at Kulamavu, Kerala. *In:* Sharma, J.K. *et al.* (eds.) Eucalypts in India: past, present and future. Kerala Forest Research Institute, India, 200-209.

Negi, J.D.S. and Sharma, M.C. 1985 Biomass and nutrient distribution in an age series of *Eucalyptus* hybrid plantations in Tamil Nadu. Distribution of organic matter. Indian Forester 111: 1113-1124.

Sankar, S., Mary, M.V. and Alexander, T.G. 1988 Foliar analysis in *Eucalyptus tereticornis* and *E. grandis* to assess soil test methods for nitrogen, phosphorus and potassium. KFRI Research Report No. 53. Kerala Forest Research Institute, India, 18 p.

Sharma, J.K., Mohanan, C. and Florence, E.J.M. 1985 Disease survey in nurseries and plantations of forest tree species grown in Kerala. Kerala Forest Research Institute Research Report No. 36. Kerala Forest Research Institute, India, 268 p.

Singh, S.B., Prasad, K.G., Gupta, G.N. and Subramanian, V. 1988 Causes of decline of *Eucalyptus grandis* in Nagarampara Range, Kerala – a survey note. Journal of Tropical Forestry 4: 260-268.

7. Eucalypt Plantations in South-Western Australia

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Abstract

Hardwood plantation forestry is a new and expanding industry in south-western Australia where *Eucalyptus globulus* plantations are established on agricultural land. First-rotation growth rates are high, partly because of previous use of fertilisers and annual leguminous pasture species by farmers. A series of inter-rotation experiments has been established at two sites with contrasting soils to investigate options for plantation management that will maintain soil fertility and stand productivity in subsequent rotations. These experiments include alternatives for managing harvest residues, use of inter-row legumes and nutrient application rate trials. After harvest, about one-quarter of the N and half of the P and Ca in the trees was exported from the sites in logs. Most of the exported N and P was in the wood, whereas most Ca was in the bark. Where burning was used to remove harvest residues and prepare the site for planting, more than 500 kg ha^{-1} of N was lost from the more fertile site. Retention of harvest residues tended to increase soil moisture, moderate diurnal temperature fluctuations and enhance the pool of potentially available N. Soil organic matter content declined in the first two years following harvest, largely due to a reduction in the labile pool of soil carbon. There are indications of a reversal in this trend in the third year after harvesting, probably due to inputs of plant residue from turnover of roots. Early growth rates of trees were enhanced by retention of harvest residues, but longer-term measurements are needed to confirm this trend.

Background

Hardwood plantation forestry is a new and expanding industry in south-western Australia. More than 100 000 ha had been established by 1998 and the planting rate is currently about 20 000 ha yr^{-1}. *Eucalyptus globulus* is the desired species because of its high growth rate, short rotation length (»10 years) and favourable pulpwood properties. These plantations are established on agricultural land (Fig. 1) because of the much lower productivity observed on land recently cleared of native vegetation and by the promotion of farm forestry. Within this region, growth rates are high because of favourable temperatures, abundant incident radiation and the capacity of deep soil profiles to store water required to maintain growth during the hot dry summer period. However, high growth rates also depend on the elevated fertility status of ex-farm soils because of past fertiliser applications and pasture management practices. Sustaining tree productivity in the future will depend on maintaining levels of soil fertility in subsequent plantation rotations. Development of methodologies to identify and correct nutritional constraints to growth is essential if the high productivity expected from second-rotation plantations is to be realised.

Plantations established in the mid to late 1980s in south-western Australia are nearing harvest and clearfelling of some stands commenced in 1994. Second-rotation plantations on these sites are providing the first opportunity to determine the effects of a full short-rotation of hardwoods on farmland in this environment. A research project aimed at understanding the influence of plantation eucalypts on soil fertility has been initiated. The aim is to develop methodologies to ameliorate any induced nutrient decline so that high productivity is maintained.

Soils and Climate

Soils of the region are derived from the erosion of an ancient plateau mantled by laterite, and the profiles are deep and highly leached (McArthur 1991). Consequently they are inherently low in nutrients and organic matter, and generally contain high levels of iron and aluminium oxides that are strongly reactive with applied phosphorus (Turton *et al.* 1962). Improvement and maintenance of

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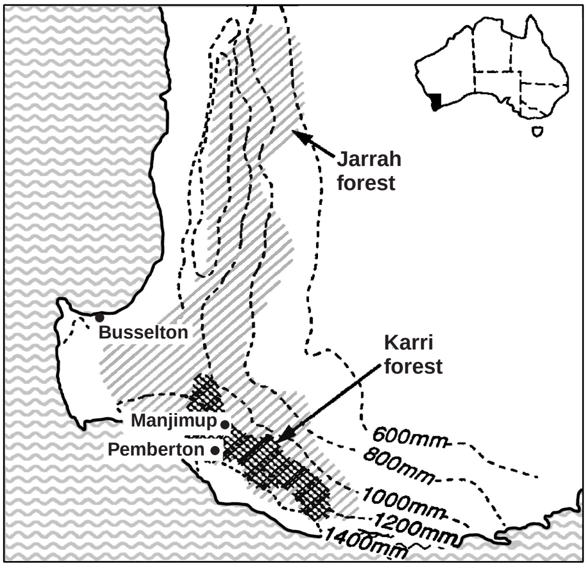
Figure 1. South-western Australia showing the areas of native jarrah (*Eucalyptus marginata*) and karri (*E. diversicolor*) forest and rainfall isohyets. Eucalypt plantations are mainly located on agricultural land with annual rainfall exceeding 700 mm.



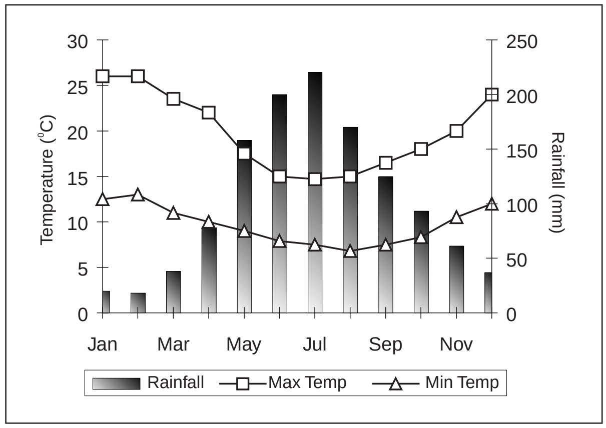
agricultural crop production have been possible only through frequent application of fertilisers and by crop rotation systems incorporating legume-based pastures.

The climate of the south-western region of Australia is Mediterranean (Fig. 2). There is marked seasonal variation in rainfall and temperature. The winter months are cool and moist while the summers are hot and dry. About 70-80% of annual rainfall occurs in the period May to September. There is a strong rainfall gradient from south-west to north-east from the southern coast and from west to east along the western coast. Maximum annual rainfall of about 1500 mm occurs near the south coast and on the Darling escarpment just south of Perth. Mean monthly temperatures increase from south to north and summer evaporation increases two-fold from the southern coast to the northern extent of jarrah forest near Perth. The extreme seasonal climate of the region exerts a strong influence on the soil microclimate, on biological processes occurring in the soil, and on plant growth (O'Connell 1987; O'Connell and Grove 1987; O'Connell and Rance 1995). Annual rainfall is one of the main factors delineating the area in which hardwood plantations for wood production are established.

Research Objectives

- Quantify longer-term changes in the nutrient-supplying capacity of soils in eucalypt plantations growing on agricultural land;

Figure 2. Seasonal variation in temperature and rainfall at Pemberton, within the main *Eucalyptus globulus* plantation region of south-western Australia.



- Determine nutritional requirements for growth of trees in second-rotation plantations; and
- Develop methodologies to manage soil fertility to maintain high productivity.

Methodology

Research is being conducted within two general frameworks:

1. Second-rotation sites

Experiments have been established on plantation sites clearfelled in 1994 and 1995:

(a) organic matter amendment experiments to determine effects of litter and slash residue management;
(b) utilisation of legume inter-row crops to manipulate soil organic matter quality and N supply; and
(c) nutrition experiments to determine responses of *E. globulus* to applied P and N and changes in nutrient supply rates.

Detailed measurements are being made of seasonal variation in soil nutrient mineralisation, plant nutrient uptake and tree growth.

2. Plantation/pasture paired sites

The influence of plantations on soil fertility is being measured in approximately 40 first-rotation (age 6 to 14 years) sites across a range of soil types, climate and stand productivity. Soil chemical properties, laboratory incubation methods and glasshouse bioassay studies are in progress to elucidate the differences in soil carbon, nitrogen and phosphorus status between paired pasture and plantation sites. This will allow prediction of the extent to which differences in nutrient uptake and growth can be explained by the length of time under plantation and by soil properties determining soil N and P supply.

Second-Rotation Sites

Sites

Experiments have been established at two sites that had supported a single rotation of *E. globulus* and which had previously been used for agriculture. One site near Manjimup has an annual rainfall of about 1100 mm and is on relatively fertile karri forest soil (red earth – Ferralsol). An 8-year-old stand of *E. globulus* on the site was clearfelled in August 1994. The second site near Busselton has an annual rainfall of about 1000 mm and is on a low-fertility soil (grey sand over laterite – Podzol). An 8-year-old *E. globulus* stand on the site was clearfelled in May 1995. On areas selected for experiments, slash was uniformly redistributed soon after clearfelling.

Experiments in experimental design

Four experiments have been established at each of the sites:

(i) Organic matter amendment (slash management)

(ii) Legume species experiment examining establishment and growth of five agricultural legumes in eucalypt slash plus a control (no legume)

(iii) N rate experiment — 5 rates of N (0, 40, 125, 250, 500 kg N ha^{-1}) as urea with a basal dressing of P, K, S and minor elements, + a nil N – nil P treatment

(iv) P rate experiment — 5 rates of P (0, 20, 50, 125, 250 kg P ha^{-1}) as triple superphosphate with a basal dressing of N, K, S and minor elements, + a standard spot fertiliser treatment — 100 g $tree^{-1}$ Agras (18:8:16, N:P:S)

Experimental design

For each experiment, a randomised block design was used with six treatments randomised within each of four replicate blocks. Treatment plots measure 18 x 18 m except for the legume experiment where single row 18 x 6 m plots were used.

Slash management treatments were:

- (**BL_0**) No slash — all litter and slash material removed
- (**BL_2**) Single slash — uniformly redistributed
- (**BL_3**) Double slash — addition of slash from the 'no slash' (**BL_0**) treatment
- (**B**) Burn – (**BL_2** – slash burnt) (**BL_2** + fertiliser) — broadcast (50 kg P ha^{-1} as triple superphosphate and 45 kg K ha^{-1} as K_2SO_4)
- (**BL_2** + fertiliser + legume) — broadcast P and K fertiliser with cover crop of vetch (*Vicia sativa*)

Sampling and measurements

Nutrient content of slash residues was determined after harvest. Stem volume measurements and nutrient concentrations in branches and stems were used to estimate nutrient contents of harvested logs and larger (>3 cm) stem and branch residues on the site. Surface (0-5, 5-10, 10-20 cm) soils sampled annually at each site have been analysed for pH (5:1 in water) and a range of total and labile nutrients. Soil moisture, concentrations of mineral N, rates of N mineralisation and potentially mineraliseable N are determined each four weeks using *in situ* coring. Soil temperature is being monitored continuously at hourly intervals, and an automatic weather station is providing meteorological data.

Results

Soil Chemical Properties

Concentrations of total N and P and extractable P in soils are much higher at the red earth site than at the grey sand site (Table 1). However, pH and organic carbon at the two sites are comparable. Large increases in labile P at the red earth plantation site relative to similar native forest soils (Karri forest) are attributed to fertiliser application during agricultural operations.

Table 1. Chemical properties of surface (0-10 cm) soils at the two sites and in forest and agricultural soils.

Site	pH	Organic C	Total N	Total P	Bray P
			($g\ kg^{-1}$)		($mg\ kg^{-1}$)
Red earth	5.5 (0.02)[a]	50 (3)	3.0 (0.3)	0.46 (0.05)	90 (12)
Grey sand	5.8 (0.04)	39 (3)	1.5 (0.1)	0.08 (0.01)	4 (4)
Karri forest soils	6.9 - 7.1	45 - 58	1.9 - 3.1	0.14 - 0.27	6.8 - 8.9
Agricultural soils	5.3 - 5.6	21 - 74	1.4 - 4.4	0.20 - 0.74	59 - 103

[a] SD in brackets.

Amount and Nutrient Content of Slash Residues

At the red loam site, concentrations of N and P in leaves were more than double the concentrations in other major tree components. Concentrations progressively decreased with increasing size of wood components (Table 2). The gradient in Ca concentrations was much less marked.

Table 2. Nutrient concentrations in slash components - red earth site.

Slash component	N	P	Ca
		($g\ kg^{-1}$)	
Leaves	11.8	0.67	14.8
Twigs (<1 cm)	3.4	0.31	11.9
Branches (1-3 cm)	1.9	0.21	4.8
Bark	2.6	0.17	12.6
Miscellaneous	6.5	0.55	12.4
Stems (3-15 cm)	1.1	0.18	2.9

The yield of wood from the experimental area was estimated to be 330 $m^3\ ha^{-1}$, equivalent to about 194 $t\ ha^{-1}$ of stems removed from the site and 71% of the total aboveground biomass. Leaves made up 27% of the slash but they contained 68% of the N and 52% of the P (Table 3). About one-quarter of the N in the trees, but a much higher proportion of the P (50%) and Ca (44%), was exported from the site in harvested logs. Most of this P was in the wood, whereas most Ca was in the bark. The combined effect of log export and burning of harvest residues to prepare for planting of new seedlings resulted in loss of more than 500 $kg\ ha^{-1}$ of N from the site.

Effect of Slash Treatment on Soil Moisture and Soil Temperature

Addition of slash residues improved retention of soil moisture (Fig. 3), especially in the first year after planting. In the second year when plantation trees were well established the differences in surface soil moisture between slash residue treatments was small. During summer, soil temperatures were generally lower and diurnal variation smaller on treatments with large amounts of slash (Fig. 4). During the cooler winter period, diurnal variation in surface soil temperatures was still greater on zero-slash (BL_0) plots but mean daily temperatures were more similar between treatments.

Effect of Slash Treatment on Soil Nitrogen Status

Slash treatments had a marked effect on soil mineral N pools. Mineral N accumulated to approximately 70 $kg\ ha^{-1}$ in the absence of slash (burnt or slash removed) during

Table 3. Amount and nutrient content of slash and harvested logs - red earth site.

	Dry weight	N	P	Ca
	($t\ ha^{-1}$)		($kg\ ha^{-1}$)	
Slash material				
Leaves	21.5	259	14.6	315
Twig + branch (<3 cm)	22.4	60	5.8	189
Bark and fine material	7.2	28	2.1	93
Branch and stem (>3 cm)	30	34	5.4	87
Exported logs				
Wood	170	95	22.2	104
Bark	24	45	5.8	423
Total aboveground	**275**	**521**	**55.9**	**1211**
Exported (%)	71	27	50	44
Natural forest in S.W. of WA[a]				
36-yr-old karri forest				
Tree (aboveground)	225	189	18	698
Soil - total		7439	1718	10224
- extractable		-	54	3827
Pole stand jarrah forest				
Tree (aboveground)	262	321	13	402
Soil - total		1802	969	3589
- extractable		-	106	1147

[a] Natural forest stand data from Hingston *et al.* (1979, 1981).

Figure 3. Seasonal variation in surface soil (0-10 cm) moisture in relation to harvest residue treatments at the red earth site near Manjimup.

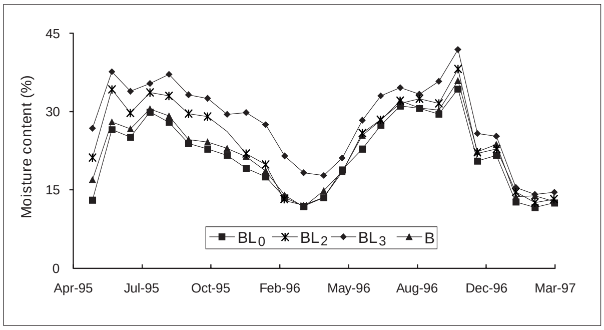
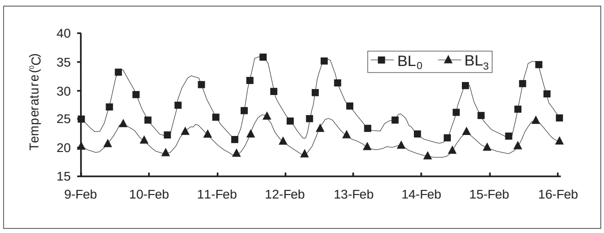
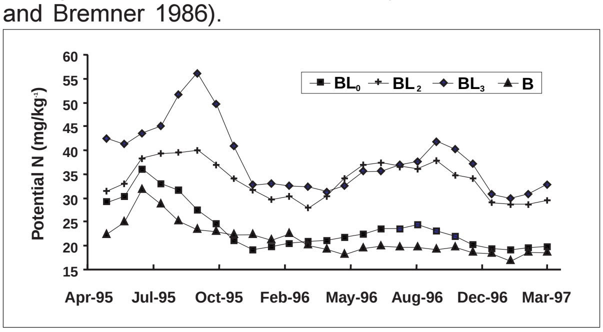


Figure 4. Variation in surface soil (0-10 cm) temperature in relation to harvest residue treatments during one week in summer at the red earth site near Manjimup.



the first two summers following harvest. Much of this mineral N was probably leached from the soil during the subsequent wet season. Mineral N pools on treatments where slash was retained were significantly lower and N losses were probably correspondingly reduced. Potentially available N, as measured by anaerobic incubation at 40^0C, tended to be greater on treatments with higher levels of slash (Fig. 5). Although potentially available N declined with time on all treatments during the first two years following harvest, the levels still remained higher on high-slash residue treatments.

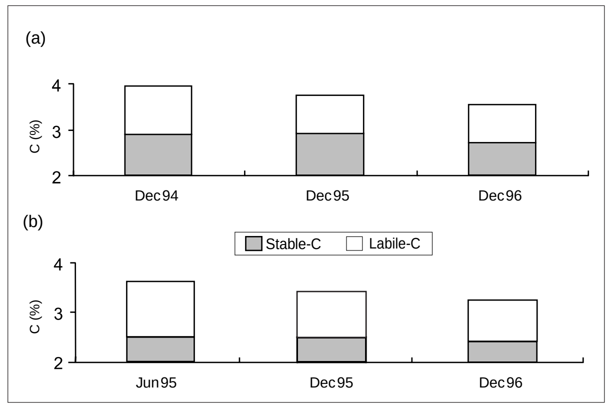
Figure 5. Seasonal variation in potentially mineraliseable N in surface soil (0-10 cm) in relation to harvest residue treatments at the red earth site near Manjimup. Potentially mineraliseable N determined as ammonium produced during anaerobic incubation for 7 days at 40ºC (Gianello and Bremner 1986).



Effect of Residue Treatment on Soil Carbon Status

None of the slash residue treatments significantly affected soil C status. However, over all slash treatments there was a decline in the labile component of soil carbon in relation to time since harvest. The stable component of soil carbon remained unchanged over the sampling period (Fig. 6). Annual measurements to determine concentrations of soil carbon fractions are continuing.

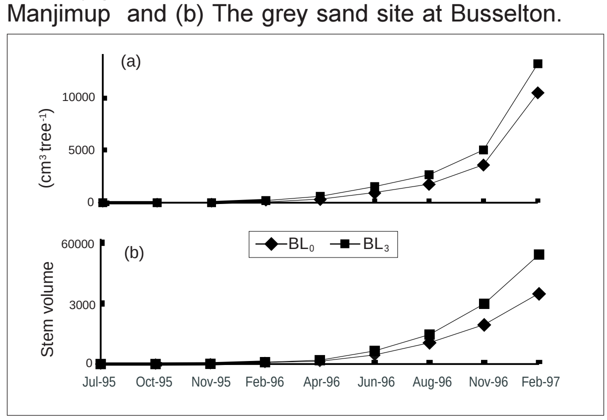
Figure 6. Temporal variation in soil carbon fractions at (a) The red earth site at Manjimup and (b) The grey sand site at Manjimup (mean of all slash management treatments). Labile C determined by partial oxidation of soil C using $KMnO_4$ (Blair *et al*. 1995). Stable C calculated as the difference between total and labile C.



Effect of Slash Treatment on Tree Growth

Application of slash residues at the highest level (treatment BL_3) enhanced early tree growth (after 19 months) relative to the zero-slash treatment (BL_0), but this effect was only significant at the red earth site (Fig. 7). Measurements over longer periods are required to fully assess treatment effects on tree growth.

Figure 7. Effect of slash residue treatments (BL_0, BL_3) on early growth of *E. globulus* at (a) The red earth site at Manjimup and (b) The grey sand site at Busselton.



Discussion

One of the factors responsible for high growth rates of *E. globulus* plantations in south-western Australia is the enhanced fertility of agricultural land on which trees are established. This is largely due to the previous applications of phosphate fertilisers and the use of legume-based pastures by farmers for many years. When plantations are established, regular applications of fertilisers usually cease and the nature of organic residues entering the soil changes markedly, i.e. pasture legume residues with high N contents compared to low-nitrogen, high-lignin eucalypt litter. The impact of these two changes on long-term nutrient supply to the plantation trees is uncertain. Manipulation of harvest residues, use of legume intercrops and application of fertilisers are options for modifying soil nutrient status and nutrient supply rates.

Burning of harvest residues is an attractive option from an operational viewpoint, allowing easy access to the site for management practices including weed control and fertilising. This is particularly so where plantation management is highly mechanised. However, burning leads to release of large amounts of N to the atmosphere. At some sites regular burning of harvest residues is likely to cause a long-term decline in soil nitrogen status. Removal of slash also has a marked effect on the soil environment and thus on the dynamics of microbially mediated nutrient mineralisation processes.

Other soil properties such as soil carbon status are also likely to be affected by slash management practices in the longer term. Our results show a decline in the pool of labile organic carbon 2-3 years after harvest. However, treatment effects due to alternative slash management procedures are not evident within this time frame. Longer-term monitoring is necessary to gain a better understanding of the trends in soil carbon status in these short-rotation plantations and to identify silvicultural practices that may be beneficial to improve soil carbon status.

Alternative slash management practices have markedly affected soil nitrogen status. Potentially mineraliseable nitrogen stores are enhanced by slash retention and the forms of mineral N in soil are modified. Slash retention tends to inhibit net N mineralisation and nitrification, probably through microbial immobilisation of mineral N. This process may be important for N conservation during plantation establishment when pools of mineral N are often large and trees have limited spatial development of their root systems. Manipulation of the quality of organic matter using annual inter-row legume crops is also an option for maintenance of soil fertility (Nambiar and Nethercott 1987) and productivity.

Retention of harvest residues and use of other inter-rotation management practices to manipulate soil organic matter quantity and quality is clearly desirable for enhancing soil biological and physical properties important for long-term soil fertility. Designing management systems that allow normal inter-rotation forest operations to be conducted while maintaining the benefits of retaining organic residues on the site will be a challenge for researchers and managers in the future. Accordingly, the next phase of our research is the establishment of new sites where a range of practical soil organic matter manipulation treatments suited to mechanised forest operations are being applied. This work is in progress.

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References

Blair, G.J., Lefroy, R.D.B. and Lisle, L. 1995 Soil carbon fractions based on their degree of oxidation, and the development of a carbon management index for agricultural systems. Australian Journal of Agricultural Research 46: 1459-1466.

Gianello, C. and Bremner, J.M. 1986 A simple chemical method of assessing potentially available organic nitrogen in soil. Communication in Soil Science and Plant Analysis 17: 195-214.

Hingston, F.J., Dimmock, G.M. and Turton, A.G. 1981 Nutrient distribution in a jarrah (*Eucalyptus marginata* Donn ex Sm.) ecosystem in south-west Western Australia. Forest Ecology and Management 3: 183-207.

Hingston, F.J., Turton, A.G. and Dimmock, G.M. 1979 Nutrient distribution in karri (*Eucalyptus diversicolor* F. Muell.) ecosystems in southwest Western Australia. Forest Ecology and Management 2: 133-158.

McArthur, W.M. 1991 Reference soils of south-western Australia. Department of Agriculture, Perth, W.A., 265 p.

Nambiar, E.K.S. and Nethercott, K.H. 1987 Nutrient and water availability to growth of young radiata pine plantations intercropped with lupins. New Forests 1: 117-134.

O'Connell, A.M. 1987 Litter dynamics in karri (*Eucalyptus diversicolor*) forests of south-western Australia. Journal of Ecology 75: 781-796.

O'Connell, A.M. and Grove, T.S. 1987 Seasonal variation in C_2H_2 reduction (N_2-fixation) in the litter layer of eucalypt forests of south-western Australia. Soil Biology and Biochemistry 19: 135-142.

O'Connell, A.M. and Rance, S.J. 1995 Predicting nitrogen supply in plantation eucalypt forests. *In*: Schulte, A. and Ruhiyat, D. (eds.) Soils of tropical forest ecosystems. Mulawarman University Press, Samarinda. Vol. 4, 136-147.

Turton, A.G., Marsh, N.L., McKenzie, R.M. and Mulcahy, M.J. 1962 The chemistry and mineralogy of lateritic soils in the south-west of Western Australia. Soil Publication No. 20. CSIRO Australia, Adelaide.

8. Pine Plantations on the Coastal Lowlands of Subtropical Queensland, Australia

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Abstract

Queensland Department of Primary Industry Forestry manages extensive exotic pine plantations consisting mainly of slash pine, Honduras Caribbean pine and the hybrid of these two taxa. Most of these plantations are located on the infertile coastal lowlands of south-east Queensland. They are managed intensively and there is concern about the maintenance of long-term productivity. One of the major opportunities for influencing sustainability is the period between harvesting and establishment of the succeeding crop. Removal of nutrients in logging and the use of fire to prepare second-rotation sites results in significant loss of nutrients from the site and large changes in the availability of nutrients. Ecologically sound harvesting combined with other desirable management practices are needed to ensure sustainable production. These practices need to be underpinned by a sound scientific basis.

Estimates of biomass and nutrient distribution in the biomass were made to provide a basis for interpreting changes in nutrient dynamics and tree response to residue management practices.

An experiment testing a range of clearfell residue manipulation treatments was established on a typical second-rotation slash pine site at Toolara in south-east Queensland. Growth of F_1 hybrid pines on this site is being monitored. Retention of litter and logging residues has not affected survival but has improved height growth by 11-24% at age 17 months. The site is to be used as a reference site in further investigations of key soil processes. The direction of future research required to interpret these findings and to provide a scientific basis for best forest management practices is discussed.

Introduction

Queensland Department of Primary Industry (QDPI) Forestry manages about 130 000 ha exotic pine estate of which 75% is located in the south-east of the State (Queensland Department of Primary Industries 1996). The resource consists of 42% slash pine (*Pinus elliottii* Engelm.), 42% Honduras Caribbean pine (*P. caribaea* var. *hondurensis* Barr. *et* Golf.) and 11% of the hybrid between these two taxa. Since 1991 the hybrid has been the major taxa planted. In 1995-96, 90% of the planting has been with the hybrid and over 85% of sites planted have been second-rotation areas. The earliest pine plantings date from the late 1920s, but most of the plantation was established between 1960 and 1980. Typical rotation length is 30-35 years and increasing areas of first-rotation stands are now being clearfelled and re-established. Little expansion of the present area is envisaged and increases in productivity and profitability will rely on the application of research results to improve silvicultural techniques and management efficiency. Maintenance or improvement of long-term site productivity is an essential component of this research.

The plantations are located essentially on coarse-textured infertile coastal lowland soils and their success is inextricably linked to the widespread use of fertiliser, especially phosphorus (Simpson and Grant 1991; Simpson 1995). While the long-term beneficial residual effects of phosphorus applied to first-rotation stands have been well documented, little is known about the change in availability of other nutrients and key soil processes as plantations age or during the inter-rotation period. There is concern about the maintenance of overall soil productivity. Changes in soil physical, chemical and biological properties resulting from inappropriate

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management are likely to have adverse effects on long-term plantation productivity. These changes are likely to be significant and take effect rapidly in the high-productivity plantations growing on poorly buffered sandy soils in a subtropical environment. Squire *et al.* (1979) suggested, after a review, that productivity decline between successive crops was more pronounced on coarse-textured infertile soils rather than on fine-textured fertile soils.

Forest managers have a major opportunity to influence long-term site productivity through soil and site management during the transition between successive rotations. Removal of nutrients in logging, coupled with the use of fire to prepare sites for re-establishment, can result in major nutrient losses from the site and changes in the mobility of plant nutrients. In addition, the unprotected soil surface on burnt areas exposes the site to accelerated soil erosion losses. More subtle but perhaps equally important deleterious changes occur as a result of removal of logging debris. Not only does retention of debris stabilise the soil surface, it also reduces soil moisture loss and soil temperature extremes and maintains or improves soil organic carbon condition (levels and quality), nutrient availability and soil microbial activities.

An experimental programme was initiated in 1995 to gather data on biomass accumulation and nutrient pools in a slash pine stand to gain a better scientific understanding of the processes. Following this work a field trial was established on the site to record the growth of second-rotation stands and the responses to alternative residue and site management regimes. This trial will be used for the detailed investigation of key soil-based processes. Future research required to improve the understanding of key soil processes, to maintain ecosystem functioning, to provide the scientific basis for the development of codes of best forest practice, and to allow identification and calibration of indicators of sustainable plantation forest management, is discussed.

Site Details

This case study was carried out at Toolara in Queensland, Australia (lat. 26°00'S, long. 152°49'E, altitude 61 m) in stands representative of the major contiguous Toolara–Tuan exotic pine plantation complex (80 000 ha). The site carried dry sclerophyll forest before clearing in 1959 for plantation establishment (see Coaldrake 1961 for detail). The area has a humid subtropical climate, with a mean annual rainfall of 1354 mm of which about 60% falls in the summer period between December and March. Mean temperature ranges between 14°C in winter and 24.9°C in summer (Shea 1987). Details of rainfall and temperatures are given in Table 1.

Occasional frosts occur in winter. Soils at the site are derived from Mesozoic sandstones, and are acid, deep and sandy, and classified as Grey Kandosols (Isbell 1996) or Gleyic Acrisol (FAO 1974). Fertility is low (Table 2) and large responses of the first-rotation stand to the additions of phosphorus fertiliser would have been expected. The soils are well drained in the upper horizons but can become waterlogged for short periods during the wet season with the watertable within 50 cm of the soil surface.

First-Rotation Stand Details

The first-rotation slash pine (seed orchard quality) stand was planted by hand in July 1966 with one-year-old open root nursery stock at a spacing of 3.0 x 2.4 m (1234 stems ha^{-1}). Fertiliser, 310 kg ha^{-1} Nauru rock phosphate containing 50 kg ha^{-1} phosphorus (P) was broadcast applied to the site in 1966 and a further application of 44 kg ha^{-1} P, as triple superphosphate, was aerially applied in 1980. Thinning was carried out at age 15.6 years by removing every fifth row and some trees within the bays to reduce stocking to 679 stems ha^{-1}.

The stand was periodically prescribed burnt on several occasions during the rotation with the last burn being within one year of clearfelling. All burns were carried

Table 1. Climatic details for Toolara. (Twelve-year averages, from Australian Bureau of Meteorology 1988, Climatic Averages Australia, AGPS).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean daily maximum (°C)	29.8	29.4	28.6	26.7	24.1	21.5	21.4	22.8	25.0	26.5	28.5	30.3	26.2
Mean daily minimum (°C)	19.8	19.8	18.8	14.9	12.0	7.9	6.3	7.5	10.1	12.9	16.6	18.9	13.8
Humidity (%) 0900 hr	73	75	77	76	80	78	79	72	65	61	65	67	72
Humidity (%) 1500 hr	63	64	66	61	63	56	50	47	48	52	56	57	57
Rainfall (mm)	187	212	147	89	110	53	55	42	44	84	129	143	1328
Raindays (no.)	15	17	16	13	13	8	9	8	8	10	13	12	142

Table 2. Soil properties of the experimental site.

Soil horizon[a] ⇨ Parameter[b] ⇩	A_1 (0-10 cm)	A_2 (10-40 cm)	A_3 (40-60 cm)	B_1 (60-80 cm)	B_2 (80-120+ cm)
Bulk density (g cm^3)	1.32	1.51	1.56	1.56	1.67
Coarse sand (%)	47.9	49.4	46.4	45.3	47.2
Fine sand (%)	36.1	35.6	39.6	38.7	28.8
Silt (%)	10.5	10.0	8.0	10.0	6.0
Clay (%)	5.5	5.0	6.0	6.0	18.0
pH	5.7	6.0	5.5	6.5	5.5
EC25 (dSm^{-1})	0.029	0.016	0.013	0.015	0.029
OC (%)	1.59	0.39	<0.1	<0.1	<0.1
N total (%)	0.047	0.016	<0.010	<0.010	<0.010
P total (mg kg^{-1})	39	11	7	10	20
CEC (c mol kg^{-1})	6.59	2.98	1.21	1.47	2.81
Na (c mol kg^{-1})	<0.01	<0.01	<0.01	<0.01	0.14
K (c mol kg^{-1})	<0.01	<0.01	<0.01	<0.01	<0.01
Ca (c mol kg^{-1})	1.77	0.40	0.23	0.17	<0.01
Mg (c mol kg^{-1})	0.72	0.21	0.17	0.20	1.01

[a]Horizons as defined by McDonald *et al.* (1990); [b]Methods as described by Kennedy and Collins (in prep.).

Occasional frosts occur in winter. Soils at the site are derived from Mesozoic sandstones, and are acid, deep and sandy, and classified as Grey Kandosols (Isbell 1996) or Gleyic Acrisol (FAO 1974). Fertility is low (Table 2) and large responses of the first-rotation stand to the additions of phosphorus fertiliser would have been expected. The soils are well drained in the upper horizons but can become waterlogged for short periods during the wet season with the watertable within 50 cm of the soil surface.

out under mild conditions to remove the upper litter layer only and hence reduce the fire hazard and to improve access. Woody weed regrowth was controlled and at clearfelling very little living vegetation (apart from the crop) existed on the site. The stand was clearfelled in November 1995, aged 29.4 years. The site index (average height (m) of the 50 tallest stems ha^{-1} at age 25 years) of the area was 23.7, compared with a district average of 23.4 for the species. At clearfelling the stand had a predominant height of 25.2 m, standing basal area of 39.6 m^2 ha^{-1} and standing volume of 325.4 m^3 ha^{-1}.

Biomass and Nutrient Distribution in a Rotation-Aged Slash Pine Stand

Methods

Stand details were obtained from a permanent inventory plot on the site and ten trees were selected, one from near the median point of each 10 percentile DBH (diameter breast height). The mass and nutrient content of stemwood, bark (total and to 7 and 15 cm top end diameters), living and dead branches, foliage and stump (including all roots >100 mm diameter) were measured. Regression equations relating biomass of each tree component to DBH were developed using the model:

$$Y = a + bx$$

where Y is the biomass of the tree component in kilograms and x is the diameter at breast height in cm. Various transformations of DBH and DBH by height were tested but resulted in no real improvement in the coefficient of determination of the regressions. Biomass and nutrient distribution of the stand were estimated from the inventory plot measurement data using the developed regressions.

Litter (fresh, decomposing and woody material) was sampled before clearfelling. Fine roots were sampled from vertical sections taken to a depth of 1.1 m from open trenches dug between stumps of average diameter and at 3.8 m between centres (representing 679 stems ha^{-1}). These roots were sorted into diameter size classes (<5 mm, 5-10 mm, 10-50 mm, 50-100 mm) weighed and subsampled for determination of moisture content and chemical analysis.

Results

In this study 80% of the biomass on the site occurs above ground and contains between 72% and 78% of the major

Table 3. Biomass and nutrient distribution in a 29.4-year-old slash pine stand.

Component	Biomass	N	P	K	Ca	Mg
			(kg ha^{-1})			
Foliage	2028	16.0	1.3	4.1	7.8	4.0
Live branches	18495	41.8	3.6	15.7	58.0	15.4
Dead branches	4107	4.8	0.1	0.8	9.0	1.7
Stemwood						
Total	176331	129.4	5.4	37.1	105.4	44.7
to 7cm TED	174868	128.4	5.4	36.7	104.5	44.3
to 15 cm TED	153624	112.8	4.7	32.3	91.8	38.9
Bark						
Total	30987	61.2	5.4	26.6	66.1	20.3
to 7cm TED	30874	60.7	5.4	26.5	65.8	20.3
to 15 cm TED	26552	52.2	4.7	22.8	56.6	17.4
Stemwood + bark						
Total	207318	190.6	10.8	63.7	171.5	65.0
to 7cm TED	205742	189.1	10.8	63.2	170.3	64.6
to 15 cm TED	180176	165.0	9.4	55.1	148.4	56.3
Tree above ground	231948	253.2	15.8	84.3	246.3	86.1
Litter						
Fresh	925	3.7	0.17	0.43	4.7	1.8
Decomposing	14126	82.9	3.67	3.11	68.4	15.4
Woody material	4719	11.6	0.42	1.18	10.4	3.1
Total litter	19800	98.2	4.26	4.72	83.4	20.3
Total above ground	251748	351.4	20.01	89.02	329.7	106.4
Stump	33000	38.3	2.1	11.1	20.7	10.7
Roots						
0 - 5 cm	7777	35.7	2.3	0.8	33.4	11.4
5 - 10 cm	4451	14.1	0.8	0.9	8.8	0.8
10 - 50 cm	15911	41.4	1.9	13.3	27.4	9.1
50 - 100 cm	2803	4.8	0.1	1.4	2.0	0.9
Total roots	30943	95.7	5.1	16.4	71.6	22.2
Total below ground	63943	134.0	7.2	27.5	92.3	32.9
Total biomass	315691	485.4	27.3	116.5	422.0	139.3
Logging residue - above ground						
Tree residue						
to 7cm TED	26206	64.1	5.0	21.1	76.0	21.5
to 15cm TED	51772	88.2	6.4	29.2	97.9	29.8
Above ground - Biomass on site after logging (i.e. + litter)						
to 7cm TED	46006	162.3	9.3	25.8	159.4	41.8
to 15cm TED	71572	186.4	10.7	33.9	181.3	50.1
Total biomass after logging (above ground + stump & roots)						
to 7cm TED	109949	296.3	16.5	53.3	251.7	74.7
to 15cm TED	135515	320.4	17.9	61.4	273.6	83.0

TED: Top end diameter over bark.

nutrients held in the biomass (Table 3). Between 52% and 72% of the nutrients in the biomass are in the aboveground parts of the tree. The quantity of potassium in the litter is relatively low. Depending on the nutrient, between 16% and 28% of the nutrients in the biomass are in the tree roots. Harvesting sawlogs (15 cm TED) removes 57% of the biomass from the site and, depending on the nutrient, between 34% (nitrogen and phosphorus) and 47% (potassium) of the nutrients. Integrated logging (to 7 cm TED) removes 65% of the biomass and between 39% (nitrogen and phosphorus) and 54% (potassium) of the nutrients. The mass of aboveground residues (including litter) is much lower (46-71 t ha^{-1}) than the merchantable timber removed (180-205 t ha^{-1}) but contains similar quantities of nutrients (except potassium where greater quantities are removed than retained). These data suggest that it is the manner in which the logging residues are managed that is likely to have a significant impact on the long-term productivity of the site.

Residue Management Trial

Experimental Design and Treatments

This experimental phase was designed to be assessed over a full rotation of 30-35 years. The trial consists of six treatments laid out as a randomised complete block replicated four times. Gross plots are 12 rows by 12 trees at 3 x 3 m spacing (0.13 ha) with a 6 m isolation and net plots of 0.058 ha. The treatments were designed to manipulate the levels of biomass on the soil surface, and competition levels, during the second-rotation establishment phase.

The treatments include:

BL_0 Removal of both litter and slash + 50 kg P ha^{-1}
BL_2 Retention of both litter and slash + 50 kg P ha^{-1}
BL_3 Double quantities of litter and slash + 50 kg P ha^{-1}
BL_2 + leguminous cover crops
BL_2 + complete weed control
BL_2 without fertiliser (P) addition.

Establishment

The treatments were applied to plots in February 1996, three months after clearfelling. Immediately after, estimates of retained biomass were made for individual plots. Five 1.0 m^2 quadrats were systematically located and samples were collected from each quadrat and separated into components. Moisture contents of the samples were determined for each component and dry weights calculated.

Planting spots were prepared using an excavator-mounted rotary cultivation head. Pre- and post-planting herbicides were sprayed in bands to control weed growth along the rows. The plots were planted in May 1996 with container-grown F_1 hybrid seedlings from eight unrelated families, retaining family identity. An individual-tree application of triple superphosphate was applied at planting to supply 45 g P to each seedling (apart from BL_2 without P). A mixture of legume seeds containing Lotononis (*Lotononis bainesii*), Wyns cassia (*Cassia rotundifolia*) and Maku lotus (*Lotus pedunculatus cv Maku*) was sown on three occasions in the plus legume treatment. Legume cover has been slow to develop.

Results

Total clearfelled timber removals from the site amounted to 311 m^3 ha^{-1} (sawlogs plus tops to 7.0 cm top end diameter). Estimates of biomass on the soil surface after the residue manipulation treatments are:

- Nil residue treatment 9.0 t ha^{-1}
- Normal residue 50.8 - 73.9 t ha^{-1}
- Double residue 141.4 t ha^{-1}

These estimates are in close agreement with the expected values derived from the preceding study (46.0-71.6 t ha^{-1}).

It was not possible with the equipment used to remove the small amount of litter (<10 t ha^{-1}) remaining on the nil litter treatment (BL_0) without causing excessive site disturbance. The ‘retention of normal litter’ treatments carried 60 t ha^{-1} (50.8 to 73.8) of which it was expected that approximately 40% was the original forest floor litter. The ‘double litter’ was not intended as an operational practice; it provided an opportunity to widen the experimental treatment range and to facilitate interpretation of results of both the growth studies and studies of key soil processes.

Survival of the planted stock was excellent (99%) and early growth has been quite acceptable (Table 4). The treatments have not had any effect on survival. This is not surprising as the individual planting spots were cultivated after the coarse logging debris was removed from the spot prior to cultivation, so at planting there was little difference in the immediate plant environment.

Little growth occurred during the winter after planting and no treatment effects were apparent by spring. However, treatment differences appeared during the following growing season. There was no difference in

Table 4. Survival and development of F_1 hybrid pines on a second-rotation site at Toolara.

Treatment	Stocking at 5 months (stems ha^{-1})	Mean height (cm)		
		0 month	5 months	17 months
BL_0	1107	40	42	132
BL_2	1102	43	43	153
BL_3	1094	43	44	157
BL_2 + legumes	1098	42	43	163
BL_2 + weed control	1107	42	43	146
BL_2 without P	1102	43	44	135
Mean	1102	42	43	148
LSD (P=0.05)	NS	NS	NS	17

NS: non significant; LSD: least significant different.

development of the trees in the treatments where litter was retained and P fertiliser applied. Tree height was however significantly poorer in treatments involving the removal of litter or where no P fertiliser was applied. Litter retention resulted in a 17.2% (10.6-23.5%) improvement in tree height. This growth response, at this age, is equivalent to the response attributable to application of P fertiliser at 50 kg P ha^{-1}. Higher rates of litter, legume cover crops, or total weed control treatments did not show any growth advantage over the standard litter retained with 50 kg P ha^{-1} treatment at this young age.

Soil samples (0-10 and 10-20 cm) were collected in December 1997 to examine the effect of the residue management treatments on soil chemical and biological properties.

Future Research Directions

Careful management of the infertile sandy coastal soils used for exotic pine plantations in the tropics and subtropics is essential if site productivity is to be maintained or enhanced. It is generally agreed that the combined nutrient losses (especially nitrogen) due to harvesting and the removal of litter and logging residue (slash) are significant and in some cases high in relation to the total nutrient pools in the ecosystem and the likely levels of accretion; and that the sites will be less productive in subsequent rotations unless additions of fertiliser compensate for the net nutrient losses. Loss of organic matter will also seriously reduce the capacity of these sites to maintain the plantation productivity.

In order to develop best forest practices for tropical and subtropical situations it is necessary to understand key soil processes in these environments and how to manipulate these processes to ensure maintenance of site productivity. Detailed studies are required to develop a basis for interpreting results of experimental work, to aid in the design of codes of best forest practice and to establish indicators of sustainable forest management.

In the past, most of the Soils and Nutrition Research Program of QDPI Forestry has focused on improving the productivity of exotic pine plantations through use of fertilisers, particularly with P fertilisers. While applied soil fertility and stand nutrition research will be continued, there are increasing efforts in conducting studies on important soil-based processes which underpin the plantation sustainability and environmental impacts of both exotic pine plantations and native hoop pine plantations in Queensland.

Collaborative research programmms are being implemented to:

- assess changes in soil properties and processes under plantations;
- identify potentially useful indicators of sustainability;
- assess, test and interpret indicators of sustainability;
- quantify the impact of best management practices on off-site effects;
- partition productivity differences between rotations;
- quantify the impacts of soil and site management on microbially mediated soil processes in relation to soil organic matter (SOM) quality and quantity;
- improve understanding of N dynamics and cycling; and
- evaluate the effects of soil and site management during the critical inter-rotation period on soil physical processes.

The site of the experiment described is being used as an important resource for aspects of these studies and for other postgraduate research projects. The experiment will be periodically updated and reported to both the clients and the scientific community.

Conclusions

QDPI Forestry manages an extensive area of exotic pine plantation on infertile sandy coastal soils. Future plantings will be on second and subsequent rotations and there is increasing urgency associated with being able to demonstrate the sustainability of these plantation ecosystems. Manipulation of litter and logging residues in the inter-rotation period is one of the critical activities which affect long-term productivity. Early data from this trial indicate the value of retaining logging residues. This research will be continued to provide a scientific basis to sustainable management of these potentially fragile sites. Results from these trials and other comprehensive research are expected to underpin research on indicators of sustainability and further development of codes of forest practice.

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References

Coaldrake, J.E. 1961 The ecosystems of the coastal lowlands (Wallum) of southern Queensland. Bull. No. 283. CSIRO, Melbourne, 138 p.

FAO 1974 FAO – Unesco soils map of the world 1:5 000 000. Vol. 1 Legend. Unesco: Paris, 59 p.

Isbell, R.F. 1996 The Australian Soil Classification. CSIRO Publishing, Collingwood. 143 p.

Kennedy, M. and Collins, P. (in prep.) Methods of soil and plant analysis of Queensland Forestry Research Institute. QDPI-Forestry, Technical Paper.

McDonald, R.C., Isbell, R.F., Speight, J.G., Walker, J. and Hopkins, M.S. 1990 Australian Soil and Land Survey field handbook, Second Edition. Inkata Press, Melbourne, 198 p.

Queensland Department of Primary Industries - Forest Service.1996 DPI Forest Service 1995-1996 Yearbook. Department of Primary Industry, Brisbane, 47 p.

Shea, G.M. ed. 1987 Aspects of management of plantations in tropical and subtropical Queensland. Queensland Department of Forestry, Brisbane, 71 p. Revised edition of Hawkins, P.J. and Muir, J.A. original paper for the Ninth Commonwealth Forestry Conference, New Delhi, India. 1968, 35 p.

Simpson, J.A. 1995 Site-specific fertiliser requirements of exotic pine plantations in Queensland. p. 90-106 *in* Proceedings of the International Congress (Third Conference on Forest Soils), 'Soils of Tropical Forest Ecosystems. Vol. 5: Soil Fertility and Fertilisation'. Schulte, A. and Ruhiyat, D. eds. Balikpapan, Indonesia, 29 October - 3 November 1995. Mulawarman University Press, Samarinda, Indonesia.

Simpson, J.A. and Grant, M.J. 1991 Exotic pine fertiliser practice and its development in Queensland. Queensland Forest Service Technical Paper No. 49, 1-17.

Squire, R.O., Flinn, D.W. and Farrell, P.W. 1979 Productivity of first and second rotation stands of radiata pine on sandy soils. 1. Site factors affecting early growth. Australian Forestry 42: 226-235.

9. Chinese Fir Plantation in Fujian Province, China

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Abstract

A field experiment was established to study the impact of site management on productivity of multiple-generation plantations of Chinese fir. Five different logging residue levels were applied during the harvest of a Chinese fir plantation after which a second-generation plantation was established. Measurements after one year indicate that leaving the greatest amount of logging slash was the most favourable treatment for growth of Chinese fir and the most unfavourable for ground vegetation. Burning of the logging residue had no significant effect on the growth of one-year-old Chinese fir, but reduced the biomass production of the ground vegetation. Tree growth on the complete removal treatment was intermediate; otherwise the growth increased as the amount of logging residue left on the site increased. The understorey vegetation dominated the site and accounted for 93% of the biomass production of Chinese fir stand after one year. About 50% of the harvest residue had decomposed at 16 months after harvesting. Regression analysis showed predicted complete decomposition of the harvest residue at 33 months.

Introduction

Chinese fir (*Cunninghamia lanceolata* (Lamb.) Hook.) is native to central and southern China but it has been planted in large areas elsewhere in the country. Because of its fast growth and desirable wood properties, Chinese fir is one of the world's most important timber species. The species has been cultivated for over one thousand years, and farmers have developed extensive expertise in its management. In spite of this long history of successful management, the possibility of site deterioration and productivity decline of Chinese fir plantations has become a serious concern during the last thirty years. Growth declines in the second and third rotations have been reported. While there are many potential causes for such a decline, unsuitable cultivation systems may be a key factor. The effects of burning and site preparation on water runoff, soil erosion and fertility have been studied in field plots. However, the effects of harvest methods and logging residue management on Chinese fir productivity are unknown.

We have established a study to evaluate the effects of harvesting intensity and residue burning in a 29-year-old Chinese fir plantation. The objective is to measure the impact of soil and site management practices on the growth of the next rotation of Chinese fir. Management options for maintaining or increasing soil fertility and stand productivity under successive rotations will be developed.

Site Details

The trial site is located in south-eastern China in Fujian Province (longitude 118°10'E, latitude 26°45'N) on the Xiayang Forestry Farm. Because of the warm, moist summers and deep soils, Chinese fir is very productive and has been planted in this area for hundreds of years. The site is in the middle subtropical zone, with a mean annual precipitation of 1817 mm and a mean annual temperature of 19.4°C. The temperature ranges from -5.8 to 41°C. The soil is an unidentified red soil with a

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profile more than 1 m deep (Table 1). Because aspect may affect growth, the experiment was laid out so that all plots in a block have a common aspect (Table 1). The altitude above sea level was also significantly affected by blocking and ranged between 230 and 278 m (Table 1). The thickness of the A horizon of the soil was measured at 5 m intervals along the length of each plot.

Table 1. Details of difference between blocks on the site of the experiment.

Block	Elevation	Aspect	Depth of A horizon	Soil depth
	(m)		(cm)	
1	278	W	18	>100
2	244	W	17	>100
3	255	N	16	>100
4	230	E	22	>100

The variation between blocks is only 16 to 22 cm and is not statistically different. Soil samples were collected from 5 points in each plot at the depths of 0-10, 10-20 and 20-40 cm. Total organic C (potassium dichromate digest), pH (water), total N and P, available P and exchangeable K, Ca, Mg, and Al was determined. The soils are acid and have high levels of exchangeable Al (Table 2), but exchangeable K and Ca appear to be sufficient for fir growth.

Table 2. Soil chemical properties of the experimental site.

Parameter	Soil depth (cm)		
	0-10	10-20	20-40
pH	5.1	4.9	4.9
Organic matter (%)	5.3	4.3	3.0
Total N (%)	0.113	0.088	0.067
Total P (m g kg^{-1})	367	357	411
Available P (m g kg^{-1})	3.1	2.3	1.1
CEC (cmol kg^{-1})	156.5	132.6	126.6
Ex. Ca (cmol kg^{-1})	10.7	6.6	5.8
Ex. Mg (cmol kg^{-1})	5.5	2.8	2.3
Ex. K (cmol kg^{-1})	2.5	1.6	1.2
Ex. H (cmol kg^{-1})	1.5	1.1	1.0
Ex. Al (cmol kg^{-1})	53.6	57.9	51.2

Stand Description

The Chinese fir crop of the last rotation was planted in spring of 1967 and felled in winter of 1996. No information is available about management of the stand between planting and harvesting. Before felling, the height and diameter of all trees in the plots were measured. Biomass and nutrient content were determined on selected sample trees before harvest. The biomass in the litter and understorey was also determined. At the time of felling, the Chinese fir averaged 19.6 m in height and 23.7 cm DBH. The average stocking was 1259 trees ha^{-1}, but ranged from 783 to 1767 trees ha^{-1} on individual plots. The average volume for the experimental area was 518 m^3 ha^{-1} so the average annual volume growth was 17.9 m^3 ha^{-1} yr^{-1}.

Materials and Methods

The experimental design is a completely randomised block with four replications each containing five plots. The five treatments consist of four levels of logging residue or slash removal plus one burning treatment. The treatments are:

BL_0BM_0 Complete — All aboveground organic residue including the crop trees, understorey and litter was removed from the plots.

BL_1BM_0 Whole-tree harvest — All aboveground parts of the trees removed.

BL_2BM_0 Stem + bark harvest — Only the main bole and attached bark was removed.

BL_3BM_0 Double slash — Branches, leaves and other non-commercial components of trees from the BL_1BM_0 treatment were applied to this treatment.

BL_2BM_1 Stem and bark harvest + burning — Same as BL_2BM_0 except the residue was burned.

Each plot is 600 m^2 and has 180 trees or 3000 planted trees ha^{-1}. Soil preparation was done by hand and consisted of planting holes 50 x 50 cm and 40 cm deep. Planting was done in February 1997, and a complete fertiliser (NPK) was applied in May 1997 at a rate of 100 g per tree. Rim weeding was done twice in the first year (July and November). Weeding will be repeated in later years.

In January 1998, after one growing season, total height, diameter at ground level, and crown diameter of all the Chinese fir were measured. One tree in the border area of each plot was felled for the development of biomass equations. The equations were used to estimate the biomass on each plot. In May 1998, ground cover including litter, brush and grasses was clipped from 3 subplots (1 m^2) within each plot. Analysis of variance was used to determine the statistical significance of the treatments.

To measure rates of decay, samples of harvest residue were collected from the stem + bark harvest (BL_2BM_0) treated plots at 2, 4, 6, 11 and 16 months after harvesting.

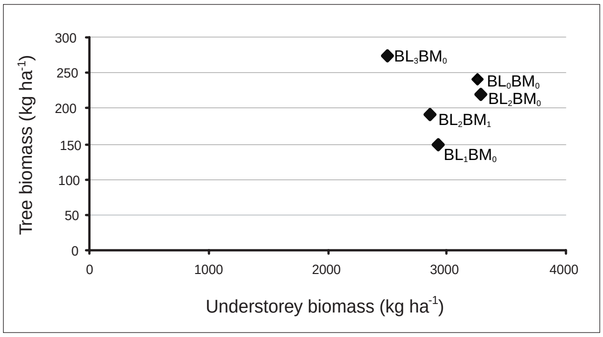
Within-plot samples of the logging residue were collected at the upper, middle and lower part of the slope. The samples were dried and weighted. The rate of decomposition was determined by comparing the weight at each sample time with the weight at harvesting.

Results and Discussion

After one season, the treatments had a statistically significant effect on height and diameter growth of Chinese fir (Table 3). The trees on the double slash treated plots were the largest, followed by the trees on the complete removal plots. Except for the total removal treatment, tree growth increased as more residue was left on the ground. Compared to the treatment with the same amount of residue left, the burning treatment had no significant effect on the growth of the trees. The survival of the trees was not significantly affected by the treatments with an average survival of 66%, leaving 2003 trees ha^{-1}.

The understorey vegetation dominated the site after one growing season, accounting for 93% of the biomass. The treatments had only a small effect on the amount of understorey biomass (Table 3). The double slash treatment reduced the amount of understorey biomass by 23% compared to the stem + bark harvest. Even thought the competing vegetation was controlled around the Chinese fir, the understorey vegetation affected the growth of the trees. The linear relationship between understorey biomass and tree biomass is significant and negative. On average, the biomass of the fir was reduced by 0.087 kg ha^{-1} for every kg ha^{-1} of understorey biomass on the plots (Fig. 1). This relationship may partially explain the effect of treatments on tree growth. The double slash treatment probably acts as a mulch in the first growing season, inhibiting the production of some understorey competition.

Figure 1. Tree-understorey biomass relationship.



Compared to the amount of residue remaining after harvest, about 50% of the logging residue was decomposed 16 months after harvesting. Two regression equations were fitted to the amount of logging residue remaining 0, 2, 4, 6, 11 and 16 months after harvesting (Table 4). The estimated time for complete decomposition of the harvest residues was 33 months for both regression equations.

Table 3. Effect of treatments on the heights, ground line diameters, and biomass of Chinese fir and understorey biomass after one growing season.

Treatment	Height (m)	Diameter at ground level (cm)	Tree biomass (kg ha^{-1})	Understorey biomass (kg ha^{-1})
BL_0BM_0	0.9 bc	1.5 bc	242 b	3253 ab
BL_1BM_0	0.7 a	1.2 a	150 a	2931 ab
BL_2BM_0	0.8 ab	1.4 ab	219 ab	3285 b
BL_3BM_0	1.0 c	1.7 c	275 b	2503 a
BL_2BM_1	0.8 ab	1.4 ab	192 a	2858 ab

Values in a column followed by the same letter are not significantly different (alpha=0.05).

Table 4. Regression equations predicting the percentage of logging residue remaining from the time in months after harvest.

Regression equation	R	N	Theoretical complete decomposition month
P=99.6011-3.017478*M	-0.9657	24	33.0
P=100-2854.212*(1-exp(-0.001077375*M))	0.9521	20	33.1

P: Percentage remaining cutting (%); N: Number of months after cutting.

Conclusions

1. The Chinese fir were largest on the plots receiving the double slash treatment (BL_3BM_0) but this treatment was also the most unfavourable for the ground vegetation. The treatments BL_2BM_0 and BL_2BM_1 had similar effects on the growth of Chinese fir after one growing season, indicating that clearance burning had no significant effect on the growth of Chinese fir. However, the burning reduced the biomass production of the ground vegetation by 13%. Excluding the total removal treatment, tree growth was reduced as more residue was removed so the worst treatment was BL_1BM_0.
2. The total biomass production of the one-year-old Chinese fir stand was reduced as the biomass production of the understorey vegetation increased, suggesting that additional control of the understorey may be beneficial to the Chinese fir.
3. About 50% of the harvest residue was decomposed 16 months after harvesting. Regression analysis showed that theoretical time for complete decomposition of the harvest residue is 33 months.
4. As results reported here are based on only one year of data, further measurements and observations are necessary for reliable conclusions. This experiment will continue for one rotation.

A Progress Report

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Introduction

This project was finally planned at a workshop held at the Forest Research Institute of Malaysia in November 1995. On that occasion, the objectives, approach, methodology and coordination were finalised by the partners and the Science Advisory Group (SAG). The papers to the present workshop, describing the progress at individual sites, illustrate that the partners have implemented the plan in two years on a broad range of sites representative of plantation forestry in the tropics. While each site is designed as a self-contained study, the linkages within the network will enhance the value of the results to all partners. This summary of the location and environment of the sites and the data collected indicates that a robust network has been established. Linkages between the sites and between scientists are being developed to better understand the science and the basic processes that influence productivity of tropical forest plantations.

Location and environment of sites

As a part of this network, activities at 15 sites have been initiated or are in the final stages of planning (Table 1). The sites are located on all four continents that have land mass in the tropics and range in latitude from 26°N to 34°S. All sites are in the lowland tropics but both tropical moist forest and tropical dry forest types are included.

Climate

The climatic conditions at the sites cover the ranges where plantation forestry can be developed. Annual rainfall ranges from 877 mm at one of the South African locations to 3000 mm or more at a site in Kerala, India. However, rainfall distribution and seasonal evapotranspiration rates also vary widely and they are often likely to affect growth of the trees more strongly than total rainfall. At the sites in south-western Australia, South Africa and the Congo, evapotranspiration exceeds precipitation for several months in most years. Under the monsoonal climate in Kerala water deficit is a common feature during dry months despite the high annual rainfall.

Treatments that affect water loss, such as removal of all aboveground organic matter (BL_0), are expected to stress the tree more in sites where seasonal water deficits occur than where rainfall is more evenly distributed and drought stress occurs less frequently or to a lesser degree. However, in areas with high rainfall, leaching of nutrients from the soils may be a problem, especially when most of the slash is removed. At these sites, good residue management may improve tree growth by conserving nutrients on the site. Temperatures at sites near the equator, such as in Sumatra, are never low enough to limit biological activity including tree growth and litter decomposition. In contrast, temperatures may get below freezing at the South African, Australian and Fujian (China) locations for short periods, interrupting biological processes.

Geographic features

The topography at most of the sites is described as flat to rolling with the exception of the Fujian, China, plantation, which is located on steep but uniform slopes. The soils have not been completely described and classified at all sites as yet, but in general they are coarse textured with low fertility, low water-holding capacity, and little organic matter. The low fertility is partly due to natural causes including small amounts of weatherable minerals and the large amount of leaching that occurs in the wetter areas. The low levels of fertility and soil organic carbon can also be traced to past land use practices that degraded the soil.

The sites in South Africa range from sands to silty clays to clays, so these will be a good test of the interaction

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Table 1. Location, species, climate and rotation length at sites where studies are in progress.

Site and Species	Rainfall (mm yr^{-1})	Minimum temperature (°C)	Maximum temperature (°C)	Rotation length (yr)
Queensland, Australia *Pinus elliottii × P. caribaea*	1354	14	25	30
South-western Australia – 2 sites *Eucalyptus globulus*	1000-1100	9	25	8
Itatinga, Brazil *E. grandis*	1579	18	22	7
Fujian, P.R. China *Cunninghamia lanceolata*	1817	NA	NA	29
Guangdong, P.R. China *E. urophylla*	2178	15	28	6
Pointe-Noire, Congo Eucalypt hybrids	1200	22	27	8
Kerala, India – 4 sites *E. tereticornis, E. grandis*	3000	20	42	7
South Sumatra, Indonesia *Acacia mangium*	2000-3000	29	29	7
Natal, South Africa – 3 sites *E. grandis, P. patula*	877	3	25	25

between the forest management treatments and soil texture. The broad range of soil properties represented in the projects is reflected in the types of site-specific treatments selected to enhance productivity. The establishment of four sites across four distinct environmental zones within the monsoonal humid tropical belt of Kerala may provide an opportunity to explore some of these key interactions.

Tree Species

Exotic species have been planted at each site except at the Chinese fir (*Cunninghamia lanceolata*) site in China. This reflects the general development of plantation forestry in the tropics and subtropics, which is predominantly based on eucalypts, acacias and pines. The species chosen for each location has a known history of productivity at that site, and is the same as the crop being harvested. The latest genetic selections are being used in plots where regeneration is not by coppicing. This ensures that the genetic material is adapted to the site and that advances from genetic improvement are used to maximise production.

Eucalyptus grandis is planted in 5 of the 15 sites, while *E. tereticornis* is used at two sites in Kerala and *E. globulus* at two sites in south-western Australia. Subtropical *Pinus patula, P. elliottii × P. caribaea* and *Cunninghamia lanceolata* have also been included. We will have to pay attention to the genetic variation of species between sites when we attempt to interpret the results and draw generic conclusions.

Treatments

Core Treatments

The core treatments are designed to achieve maximum contrast in levels of stress on the system and to have treatments as equally spaced as possible. At some sites, partners have refined the treatment definitions to accommodate local conditions and operational requirements. Others have not been able to install all four levels of the core treatments. Of the 15 sites installed or planned, 11 have all four levels, and 4 have three levels. Double slash (BL_3) is missing at Itatinga, Brazil, and whole-tree harvesting (BL_1) is not included at the three Australian sites. Despite these variations, core treatments have been applied with sufficient uniformity to enable us to look forward to results of generic value.

Aboveground residue treatments can affect the soil water regime through changes in infiltration and evaporation. Soil fertility will be influenced because of the nutrients in the residue retained or removed, by changes in soil erosion, and changes in the amount of leaching.

Optional Treatments

The optional treatments are management options that are expected to increase the productivity of the plantation and are complementary to the core treatments. They are also to be used for testing various ideas that are proposed by local managers. These are applied at one level of the core treatment, usually BL_2, but have a cultural treatment applied differently from that for the core treatments.

As an example, fertiliser is applied to all of the core treatments at Guangdong, China, but an optional treatment of no fertiliser and a high rate are also included. Burning of the logging residue to facilitate planting is the most popular optional treatment, even though such a practice may release large amounts of N to the atmosphere and in some regions (e.g. Sumatra, Indonesia) regulations prohibit slash burning. Fertiliser application, usually of N or P, has been selected for several sites, while cover crops, weed control and soil tillage have been added at two or more locations. Use of N-fixing understorey has been included at some sites. In a project of this kind where environmental, site and stand characteristics differ widely between sites, the value of optional treatments to examine particular issues cannot be over-emphasised.

Databases

A minimum set of measurements must be made on all sites in order to permit comparison and synthesis of results and to assist in the transfer of process-based information to sites where intensive work is not initially possible. The minimum data set must be collected with a common goal of comparing the information and using standard methods. A pre-harvest data set comprising descriptive measurements of stand, soil and other site conditions must be collected after the plots have been established but before harvest. However, because of the wide variety of species and soils in the network, the methods are adjusted to match local conditions. As an example, at the Sumatra site, high mortality in the standing crop required development of a protocol to separate the dead trees into biomass included as litter and that included in the standing biomass. At the Pointe-Noire, Congo, plantation, fine roots at the surface were difficult to remove and were considered as part of the belowground root mass rather than surface organic residue. Refinements in the methods such as these need to be discussed as the results from these sites become available. Post-harvest descriptive measurements are made periodically during the course of the rotation. As in the case of the pre-harvest measurements, refinements in definitions and measurements of the new stand will be required. Measurements to support processed-based research are in progress where resources and skills are available.

Pre-harvest

Before harvest, trees on the plots are sampled in sufficient detail to estimate the mass of wood and bark in the main stem, branches, foliage, understorey and litter. Subsamples are collected for determination of nutrients in each class of biomass. This information is essential for calculation of the biomass and nutrients left on the plots or removed by the harvest. Usually, only the aboveground biomass is included, but root biomass and nutrient content measurements were made at the Queensland, Australia, site.

Soil measurements made before harvest include bulk density, texture and sufficient information for classification using the FAO system. At the same time, soil samples are collected from the surface for chemical analysis. Measurements include total organic carbon and nitrogen, pH, exchangeable cations including Al and exchangeable acidity, electrical conductivity, available N and P. The initial forest stand measurements will soon be completed at all sites; preparation of a summary of the data for all or some sites will be considered.

Post-establishment

Tree growth

The height and diameter of all trees on each treatment plot will be measured at periodic intervals during the rotation. Volume and biomass equations will be developed from sample trees so these variables can be estimated from the height and diameter data. Foliage samples will be collected at specified times for characterising stand nutrition. This information is already available in some cases.

Understorey and forest floor

The biomass and species composition of the understorey will be measured periodically. Litterfall will be measured using litter traps, while the forest floor will be sampled annually for mass and nutrient determinations. Studies of litter decomposition using litter bags or similar methods will be encouraged.

Soils

Bulk density and hydrological properties will be measured in the months immediately following replanting. At the same time, samples will be collected through the soil profile for chemical analysis. Depth to which soil will be collected will depend on the profile features. Measurements will include total organic carbon and nitrogen, pH, exchangeable cations including Al and exchangeable acidity, electrical conductivity, and available N and P. Total and labile organic carbon, total and anaerobic N, and available P determinations will be made on surface soil samples collected at mid-rotation or at three-year intervals. Soil strength will also be measured at those times using a recording penetrometer. Measurements that increase the understanding of processes such as N mineralisation will be encouraged. All soil samples are to be properly stored (archived), as they are expected to be valuable reference samples for long-term analysis of changes in soil properties.

Climatic data

If possible a weather station should be established on or near the site for daily measurements. Rainfall, pan evaporation, wet and dry bulb temperature and solar radiation will be measured at a specified time each day. Maximum-minimum temperatures should be recorded also. Additional parameters may be required in cases where project aims include modelling productivity.

Record of operations

A detailed log will be kept of all operations and events that may affect the productivity of the plantation. Examples are vegetation (weed) management, kinds and amounts of fertilisers, pruning, insect or fungal attacks or fires. The data should be collected in a manner that will assist interpretation, including economic analysis.

Intensive Research

Depending on the scientific resources available, diverse sets of process-based studies have been proposed for some sites. These studies are designed to develop a basic understanding of how the treatments affect specific parts of the system and thereby the productivity of the plantation as a whole. At the Itatinga, Brazil, site, studies on the fine and coarse root systems are evaluating the effect of the treatments on root growth and distribution. In south-western Australia, measurements of soil water and temperature are being used to predict changes in N availability. Because more N was mineralised and leached on plots where the logging residue had been removed, early tree growth was reduced compared to plots where residue had been retained. By understanding the mechanisms that caused the growth response, management options can be developed to maintain or enhance productivity. For example, objectives in Kerala include research on physiological parameters including water stress in trees and photosynthesis. In several cases, the economic and environmental costs of removing the slash and adding N fertiliser can be compared to retaining the logging residue and planting in difficult conditions. The intensive research of processes will be minimal to nil on some sites but concentrated on others. As these measurements are expensive and time consuming, bilateral exchange between partners is encouraged with the goal of developing linkages between two or more sites. Possible, but not exclusive, linkages are:

Parameter	Lead partner	Interested cooperators
Soluble carbon	T. O'Connell	Ben du Toit
Nitrogen availability	T. O'Connell	Ben du Toit
Phosphorus absorption	L. Gonçalves	D. Santoso
Litter decomposition	A. Sankaran	Xu Daping
Soil water balance	Peter Roberts	Georges Nizinski

In order to prioritise intensive work, key soil processes that limit productivity should be identified at each site. We will be exploring new opportunities for interaction as the network progresses.

Network Effectiveness

This partnership has been established successfully. Now the project must build on these established sites and enhance the network by exchanging ideas, results and interpretations as they become available. As results are produced they should also be communicated to interested local groups including landowners, managers and public organisations. By sharing information with others in the network, gaps in measurements can be identified and filled. While intensive process-based studies are not being done at all sites, all partners will benefit from the basic understanding of the plantation ecosystem that these studies will supply. As scientific capabilities are increased, more of the sites will be able to use the process-based data to improve interpretation of local results, develop management alternatives to correct any decline in productivity, and begin studies on the local sites that are targeted to their own conditions.

Sites have been chosen on the basis of having strong partners, the necessary research resources, and plantations that are of sufficient size and age to allow installation of plots that fit the protocols prescribed in the plan. This process has resulted in an apparent random choice of site locations. Nevertheless we have sites in about half of the important plantation types and locations identified in the original strategic plan. The SAG and CIFOR, after consultations with the present partners, will use a systematic approach to expand the network to other important ecosystems whenever suitable partners and sites can be identified.

Overall, we have made significant progress in advancing the network goals since we met about two years ago to finalise the project objectives and structure. Our next meeting should give us a stimulating opportunity to compare results, strengthen linkages and hopefully to meet new partners representing another important tropical plantation ecosystem.

These proceedings describe the experimental basis and preliminary results of the CIFOR project *Site Management and Productivity in Tropical Plantations.* The papers they contain were presented at the second workshop of project partners held in Pietermaritzburg, South Africa, in February 1998. This research, which is underway at 17 sites in seven countries and involves scientists from 16 institutions, focuses on inter-rotation management. This phase between tree harvesting and replanting for the next rotation is a window of considerable risks as well as opportunities. It holds the potential for physical and chemical soil degradation, but also offers a chance to remedy past mistakes and introduce sound technology for improved long-term management of plantation soils. Although the species and the soil problems vary according to local conditions, all the experiments have been designed to provide knowledge that will benefit both the specific sites and our understanding of underlying processes of tree productivity.

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