11 Forest Rehabilitation Requires Fire Prevention and Community Involvement

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Abstract

In East Kalimantan, drought is frequently followed by fire. The eastern part of Kutai Regency is susceptible to large-scale wildfires during severe droughts related to strong El Niño Southern Oscillation (ENSO) events as shown by the 1982-83 and 1997-98 fires. Since the 1982-83 forest fire, many trials have been conducted to rehabilitate the burned forests. However, the 1998 fires burned both natural and rehabilitated forests in East Kalimantan. It is to be expected that severe droughts related to strong ENSO events and subsequent wildfires will occur again in the near future. At the time of the next severe ENSO event, we should remember that extremely severe drought is likely to recur early in the following year. Without effective fire prevention, the rehabilitated areas will be burned again and the rehabilitation process will not have enough time to reach completion. To rehabilitate burned forests and grasslands as well as to conserve the remaining natural forests, it is important that community-based initiatives are undertaken to reduce potential fire sources and to enhance fire management activities. Clear benefits to the local community should be introduced and announced to the local people before and during forest rehabilitation.

INTRODUCTION

Two of the world's largest forest fires on record occurred in East Kalimantan within a 15-year period. The first fire was related to an unusually prolonged and severe drought, linked to a strong El Niño Southern Oscillation (ENSO) event in 1982-83 (Goldammer *et al*. 1996). The drought lasted from July 1982 until April 1983, consisting of two rainless phases, one from July to October 1982, and the other from January to April 1983. A later ENSO event from 1997 to 1998 caused another severe drought that also consisted of two rainless phases, from July to October 1997, and from January to April 1998 (Toma *et al*. 2000a). Consequently, huge areas of rain forest in East Kalimantan that had been burned in the 1982-83 fires were again damaged by drought and drought-related fires during the rainless phases in 1997-98 (Toma 1999, Mori 2000).

Fires during severe droughts are an overwhelming problem for workers attempting to rehabilitate forests in East Kalimantan. Up to 1997 (before the 1997-98 fires), semi-natural dipterocarp forests that had been disturbed by selective logging in the 1970s and the 1982-83 fires were on the way to recovery (Toma *et al*. 2000b). Various rehabilitation trials had also been initiated in burned and degraded forests after the large fires in 1982-83. Furthermore, fallow

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grasslands had been rehabilitated as industrial plantations of fast growing species, and enrichment planting by commercial dipterocarp species had been conducted in secondary forests dominated by pioneer species (Sutisna and Fatawi 1994, Fatawi and Mori 2000). Since few dipterocarp trees regenerate naturally in severely burned forests, rehabilitation plantings are an effective means of reducing the time needed for forest recovery. The initial stage of these rehabilitation activities had proceeded successfully (Sutisna 1996, Mubarizi and Nakagoshi 1999, Soda *et al.* 1999). However, the 1997-98 fires burned both the recovering and rehabilitated forests. Indeed, the semi-natural forests were damaged more severely by the 1997-98 fires than they had been by the 1982-83 fires, since they had not recovered their previous health in the intervening period (Goldammer 1999, Mori 2000, Toma *et al.* 2000b). In the rehabilitated forests, the planted trees had not grown enough to survive the fire, so they too were heavily damaged. Clearly, fires degrade forests very quickly but the recovery of forests takes a long time, even with rehabilitation measures. In this context, all silvicultural techniques are useless for forest rehabilitation, unless they include fire prevention. The prevention and management of fires are vital to allow forest recovery and rehabilitation to proceed.

This paper reports on the 1997-98 fires in East Kalimantan and addresses the important questions of what fire prevention measures should be implemented, and what measures should be taken if fires do occur. Secondly, we discuss steps that should be taken to eliminate the problems caused by forest fires in the long-term.

FIRES IN 1997-98

Maps of the hot spots during the rainless period of 1998 in East Kalimantan show that the areas affected by fires overlapped considerably with those affected by the great forest fires of 1982-83 (Fig. 1). The parts affected by the fires both in 1982-83 and 1997-98 were concentrated in low hills in the eastern part of Kutai Regency. The repeated large-scale fires show that this area is prone to catch fire during severe droughts. The remaining forests in the eastern part of Kutai Regency are surrounded by degraded vegetation, mainly alang-alang (*Imperata cylindrica*) grassland. Grassland fires spread rapidly, with large and vigorous flames. Such intense grassland fire easily escapes control and attacks the forested land from all directions. Fires successfully invading the forest burn mainly the litter layers on the forest floor and progress slowly along the surface of the ground. This type of fire is known as "surface fire" and most forest fires in 1997-98 in East Kalimantan were of this type. Usually, spreading surface fire can be checked simply by clearing the litter layers from a strip beyond the fire, as little as 1 m wide, or less. However, the 1997-98 fires in the forests in East Kalimantan were difficult to control in this fashion, because a lot of fires reached the forested areas simultaneously.

In East Kalimantan, there are two rainless periods during strong ENSO events, and droughts and fires are generally more intense in the second rainless period compared to the first. An ENSO event tends to commence in March to May and to last for a year, or sometimes longer (Walsh 1996). Droughts normally occur over the whole of Indonesia during the first year of an ENSO event. A pronounced ENSO event would also cause a drought in the eastern part of Borneo Island early in its second year (Walsh 1996). In the case of the 1997-98 ENSO events, unusually high air temperatures and low humidity were recorded during the drought in the second year (Fig. 2) (Toma *et al.* 2000a). These weather patterns may have been caused by interaction between the foehn phenomenon and a high pressure air mass generated by the high temperatures associated with the ENSO event (Mori *et al.* 1999, Mori 2000). As a result, the 1998 forest fires in East Kalimantan were more intense than those of 1997. According to a report by the Ministry of Forestry and Estate Crops, the area of burned forest in East Kalimantan was 26 000 ha in 1997 and 533 000 ha in 1998 (Mori 2000). These figures reflected the fact that the fires in 1997 did not invade the well-developed forests, unlike the fires in 1998.

Recent studies using coupled ocean-atmosphere models have shown that increased

Figure 1. Fire-affected areas in East Kalimantan, Indonesia

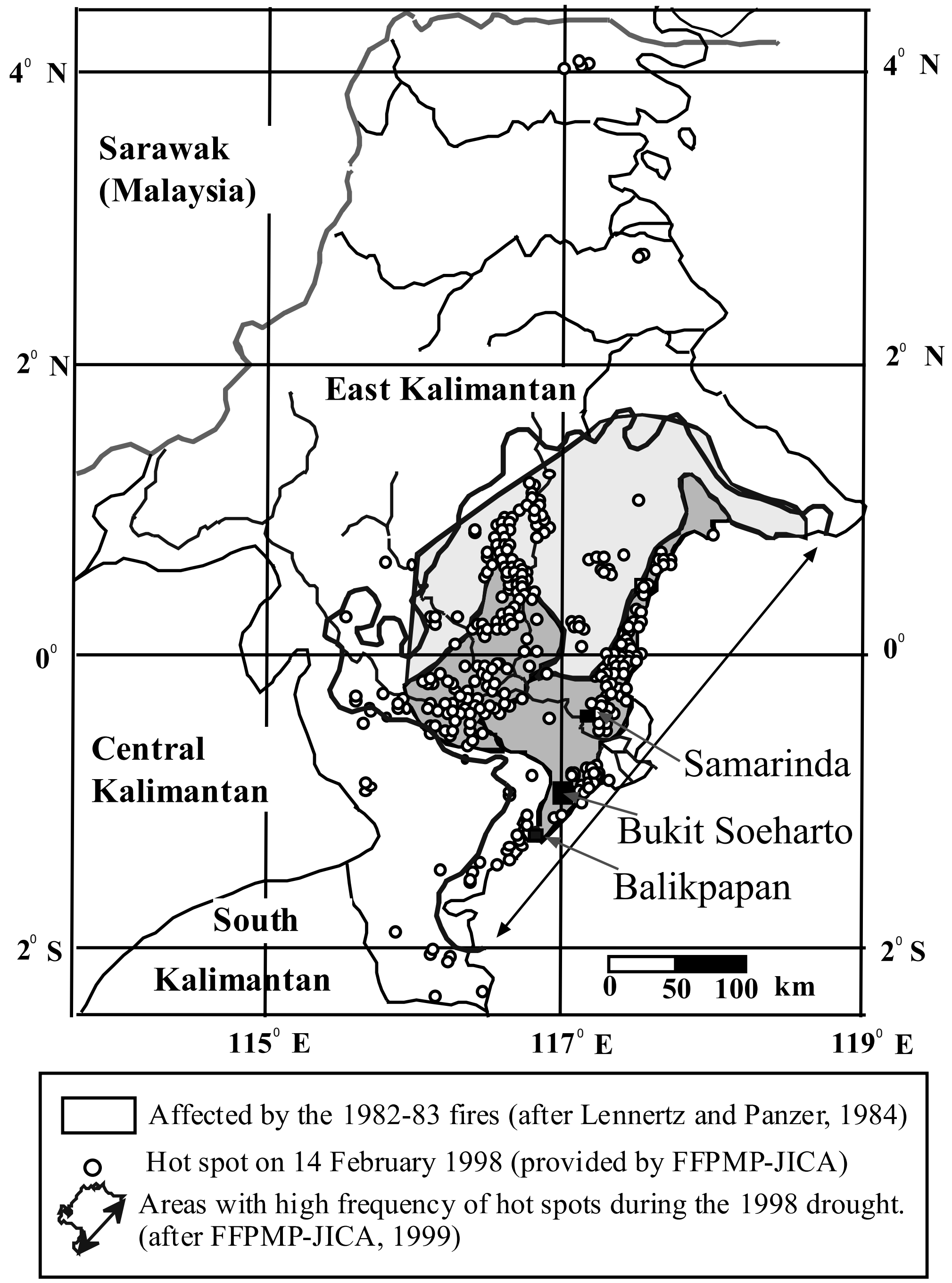
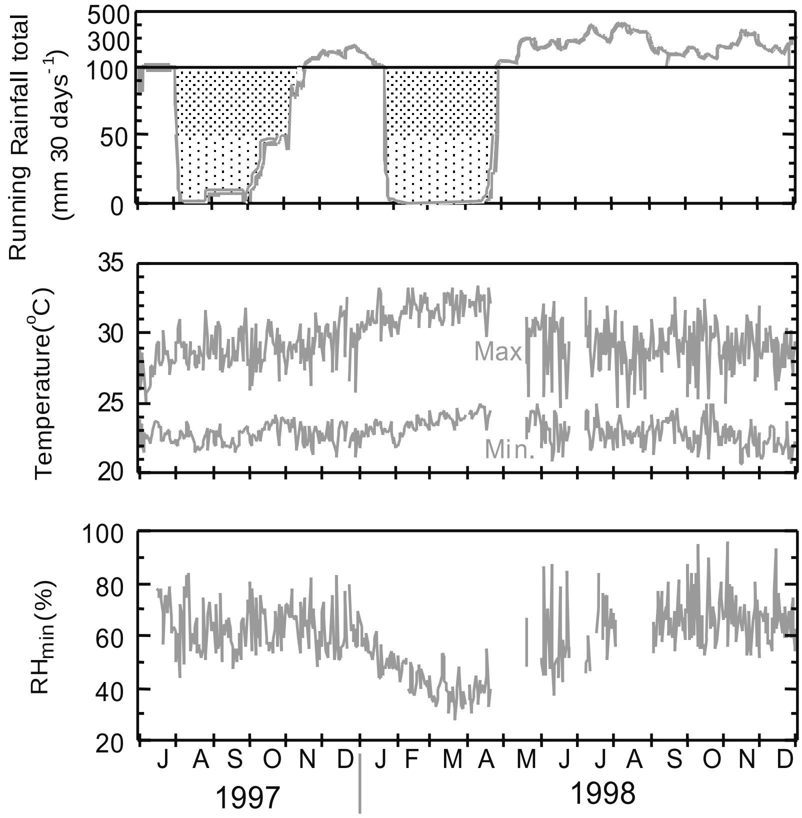


Figure 2. Climatic conditions at Bukit Soeharto Education Forest, East Kalimantan, from July 1997 to December 1998. Upper: Running 30-day rainfall totals. The running 30-day rainfall, on a day is the sum of precipitation of the preceding 30 days. Middle: Daily maximum and minimum air temperature at the top of a 60 m tower in a near primary dipterocarp forest. Lower: Daily minimum relative humidity (RHmin) at the top of a 60 m tower in a near primary dipterocarp forest



atmospheric carbon dioxide concentrations lead to El Niño-like global climate changes (Tett 1995, Meehl and Washington 1996). Furthermore, the severity and frequency of extreme ENSO events are expected to occur in Oceania (Timmermann *et al*. 1999). If more extreme ENSO events do occur, they will inevitably cause severe droughts and wildfires (Goldammer *et al*. 1999). In the first year, we could see drought and subsequent large-scale wildfires throughout the whole of Indonesia. The drought and fires might terminate once rainfall recommences at the end of the year. However, we should remember at that point that more severe drought is likely to return to East Kalimantan, early in the following year.

FIRE PREVENTION MEASURES

During severe drought, fires ignited by human activity easily spread out to become wildfires. Wildfires usually start from fires used for slash-and-burn land preparation, by large companies as well as smallholders. In addition to the fires started to clear land, some fires are started intentionally as a weapon in social conflict (Tomich *et al*. 1998, Gouyon 1999). It has been said that people in East Kalimantan, like people everywhere, typically act in the belief that what they are doing satisfies their best interests, and much of their forest-destroying or land-degrading behaviour is profitable to them (Kartawinata *et al*. 1981). However, it can also be argued that the fires were started in the hope of short-term profits, and the instigators had only a very vague idea of what lay ahead. Such shortsightedness, with respect to fire, has to be improved.

Slash-and-burn clearance for agriculture has been widely applied in Indonesia for centuries. Although it is prohibited officially by the Presidential Declaration of 1st June 1995, the rule is not widely respected, since the people see fire as a cheap and effective tool for land preparation (Saharjo 1999). Given normal levels of rainfall, fires ignited by humans do not spread very widely from the targeted area. During exceptional droughts, however, the fires easily become out of control and rapidly spread to the surrounding area. Therefore, practical regulations for limiting the times that fire can be used for slash-and-burn practices need to be established.

Developing and applying alternative measures to slash-and-burn agriculture would also help prevent forest fires. Santoso *et al*. (1997) suggested that reclamation of degraded land for permanent agricultural use may be an alternative to on-going slash-and-burn agriculture. Agroforestry or social forestry can also be effective means of inducing the local community to help prevent wildfires. Intercropping with annuals in early years, just after planting trees in agroforestry systems, for instance, not only helps prevent *Imperata* grassland from expanding, but also helps smallholders fulfill their needs for food, or to earn additional money (Garrity 1997). Since there is an expensive and unproductive phase when no income is generated from the harvested materials, especially at the beginning of land improvement and agroforestry schemes, appropriate funds or other assistance, with a guarantee of stable land tenure, need to be provided (Santoso *et al*. 1997).

Because wild fires spread out through grasslands and reach forests, converting the grasslands in the remaining forest margins into productive land for the local communities would be another effective way to reduce forest fires. However, security of tenure is essential for this form of community-based fire control (Garrity 1997). It should be noted that fallow grassland has been occupied, in many cases, by local farmers who thought that they had the right to use the land. If the claim is opposed, fires may be deliberately started. For example, in South Sumatra, during conflicts over land tenure, fires are commonly used to drive rivals away, or as acts of revenge (Gouyon 1999). In areas where grassland is converted to productive forest, the farmers responsible for the work should receive priority rights over all the products, including the timber (Garrity 1997). The most effective forest rehabilitation schemes for the degraded land will be those that increase the welfare of the local people by involving them in the rehabilitation activities, by giving job opportunities, and by providing land which can be utilised to satisfy their needs (Wibowo *et al*. 1997). Thus the first step that we have to take is to develop a consensus to promote forest rehabilitation, with the participation of local people.

CONCLUSION

Most wildfires in East Kalimantan are caused by human activities. The climatic conditions in East Kalimantan will not allow rehabilitated forests to develop well, unless effective measures to prevent fire are applied. To rehabilitate the forests that have burned, and conserve the remaining natural forests in East Kalimantan, the number and size of fires started by human activity must be reduced. Community based initiatives will be essential to decrease this source of fire and to enhance fire management activities. Rehabilitation activities should bring benefits to local communities. Building a consensus is a complex and time-consuming process, compared to merely planting trees. However, if we do not bolster and explain the local benefits, uncontrolled fires will burn the planted trees, and there will never be enough time for the planted areas to become forests.

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12 Taungya Experiment for Rehabilitation of Burnt-over Forest in East Kalimantan

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Abstract

The objective of the forest rehabilitation study with taungya system was to find out optimum method, cash crop species, constraints, and how much this system benefits forest rehabilitation. It was carried out using red meranti (*Shorea smithiana*) and rubber (*Hevea brasiliensis*) as plantation trees, and rice (*Oryza sativa*), maize (*Zea mays*), soya bean (*Glycine max*) and cassava (*Manihot esculenta*) for intercropping. The research has shown that there are a number of constraints to the use of taungya in East Kalimantan for the rehabilitation of burnt, logged-over forest. The problems are a mix of technical, economic and social. It was found that the costs of establishing the taungya is comparable with that for establishment of industrial forest plantations but technical problems such as the lack of soil preparation, poor quality seed and inadequate fertiliser application techniques resulted in very low yields of the intercrops. This was exacerbated by protection problems and significant damage by birds and browsing animals further reduced yields. Some of these problems may be overcome by guarding the taungya fields and planting crops such as fibre producers which need less protection. However, unless the taungya system can be made economic and attractive to villagers it will be difficult to implement, especially in an area where there is no shortage of land close to the villages.

INTRODUCTION

Some of the natural forests in East Kalimantan, including the educational forest of the Mulawarman University in Bukit Soeharto, were burnt by wild fire in 1983, 1991 and 1998. Very few living trees remained and the fire can be classified as heavy intensity. These forests need to be rehabilitated to recover their economical and ecological functions.

In order to encourage local people participation in forestry, the Forest Service allowed timber companies to plant estate crops in the forest to benefit local people. These crop species are cocoa, fruit trees, latex-producing trees, rattan, kayu manis (*Cinnamomum*), candlenut, coffee, etc. With this permission, intercropping between the forest trees and agricultural crops in the forest land (taungya system) is legal. If the cash crops are successful their yield can cover the reforestation cost.

Ecologically, the taungya system reduces fire hazards because the intensive weeding for the cash crop plantation results in less fuel in the field. Moreover, a cash crop plantation will be able to clean the land of weeds economically, but forest plantation cannot be weeded at the same intensity because of limited income. On the other hand, reforestation with taungya system in sparsely populated Kalimantan is not yet practised because local people have enough of their own land near their village and there is no necessity to join a reforestation programme which is often located far away.

As the taungya system can benefit forest rehabilitation, it is necessary to investigate it in Kalimantan. Hypotheses for the experiment are: (1) forest rehabilitation with taungya system in Kalimantan is useful, (2) revenue from cash crops can cover establishment cost of tree planting. The objective of the forest rehabilitation study with

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taungya system is to find out optimum method, cash crop species, constraints, and how much this system benefits forest rehabilitation.

MATERIALS AND METHOD

Materials

Plant materials for experiment were seedlings of one tree species (red meranti) and seeds of five cash crops to cultivate 2 ha plots as follows:

- Meranti *(Shorea smithiana)* 225 seedlings + 29 seedlings for replanting.
- Rubber *(Hevea brasiliensis)* 375 seedlings 57 seedlings for replanting.
- Rice *(Oryza sativa*) 15 kg + 5 kg for replanting.
- Maize *(Zea mays*) 10 kg + 7 kg for replanting.
- Soya bean *(Glycine max*) 11 kg + 8 kg for replanting.
- Cassava *(Manihot esculenta*) 4800 cuttings.

To prevent nutrient deficiencies several fertilisers were applied:

- Urea (N fertiliser) 200 kg ha^{-1}
- Triple super phosphate (P fertiliser) 100 kg ha^{-1}
- Potassium chloride (K fertiliser) 100 kg ha^{-1}.

Description plant materials used:

- Maize: variety Hybrida C-3 (Cargill derivate)
- Rice seed: variety Cirata.
- Cassava cuttings: varietas ‘pacar’ from Tanah Merah, Samarinda.
- Soya bean seed: commercial seedlot.

Location, soil and climate of the experimental area

The experimental area is situated in the Bukit Soeharto Education Forest in the lowland area, between Samarinda and Balikpapan, East Kalimantan, Indonesia. It is between 115?0’54" to 116?0’54" E and 0?0’50" to 1?0’04" S, with an elevation of about 50 m. Relief of the area is low hilly with a slope between 8 to 40% (Effendi 1999). According to Ohta *et al.* (1992), the geology of the area is characterised by Neogene sedimentary rocks of alternate layers of sandstone, claystone and mudstone. Soil of the research plot is Typic Paleudults characterised by low organic matter content, low N and P concentration, medium to high K concentration, very acid to acid pH, low cation exchange capacity, and low base saturation. The texture of topsoil is sandy loam to loam with clay-loam in subsoil (Ruhiyat 1999). The climate is described by Toma *et al.* (2000) as characteristic of a tropical rain forest region: hot and wet throughout the year. From 1988 to 1998, the average annual rainfall was 2002 mm. The monthly distribution of rainfall was bimodial, with peaks of over 200 mm per month occurring both in May and December. The minimum and maximum average monthly rainfalls were 85 mm (September) and 248 mm (December), respectively. Average annual total evaporation measured by an evaporation pan (20 cm in diameter) from 1988 to 1991 was 1273 mm. The yearly mean temperatures were 29.9 ?C for daily maxima and 21.4 ?C for daily minima, and the mean air temperature differed little between months. The yearly mean relative air humidity was 93.2% for daily maxima and 58.5% for daily minima. The average daily range of relative humidity was larger than those between months.

Procedure and time schedule of experiment

Two plots of one ha each were established in the heavily burned forest. The experimental plot has been established with a procedure and time schedule as shown in Table 1. The dead trees were felled and stacked to make burning easy and secure. Each plot is divided into subplots of 20 x 20 m to facilitate planting and measuring. Data collected from the plots are growth of meranti and rubber tree, weed development, and yield of soya bean and rice. Data were processed with the Statistical Programme for Social Sciences (SPSS).

Table 1. Procedure and time schedule of rehabilitation plot establishment

Activity	Time schedule	Remarks
Plot establishment	Aug. 31 - Sep. 2, 98	-
Felling of dead trees	Aug. 18 - 22, 98	By chainsaw
Debris piling	Aug. 7 -20, 98	Manual
Debris burning	Sep. 6 - 12, 98	-
Weed spraying	first Oct. 17 - 18, second Oct. 6 -7, 98	Roundup herbicide (1% in water)
Planting	Oct. 15, 98	Meranti and rubber trees
	Oct. 16 - 17, 98	Cassava
	Oct. 20 - 21, 98	Maize
	Oct. 21 - 23, 98	Soya bean
	Oct. 24 - 27, 98	Rice
Weeding	Dec. 15 -30, 98	Manually
Fertilisation	Dec. 26, 98 - Jan. 3, 99	N, P, K. except on maize
Harvest soya beans	Feb. 9 to 14, 99	Cut and dry
Harvest rice	Mar. 15 to 20, 99	Cut and dry

Table 2. Forest structure after fire and before site preparation for the experiment

Plot (1 ha)	No. ha^{-1}	Living trees	Dead trees	Mean diameter (cm)	Basal area (m^2 ha^{-1})
A	319	44	275	20.0	11.52
B	260	39	221	20.9	11.28
Mean	290	41.5	248	20.4	11.40
Percent	-	16.7%	83.3%	-	

RESULTS AND DISCUSSION

Origin of the plots

The origin of the experimental plots was burnt-over forest on 28 February 1998. Original forest structure before it was burnt is presented in Table 2. Density of original forest shows a typical logged-over forest with 200 to 300 trees ha^{-1}. On the other hand a basal area of 11 m^2 ha^{-1} is half that of the common logged-over forest in Kalimantan. This forest was already burnt at least twice, i.e. in 1983 and 1998, and probably also in 1991. Many trees were pioneer tree species such as *Macaranga* spp., *Mallotus* spp., and *Trema* spp. The original forest was very heavily burnt with 17% living trees remaining and composition (dbh ? 10 cm) as in Table 3. According to the tree number of each hectare plot, i.e. 34 to 51 trees.ha^{-1} (equal to 1.8-2.6 m^2 ha^{-1} in basal area), it was considered that this tree density would not suppress growth of the crops in the plots.

Growth of meranti and rubber trees

Growth of the main crop meranti *(Shorea smithiana)* and rubber *(Hevea brasiliensis)* is presented in Table 4. In the first year, percentage survival trees of red meranti (86%) was higher than rubber (80%). The red meranti had higher height growth (66 cm yr^{-1}) than rubber (30 cm yr^{-1}). Because of high mortality, rubber trees needed more replanting. Red meranti in the natural forest is known to grow better in canopy gaps (Sutisna 1996, 1998), but in this intercropping experiment it was planted an open area. Die back of red meranti plantation is found not only in this experiment in the open area but also under the forest canopy. The average initial annual height growth of *Shorea smithiana* in the open area is larger than that found in an enrichment planting under burnt forest canopy in the same area (Sutisna 1994) as shown in Table 5. Through this comparison, it is clear that rehabilitation of cleared burnt-over forest with dipterocarp species is possible.

Table 3. Density and basal area of surviving and retained trees in the plots A and B (October 1998)

Plot	Local name	Species	No ha^{-1}	Basal area (m^2 ha^{-1})
A	Lain-lain	Others	34	1.1886
	Bendang	*Borassodendron borneensis*	4	0.2290
	Keruing	*Dipterocarpus humeratus*	4	0.0239
	Kayuarang	*Dyospyros borneensis*	2	0.0574
	Simpur	*Dillenia eximia*	2	0.0136
	Terap	*Artocarpus elasticus*	2	0.0175
	Keledang	*Artocarpus lanceifolius*	1	0.1698
	Meranti	*Shorea smithiana*	1	0.0031
	Ulin	*Eusideroxylon zwageri*	1	0.1332
Total A			51	1.8364
B	Lain-lain	Others	27	1.7633
	Bendang	*Borassodendron borneensis*	3	0.5480
	Keledang	*Artocarpus lanceifolius*	2	0.2188
	Keruing	*Dipterocarpus humeratus*	1	0.0114
	Ulin	*Eusideroxylon zwageri*	1	0.1539
Total B			34	2.6957

Table 4. Growth of meranti and rubber trees after one year

Plot	Plant condition	Number ha^{-1}	Height growth (cm)	Percent
A	Dead	73	-94.7	19.5
Rubber	Healthy	209	49.0	55.7
	Die back	93	-14.1	24.8
	Living	302	29.6	80.5
	Total	375	5.4	100
B	Dead	32	-35.1	14.2
Red meranti	Healthy	179	69.6	79.6
	Die back	14	26.4	6.2
	Living	193	66.4	85.8
	Total	225	52.0	100

Table 5. Height growth of natural and planted dipterocarp seedlings under burnt-over forest canopy

Tree species	Origin	Number		Height growth (cm yr^{-1})	
		shaded	gap	shaded	gap
Dryobalanops beccarii	planted	128	179	12.9	19.9
Shorea parvifolia	planted	194	202	29.8	30.1
Cotylelobium burckii	natural	2	2	20.0	12.0
Dipterocarpus confertus	natural	3	6	-21.7	3.8
Dipterocarpus cornutus	natural	3	2	5.7	-66.0
Hopea rudiformis	natural	3	1	32.0	-49.0
Shorea leprosula	natural	4	3	6.7	12.0
Shorea seminis	natural	1	2	-1.0	2.0

Cost of establishment of rehabilitation plot with taungya system

The steps and costs of rehabilitation of burnt-over forest with taungya system are shown in Table 6. The total cost of rehabilitation for 2 ha burnt-over forest was just over Rp 10 million. This establishment cost is not representative for rehabilitation cost per ha, because the cost should be calculated up to secure stage of the main crops, i.e. meranti and rubber tree. The main crop is secure when it does not need weeding any more. The cost for building fences, site preparation, plant materials, and hut dominates among cost components (72.8%), but is not expensive for several reasons:

- the fence can be used for 3 years of intercropping;
- intensive site preparation can be used for 3 years intercropping and to avoid potential fire;
- expensive plant materials (only cassava) will be paid by intercropping yields; and
- the hut can be used for at least 10 years for tending the larger rehabilitation area.

Compared to the government's cost standard of around Rp 5 million ha^{-1}, for establishment of industrial forest plantation this taungya cost is within the range of the cost standard.

Taungya yield

In the first 3 months, the taungya crops of cassava and corn had no yield at all because of pig browsing, even though a 1.5 m high wood fence protected the crops. Soya bean and upland rice produced yields in February and March 1999 as shown in Tables 7 and 8. The total yield of soya beans (87.9 kg ha^{-1}) was comparatively very low as productivity of soya beans in Indonesia during 1970-1981 reached 0.7-0.8 t ha^{-1} (Suprapto 1994). There are several reasons, why this yield is very low:

- the cleared forest land is not flat and smooth as agricultural land and some place are not plantable because of creeks, steep slopes, stumps and stems;
- there was no soil preparation in the forest land;
- low quality of seed material; and
- poor fertilisation technique.

Table 6. Activities and costs of 2 ha burnt-over forest rehabilitation with taungya system during the first 3 months

Activity	Wages (Rp)	Materials (Rp)	Cost (Rp)	Cost (%)
Lay out for plot	40 000		40 000	0.4
Bordering 2 ha plot	195 000	4 500	199 500	2.0
Sub blocking		27 500	27 500	0.3
Vegetation inventory	40 000		40 000	0.4
Site preparation	1 280 000	667 450	1 947 450	19.3
Collect plant materials		1 676 600	1 676 600	16.7
Planting	900 000		900 000	8.9
Weeding	630 000		630 000	6.3
Fertilising	190 000	632 425	822 425	8.2
Build wood fence	1 685 000	754 600	2 439 600	24.2
Border cleaning	70 000		70 000	0.7
Build hut	600 000	671 500	1 271 500	12.6
Total	5 630 000	4 434 575	10 064 575	100.0

Table 7. Density of 3-month-old soya beans

Subplot	Density 400 m^{-2}		Density ha^{-1}	
	clumps	stems	clumps	stems
B21 (valley)	1183	2154	29 575	53 850
B13 (slope)	1121	2110	28 025	52 750
B25 (ridge)	1786	4383	44 625	109 575
Mean fertilised	1363	3882	34 075	97 050
B33 (unfertilised)	1706	3654	42 650	91 350

Table 8. Yield of soya bean in 0.48 ha, and rice in 0.52 ha

Soya bean yield			Rice yield	
Sub plot 400 m^2	good quality beans (kg)	low quality beans (kg)	Sub plot 400 m	Yield (kg)
B1.1.	0.99	1.13	B3.1	3.06
B1.2.	0.33	0.00	B3.3	0.91
B1.3.	1.66	0.00	B3.5	0.63
B1.4.	3.72	2.37	B4.1	7.95
B1.5.	1.67	1.21	B4.2	1.43
B2.1.	2.25	2.94	B4.3	0.24
B2.2.	0.69	0.65	B4.4	1.26
B2.3.	3.15	1.20	B4.5	0.79
B2.4.	2.86	2.45	B5.1	1.92
B2.5.	4.24	1.80	B5.2	1.60
B3.2.	2.55	1.93	B5.3	1.38
B3.4.	1.10	1.35	B5.4	0.34
-	-	-	B5.5	0.48
0.48 ha	25.16	17.03	0.52 ha	16.49
Total 1 ha	52.42	35.48	Total 1 ha	31.71

The total yield of rice in this experiment was only 32 kg ha^{-1} compared with the yield of rice produced by the farmers that reaches 1600-2900 kg ha^{-1} (Noor 1996). The reasons for the failure are:

- rice grains in the field were partly browsed by birds; and
- a bad season that caused empty grains.

Diseases in the plots were monitored and are described by Mardji in a separate paper in these proceedings.

CONCLUSIONS

The research has shown that there are a number of constraints to the use of taungya in East Kalimantan for the rehabilitation of burnt, logged-over forest. The problems are a mix of technical, economic and social. It was found that the costs of establishing the taungya is comparable with that for establishment of industrial forest plantations and the satisfactory initial growth and survival of the meranti showed that rehabilitation of cleared burnt-over forest with dipterocarp species is possible. However, technical problems such as the lack of soil preparation, poor quality seed and inadequate fertiliser application techniques resulted in very low yields of the intercrops. This was exacerbated by protection problems and significant damage by birds and browsing animals further reduced yields. Some of these problems may be overcome by guarding the taungya fields with men and dogs; and planting non-edible crops such as fibre producers. However, unless the taungya system can be made economic and attractive to villagers it will be difficult to implement, especially in an area where there is no shortage of land close to the villages.

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Adaptability of Six Native Forest Tree Species to Degraded Lands in Pucallpa, Peruvian Amazon

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Abstract

Preliminary results of a field study to determine the establishment of six native forest tree species of economic value on degraded areas abandoned after intensive past agricultural use are reported. Study sites were on slash-and-burn farms partially covered with abandoned agricultural areas on Ultisols dominated by invading vegetation mainly composed of *Imperata brasiliensis*, *Rottboellia cochinchinensis* and *Baccharis floribunda*. Tree species used in the trials were: *Schizolobium amazonicum*, *Tabebuia serratifolia*, *Calycophyllum spruceanum*, *Terminalia oblonga*, *Amburana cearensis* and *Cedrelinga catenaeformis*. These six species were planted in three degraded habitats characterised by the presence of one of the above weed species. After 13 months, *Schizolobium amazonicum* was the best adapted in the three experimental treatments, followed by *Tabebuia serratifolia* and *Calycophyllum spruceanum*. Habitats dominated by *Baccharis floribunda* offered comparatively better conditions for tree establishment and initial growth.

INTRODUCTION

The deforestation rate in the Peruvian Amazon, about 320 000 ha year^{-1}, is alarming (Reátegui 1996) and is mainly attributed to land use change for agriculture and pasture activities, very often in areas best suited to forestry (Arca *et al*. 1996). As a result of the poor sustainability of the agricultural production and weed invasion, extensive degraded areas have appeared. Such areas are generally located near populations, have roads and therefore good access possibilities to markets. Rehabilitation of these degraded areas for production and environmental conservation is currently one, of the main concerns for local governments development programmes and research institutions.

An alternative to rehabilitate degraded areas is the (re-) incorporation of forests to the system. So far, research efforts have mainly focused on techniques and amendments, such as fertilisation, to improve the growth of trees, generally with commercial value. Few studies have addressed the question of which species show the best natural potential for adaptability? This is the case of many native forest species that have developed mechanisms to efficiently exploit the environmental conditions found in tropical humid degraded areas, particularly the low fertility of most soils.

The zone about Pucallpa, in the Ucayali Region, is an example of continued deforestation and land degradation in the lowlands of the Peruvian Amazon. Over 50 years of deforestation and a steadily growing population have led to a range of land uses and landscape conditions. Since 1992, several national and international research institutions have dedicated efforts to develop

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alternatives to rehabilitate degraded areas in this setting. In 1997, the National Agricultural Research Institute (INIA) and the Center for International Forestry Research (CIFOR) set up a collaborative research project on rehabilitation methods for degraded lands in the Ucayali Region. The initial phase of this project aimed to determine the initial adaptability of six native tree forest species of economic value in degraded areas abandoned after intensive agricultural use, and to assess the biophysical changes and dynamic processes of the vegetation and soil on the sites under treatment. This paper presents the first, preliminary results of these studies.

BACKGROUND

Decreasing economic returns for agricultural products and land degradation is one of the main causes for farm emigration in Pucallpa (Labarta 1998). Soils near Pucallpa are mainly acidic, easily compacted, with aluminium saturation and low phosphorus content (Arca *et al.* 1996). Likewise, invasion by weeds is also causing negative effects on farmers' economy. An example of the high disturbance of these habitats is the dominance of invading herbaceous and shrub plants, such as *Imperata brasiliensis* or *Baccharis floribunda* (Fujisaka *et al*. 1997, INIA/CIFOR 1998), which cause a deviation of the natural plant succession. A survey of farmers in the old agricultural frontier near Pucallpa (over 35-40 years settlement) indicated that in average 28% of the farm is covered with secondary vegetation dominated by invading herbs, compared to 15% on areas recently opened (Smith *et al*. 1999).

Since 1992 a number of species trials have been established on intensively used, highly compacted and eroded soils, mainly covered with low-productivity native pastures (ICRAF/INIA 1996). Forest species used were selected because of their capacity to improve, conserve and restore acidic soils, their fast growth rate and ability to compete with weeds. These research efforts have generated information on survival and growth for eight tree species tested in some representative degraded areas of the Pucallpa zone (INIA/ICRAF 1996, IIAP 1994, UNU 1995).

INIA/ICRAF (1996) determined up to the first year that the native species *Guazuma crinita* and *Swietenia macrophylla* established and grew better on compacted soil (apparent density 1.8 g cm^{-3} up to 10 cm depth) when hole diameter was 40 cm, independent of hole depth. *Calycophyllum spruceanum,* however, established and grew well in any combination of hole diameter and depth.

An experiment on an overgrazed Ultisol (apparent density 1.53 g cm^{-3} up to 20 cm depth) measured the effect of different supplies of an organic fertiliser (worm humus) and a chemical fertiliser on height growth of *Guazuma crinita* and *Calycophyllum spruceanum*. For both species the control (without humus) had higher values than the treatment with 2 kg of humus per hole. The experiment also determined positive growing responses with the application of higher nutrient supply to soil (N: 225, P: 75, K: 75) for *G. crinita, C. spruceanum* and *Aspidosperma macrocarpum* (IIAP 1994).

The above results were supported by a fertilisation study to establish *Guazuma crinita* on similar soil conditions. Plants reached 128 cm height with a supply of N: 150, P: 50 and K: 50. No differences in height growth were detected by applying worm humus (UNU 1995).

On pasture land dominated by *Brachiaria humidicola,* late transplants (plants with 2.5 to 3 m initial height) of *Calycophyllum spruceanum* showed 67% survival after one year, compared with 40% each for *Swietenia macrophylla* and *Guazuma crinita* (INIA 1994).

STUDY SITE AND METHODS

The study was carried out along the Campo Verde–Nueva Requena road (opened up in 1965), 34 km west of Pucallpa. The longitude is 74° 48'-74°50´W and latitude 8°18'- 8°25´S, with an average elevation of 150 m a.s.l. The climate is tropical humid, with a mean annual temperature of 25°C and about 1800 mm of annual rainfall, showing a bi-modal pattern with wet months in February-May and September-November, and dry months in June-August and December-January.

Thirty three slash-and-burn farmers were surveyed to determine the extent of land abandoned after agricultural use in their farms and the occurrence of invading vegetation. Three main 'weed' species were identified: *Imperata brasiliensis, Rottboellia cochinchinensis* and *Baccharis floribunda*. The high dominance of the above species in the degraded areas visited was taken as a criterion for defining distinctive vegetation types (experimental treatments). In order to have three replications per treatment, nine sites (farms) were selected for the trials. Each site was then characterised in terms of vegetation, land surface and soil. A plot of 40 x 40 m was installed at each site following a stratified randomised design with three replications. On each plot 120 trees of six forest tree species were planted (20 individuals per species) at 3 x 3 m spacing. The species used were: *Amburana cearensis* ('ishpingo'), *Calycophyllum spruceanum* ('capirona negra'), *Cedrelinga catenaeformis* ('tornillo'), *Schizolobium amazonicum* ('pashaco blanco'), *Tabebuia serratifolia* ('tahuarí') and *Terminalia oblonga* ('yacushapana'). At each site the vegetation was sampled according to the dominant life form (herbs and shrubs). Six plots dominated by herbaceous vegetation were inventoried following the 'botanal' method which estimates the occupation in percentage of each plant species in a 1 m^2 sampling surface. The sampling intensity was 1%, with samples distributed systematically. The remaining three plots were evaluated using the 'transect' method by a 100% inventory of the shrub vegetation (including resprouts and seedlings). Sampling intensity was 1.25% or 5 samples of 4 m^2 each one, systematically distributed. Each plot was subdivided into 25 8 x 8 m squares and soil samples taken from each square with a soil borer at 0–15 cm and 15–30 cm depth. The dominant vegetation at each sampling point was also registered. A textural analysis of the soil samples was used for stratification within each experimental plot in order to relate the resulting textural classes with the existing vegetation cover and to assess the likely effect of these classes in the initial behaviour of the tree species planted.

Site preparation for planting consisted of manually cutting the vegetation cover. No burning or addition of organic or chemical fertilisers took place. During planting approximately four fifths of the planting hole was filled with the upper, organic soil layer. Seedlings which died in the first 45 days after planting were replaced. The plantation area was weeded every two months along lines of 1 m width. The evaluations took place in the same periods by registering for each planted tree the total height, diameter at 10 cm from the base, plant vigour (1 = vigorous, 2 = normal, 3 = inferior) and relevant observations. The analysis of survival and growth was conducted 13 months after trial installation based on seven evaluations. The results obtained from this data set are therefore preliminary, but showing useful trends.

RESULTS

General characteristics of the study area

All 33 farms surveyed had abandoned land with past agricultural use ranging from one to 14 years since last cropping. Eighty per cent of the vegetation cover in the study sites was herbaceous and the remaining 20% mainly dominated by shrubs. In most cases (70%) the vegetation height was below 2 m (Table 1). The intensity of past land use in our study area could be considered high when compared with the characteristics reported by Uhl *et al*. (1988) on 8-year-old secondary forests in Pará, Eastern Brazilian Amazon.

The most frequent invading plant species ("weeds") observed were (in decreasing order of importance): *Rottboellia cochinchinensis* ('arrocillo'), *Baccharis floribunda* ('sachahuaca'), *Imperata brasiliensis* ('cashupsha'), *Pueraria phaseoloides* ('kudzu'), *Brachiaria decumbens* ('braquiaria'), *Hyparrhenia rufa* ('yaragua'), *Paspalum virgatum* ('torourco'), *Urena lobata* ('yute'), *Andropogon bicomis* ('cola de caballo'), *Pteridium aquilinum* ('shapumba'), *Pennisetum purpureum* ('carricillo') and *Scleria pterota* ('cortadera'). Surveyed farmers reported that forest

Table 1. Main biophysical characteristics of the study areas

Characteristics	Experimental sites on degraded habitats (R = replications)								
	R1	R2	R3	R1	R2	R3	R1	R2	R3
Dominant weed species* species*	*Impe.*	*Impe.*	*Impe.*	*Rott.*	*Rott.*	*Rott.*	*Bacc.*	*Bacc.*	*Bacc.*
Farm location (km)**	5.9	18	17	11	12.5	17.5	6	14	12.2
Past agricultural crop	rice	maize	cassava	cassava	maize	cassava	cassava	cassava	maize
Years since abandonment	14	2.5	5	1	7	1	3	1	2
Average stand height (m)	1.2	1	1	1.1	1.5	1.8	3.5	1.5	3
Fire frequency	annual	annual	annual	annual	annual	annual	irreg.	No	No
Slope (%)	2	1	1	1	2	2	2	1	3
Organic soil layer (cm)	2	3	3	2.5	2.5	3	2	2	2
Soil type	Ultisol	Ultisol	Ultisol	Ultisol	Ultisol	Ultisol	Ultisol	Ultisol	Ultisol
Textural class	loam	loam	loam	loam	sandy loam	sandy loam	sandy loam	sandy loam	sandy loam
Drainage	moderate	poor	good	good	moderate	good	very good	good	good
Soil acidity (pH)	5.0	4.5	6.7	5.1	4.9	5.6	4.5	5.6	4.3
Biomass (t ha^{-1})	6.4	6.7	6.4	3.9	6.3	6	6.1	4.8	15.2
Weed density (number m^{-2})	287	285	314	237	68	101	28	26	33

* *Impe = Imperata brasiliensis; Rott = Rottboellia cochinchinensis; Bacc = Baccharis floribunda.*
** Location of the farm along the Campo Verde - Nueva Requena road.

tree species in the genera *Tabebuia*, *Aspidosperma* and *Amburana* were growing well in conditions found on degraded environments and have the ability to resprout if affected by fire.

Study Sites

In the total treatment area of 1.44 ha the most important plant families were: Asteraceae (16% of the total sample), Poaceae (14%), Solanaceae (8%), Rubiaceae (6%), Papilionaceae (6%) and Euphorbiaceae (6%). Likewise the most abundant species found were (in decreasing order of importance): *Imperata brasiliensis, Rottboellia cochinchinensis, Baccharis floribunda, Pueraria phaseoloides, Hyparrhenia rufa, Pseudoelephantopus* sp. and *Brachiaria decumbens*. These results are consistent with those reported by Fujisaka *et al*. (1997) who found that *Imperata brasiliensis* was present in 51% of the surveyed farms, followed by *Homolepsis* sp. ('torourco', present in 48% of the farms), *Rottboellia cochinchinensis* (45%) and *Baccharis floribunda* (39%). The native grass 'torourco' is commonly invades abandoned pasture land in the Pucallpa zone (e.g. Clavo 1993)

Species' adaptability

Height and diameter growth, survival rate and susceptibility to pests and diseases are key variables to assess species adaptation on altered habitats (Sandoval and Cálix 1999). Table 2 presents a synthesis of the silvicultural behaviour of the six species tested.

Height growth within species was very variable (variation coefficient 15-74%), particularly in *Schizolobium amazonicum*. This species grew best at the three sites after 13 months. *Tabebuia serratifolia* performed equally well at the three sites, while *Calycophyllum spruceanum* was slightly better on Site 1.

Highest mortality was in the 3rd month (9.5%), decreasing to 1.9% in the 5th month and to 0.5% in the 11th month. *Tabebuia serratifolia* and *C. spruceanum* had the lower mortality rates at the three sites, while *Cedrelinga catenaeformis* the highest rate. This species was seriously affected during the first few months after establishment, possibly due the sudden exposure of its seedlings to full sunlight. It was also damaged by termites (80% of the dead plants

Table 2. Diameter (D) and height (H) growth and survival rate (S) of six forest tree species 13 months after establishment on three degraded sites

Species	Site 1			Site 2			Site 3		
	Imperata brasiliensis (sandy loam–loam)			*Rottboellia cochinchinensis* (sandy loam–loam)			*Baccharis floribunda* (sandy–sandy loam)		
	D (cm)	H (cm)	S (%)	D (cm)	H (cm)	S (%)	D (cm)	H (cm)	S (%)
Terminalia oblonga	1.3	107	95	1.3	73	92	1.4	66	99
Schizolobium amazonicum	2.3	127	74	3.0	167	75	3.1	170	82
Tabebuia serratifolia	1.5	111	95	1.4	105	97	1.5	109	97
Cedrelinga catenaeformis	0.6	32	5	0.8	41	3	0.7	37	17
Amburana cearensis	1.2	97	67	1.3	94	93	1.1	109	81
Calycophyllum spruceanum	1.5	106	97	1.4	91	97	1.0	65	95

were infested by Termitidae present in the earthpan).

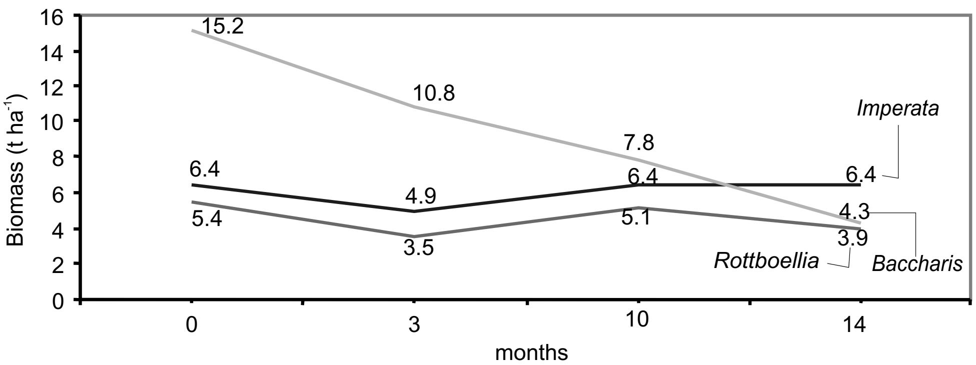
Biomass changes

Thirteen months after plantation establishment the habitat dominated by *Baccharis floribunda* (Site 3) offered comparatively better growth conditions for the tree species tested, progressively reducing the living biomass from 15.2 to 4.3 t ha^{-1} (at a rate of 0.8 t month^{-1}), or 72% reduction (Fig. 1). This finding is comparable with experiences in La Selva, Costa Rica, where the shade produced by a plantation of *Vochysia guatemalensis* contributed to the early supression of pastures (Powers *et al*. 1997). In the habitat dominated by *Rottboellia cochinchinensis* (Site 2) there are two fluctuations in the curve with the second maximum biomass value occurring after 10 months which corresponds to the vegetative time-span for this weed species. The effect of the trees planted is expressed in a biomass reduction of only 27%. In the case of *Imperata brasiliensis* (Site 1), there is no change in total biomass after 13 months; the initial biomass reduction by 20% was coincident with the dry season and the higher mortality of the herbaceous vegetation during that period (Fig. 1).

CONCLUSIONS

Land abandoned after agricultural use in Nueva Requena, Pucallpa, has a vegetation cover dominated by three main "weedy" species: *Imperata brasiliensis, Rottboellia cochinchinensis* and *Baccharis floribunda*. Of the six tree forest species planted in three degraded habitats (sites)

Figure 1. Effect of six tree species on the biomass of invasive vegetation



dominated by one of these species, *Schizolobium amazonicum* showed the best adaptation 13 months after establishment, followed by *Tabebuia serratifolia*, *Calycophyllum spruceanum* and *Terminalia oblonga*. The habitat dominated by *Baccharis floribunda* was the most favourable for tree establishment and initial growth.

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Soil Factors Affecting Growth of Seedlings in Logged-over Tropical Lowland Forest in Pasoh, Negeri Sembilan, Malaysia

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Abstract

Effects of soil properties on growth of young tree seedlings of *Hopea odorata* and *Azadirachta excelsa* in line and gap enrichment planting in logged-over tropical lowland forest were evaluated. At 13 months, the trees were grouped into "good" and "poor" growth based on their height increment in the previous 6 months. Organic matter content, penetration resistance, soil texture, thickness of A-horizon, Ca and Mg contents differed significantly between soils with "good" and "poor" growth. Organic matter, thickness of A-horizon, Ca and Mg contents were found to be significantly higher in "good" growth soils than "poor" ones, but penetration resistance was the reverse. Surface soils under "good" growth had lower clay content and higher sand content compared to that under "poor" growth. Favourable soil conditions for good growth were also manifested in biomass and litter accumulation. The mean dry biomass in the "good" and "poor" growth was 174 and 72 g m^{-2} respectively, and for dry litter 300 and 154 g m^{-2} respectively. Properties most limiting seedling growth performance were bulk density (mechanical resistance), depth of A-horizon and amount of clay in the surface soil. Correction of these factors is therefore important in ensuring the success of rehabilitation and reforestation of logged-over degraded forest.

INTRODUCTION

It is estimated that tropical forest is decreasing at the rate of 16.9 million ha $year^{-1}$ and about 5.1 million ha are annually degraded to logged-over forests. This affects timber production and causes numerous socio-economic and ecological problems such as intensified seasonal flooding with loss of lives and property, water shortages, accelerated erosion of agriculture land, siltation of rivers and coastal waters, greenhouse gas emissions, watershed stability and the loss of some species of plants and animals (Kobayashi *et al*. 1996, FAO 1998). It is therefore an urgent matter to rehabilitate these degraded forests. One promising method is "enrichment planting", e.g. by "line planting" and "gap planting".

Growth of seedlings in a forest ecosystem is influenced by soil and climatic factors. Important soil properties for the seedling growth are texture, bulk density, compaction, moisture, penetration, thickness of A-horizon, organic matter and nutrients content (Kramer and Kozlowski 1979). Plant growth is determined by an interaction of several factors because changes in one factor may bring about changes in other factors, e.g. soil compaction increases bulk density or strength of the soil, commonly referred to as its mechanical impedance, and reduces its conductivity, permeability and diffusivity to water and air (Greenland 1977). In addition, compaction reduces infiltration rate and consequently encourages soil

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and nutrient losses. Hence, it is necessary to identify factors that are more dominant so that corrective measures can be taken during rehabilitation to ensure efficient establishment of seedlings, minimise planting failure risk and reduce costs.

The objectives of the study were to: (1) compare properties of soils from seedlings with "good" growth from that with "poor" growth and (2) identify the most important soil factors influencing the growth. Two forest species, *Hopea odorata* and *Azadirachta excelsa*, commonly used in rehabilitation of lowland logged-over forest ecosystem in Malaysia were used.

MATERIALS AND METHODS

The experiment was carried out at Pasoh Forest Reserve, Jempol, latitude 3Υ03′N and longitude 102Υ21′E and approximately 80 km southeast of Seremban, Negeri Sembilan, Peninsular Malaysia. The area is logged-over forest which was clear cut using a crawler tractor and has remained untouched since 1984. The rehabilitation treatments were line planting with line width of 3m, 5m and 10m, and gap planting: 10 m x10 m x 5 ha^{-1} gaps, 20 m x 20 m x 5 ha^{-1} gaps and 10 m x10 m x 9 ha^{-1} gaps. *Hopea odorata*, *Azadirachta excelsa* and *Vitex pinnata* were planted in July. The first two species were selected because of their fast growth. At 13 months (August 1999), the trees were grouped into "good" and "poor' growth based on their height increment. Each tree was considered as one replicate. Mean height increment was measured between February–August, 1999 and the data are presented in Table 1. The difference in mean height increment between the "good" and "poor" growth for both *Hopea odorata* and *Azadirachta excelsa* was significant at 1% level according to two-paired t-test.

Surface soil samples were taken near each tree, air-dried and analysed for the physico-chemical properties. Determinations were made of texture, by pipette method (Day 1965) using calgon as a dispersing agent, bulk density by core ring method and organic matter by the wet digestion method of Walkley and Black (Allison 1965), cation exchange capacity by ammonium acetate method at pH 7, exchangeable K by autoanalyser and Ca, Mg and Na by atomic absorption spectrophotometer. *In situ* measurements of penetration using a pocket penetrometer and thickness of A- and B-horizons were made. The data from the "good" and the "poor" growth were compared statistically using analysis of variance. The above ground biomass was measured in a one metre-square plot with the planted tree in the middle.

Table 1. Mean height increment (cm) of *Hopea odorata* and *Azadirachta excelsa* for 6-month period. Data are mean of 3 trees (replicates)

Treatments	*Hopea odorata*		*Azadirachta excelsa*	
	Good	Poor	Good	Poor
Line planting, 3 m	55	19	49	3
Line planting, 5 m	47	6	29	6
Line planting, 10 m	51	18	70	2
Gap planting, 10x10 m	35	18	78	0
Gap planting, 20x20 m	35	5	63	9
Average	45	13	58	4

RESULTS

The soil conditions under "good" and "poor" growth for *Hopea odorata* and *Azadirachta excelsa* are given in Table 2. Most of the soil properties from the "good" and "poor" growth are significantly different for both *Hopea odorata* and *Azadirachta excelsa*. Organic matter, thickness of A-horizon, available water, K, Ca and Mg contents are higher in the "good" growth soils. On the other hand, penetration value and clay content were lower in the "good" growth soils. Bulk density, although not significantly different, tends to be lower in the "good" growth soils. Dry biomass and litter are significantly higher in the "good" growth soils compared to the "poor" soils. From field observation it is noted that not only the biomass is higher in the former soils but the species composition is more diverse.

Table 2. Soil conditions under the different growth groups for *Hopea odorata* and *Azadirachta excelsa*

Soil properties	*Hopea odorata*		*Azadirachta excelsa*	
	Good	Poor	Good	Poor
Bulk density (g cm^{-3})	1.32a	1.37a	1.32a	1.37a
Organic matter (%)	4.60a	3.53b	4.22a	3.04b
Penetration (Mpa)	0.35a	0.76b	0.30a	0.81b
Clay (%)	20.7a	23.9a	17.6a	26.2b
Silt (%)	13.5a	11.7a	13.1a	12.6b
Sand (%)	65.7a	63.8a	69.2a	61.1b
Thickness of A-horizon (cm)	6.0a	3.5b	5.9a	3.0b
Available water (%)	7.2a	6.0b	6.9a	5.4b
CEC (cmol(+) kg^{-1})	4.99a	4.79a	4.38a	4.5b
K (m g g^{-1})	104a	90a	101a	95a
Ca (m g g^{-1})	248a	155b	192a	106b
Mg (m g g^{-1})	43a	21b	27a	15b
Na (m g g^{-1})	4a	4a	4a	4a
Dry biomass (g m^{-2})	172a	72b	175a	72b
Dry litter (g m^{-2})	332a	153b	130a	55b

Note: within species, means with the same letter are not significantly different at $P<0.05$

The relationship between various soil properties (bulk density, organic matter, penetration, clay, silt, sand, thickness of A-horizon, available water, CEC, K, Ca, Mg and Na) and tree height increment of *Hopea odorata* and *Azadirachta excelsa* was established using multiple regression analysis (stepwise selection method). A summary of this stepwise procedure analysis is in Table 3.

Table 3 shows that percentage clay, bulk density, thickness of A-horizon and Na content were predominant factors affecting height increment of *Hopea odorata* and *Azadirachta excelsa.* This relationship is represented by the following equation.

$$Y1 = -107.5 - 0.65\,X1 + 69.75\,X2 + 11.82\,X3 + 0.86\,X4 \quad \ldots\ldots.(1)$$

Where Y1 is height increment, X1 is % clay, X2 is bulk density, X3 is thickness of A-horizon and X4 is Na content. This relationship is significant at 1% level with correlation coefficiency of 0.7552.

Table 3. Summary of stepwise procedure for relationship between soil properties and tree height increment

Variable	Parameter estimate	Standard error	Probability>F
Intercept	-107.5	37.08	0.0055
Clay	-0.65	0.34	0.0647
Bulk density	69.75	23.38	0.0043
A-horizon	11.82	1.60	0.0001
Na	0.86	0.55	0.0003

Note: All variables left in the model are significant at the 0.15 level. No other variable met the 0.15 significance level for entry into the model

Similarly, relationships between various soil properties (bulk density, organic matter, penetration, clay, silt, sand, thickness of A-horizon, available water, CEC, K, Ca, Mg and Na) and the dry biomass were established (Table 4).

Table 4 shows that bulk density and thickness of A-horizon were predominant factors affecting biomass accumulation. This relationship is represented by the following equation.

$$Y2 = -348.71 + 255.12X5 + 28.41X6 \quad \ldots\ldots..(2)$$

Where Y2 is dry biomass, X5 is bulk density and X6 is thickness of A-horizon. This relationship is significant at 1% level with correlation coefficient of 0.5513.

Table 4. Summary of stepwise procedure for relationship between soil properties and dry biomass

Variable	Parameter estimate	Standard error	Probability>F
Intercept	-348.71	138.41	0.0147
Bulk density	255.12	93.14	0.0083
A-horizon	28.41	5.88	0.0001

Note: All variables left in the model are significant at the 0.15 level. No other variable met the 0.15 significance level for entry into the model

DISCUSSION

Table 1 shows that there is a distinct difference between properties of soils of the "good" growth and that of the "poor" growth plots. Among the physical properties, organic matter, mechanical resistance, thickness of A-horizon, available water and clay content were found to be significantly different between the "good" and "poor" growth soils. Bulk density, although not significantly different, tends to be lower in the "good" growth soils. This insignificance may be due to higher coefficients of variation found for the bulk density. A similar result was reported by Alegre *et al.* (1986) and Craul (1994). Organic matter is well known to affect the fertility of soils through its influence on many other properties such as water holding capacity, soil structure and nutrient availability. Many previous studies have shown that poor establishment of seedlings during rehabilitation of logged-over forest was attributed to decrease in organic matter due to forest harvesting (Barber and Romero 1994; Kobayashi *et al.* 1996). Mechanical resistance may affect growth through its effect on root expansion and elongation. Raghavan *et al.* (1990) have shown root density decreases with increase in penetration resistance. A-horizon provides the seat for development of root systems and furthermore many plants tend to develop surface root system during initial phase of root development. Thus the thicker and the richer the A-horizon the more extensive is the root system and consequently the better the growth of the plants. A well-developed root system in the A-horizon also influences rate of water permeability into deeper soils and therefore affects water availability in the root zone.

Amongst the chemical properties studied, only Ca and Mg contents were found to be significantly higher in the "good" growth soils. The role of Ca in cell wall development and Mg in the formation leaf chlorophyll have frequently been reported. Thus their presence in available form in the soils is important for the initial growth of the seedlings.

It is envisaged that growth of trees does not depend on a single soil property but interaction of several soil properties. In this study a stepwise multiple regression analysis was carried out between the growth and the soil parameters. The equation established between height increment and soil properties suggests that tree growth was strongly and positively influenced by bulk density and thickness of A-horizon and less strongly and negatively by clay content (Equation 1). A similar result was also found for the growth of biomass where quantity of above ground biomass was strongly and positively related to bulk density and thickness of A-horizon (Equation 2). The results indicate that the two most limiting factors in affecting growth of young seedlings were bulk density and thickness of A-horizon and, to a much lesser extent, clay content. This result contradicts the earlier result that there is no significant difference in bulk density between the "good" and "poor" sites. However, although not significantly different, the bulk density tended to be lower in the "good" growth soils. Further it has been argued that the insignificance may be due to higher coefficients of variation found for the bulk density.

In general the above results imply that in evaluating the impact of forest harvesting on subsequent forest regeneration, consideration should be given to bulk density and thickness of A-horizon because both were drastically impaired due to harvesting operation (Kobayashi *et al.* 1996). So to improve growth and seedling establishment in rehabilitation of degraded logged-over forest, it is necessary to adopt silvicultural practices which can enhance soil properties. For example, the size of planting holes can be enlarged (e.g. 60 cm x 60 cm x 50 cm) and a mixture of topsoil, organic compost and fertiliser used to refill the holes after planting.

CONCLUSION

The predominant factors limiting growth performance of seedlings in the study area are high bulk density or high mechanical resistance, shallow depth of A-horizon, high amount of clay fraction in surface soil and content of Ca and Mg. High bulk density and thinness or absence of the A-horizon are most important. Correction on these factors is therefore essential for successful rehabilitation and reforestation of degraded forest ecosystems. This can be achieved through silvicultural practices which improve soil properties that are important in a sustainable forest production system. Using a modified planting technique, e.g. constructing a large planting hole and using a mixture of topsoil, organic compost and fertiliser to refill the hole after planting.

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15 Evaluation of Methods for Rehabilitation of Logged-over Lowland Forest in Pasoh, Negeri Sembilan, Malaysia

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Abstract

Four rehabilitation methods were tested in logged-over lowland tropical forest in Pasoh Forest Reserve, Negeri Sembilan, Peninsular Malaysia. The treatments were: line planting (T1), gap planting 10m x 10m x 5 ha^{-1} (T2), gap planting 20 m x 20 m x 5 ha^{-1} (T3) and gap planting 10 m x 10 m x 9 ha^{-1} (T4). *Hopea odorata, Azadirachta excelsa* and *Vitex pubescens* were planted in the lines and gaps. One year after planting, percentage survival of seedlings were: 97%, 96%, 93% and 93% respectively for T1, T4, T2 and T3 for *Hopea odorata*; 96%, 90%, 88% and 85% respectively for T4, T1, T3 and T2 for *Azadirachta excelsa*; and 97%, 94%, 87% and 76% respectively for T4, T1, T3 and T2 for *Vitex pubescens*. The costs for each treatment per hectare were RM 2862; RM 1520; RM 684 and RM 380 for T1, T3, T4 and T2 respectively. In general soil properties (bulk density, organic matter, soil moisture and pH) before and after rehabilitation treatments were not significantly different suggesting all the rehabilitation methods can prevent soil degradation. Technically, line planting and gap planting methods were suitable for rehabilitation of this area but in terms of economic cost and effective area planted, gap planting was more efficient and effective than line planting. *Hopea odorata, Azadirachta excelsa* and *Vitex pubescens* are suitable for rehabilitation of this forest.

INTRODUCTION

Tropical forest is one of the complex, self-supporting and stable ecosystems but removal of the protective forest vegetation exposes structurally unstable soil to the destructive force of raindrops resulting in drastic ecosystem changes (Meka 1994). The most notable, regional and local effects of exploitation or forest harvesting include changes in hydrologic cycle, micro climate, energy balance, nutrient recycling, and biotic environment including soil micro-floral and faunal activities (Lal 1985). To reduce logging impacts, rapid forest function recovery is essential and planting of tree species is the easiest and most reliable method to achieve this (Sakurai *et al.* 1994). The rehabilitation technique and choice of tree species are crucial factors for successful rehabilitation of degraded logged-over forest.

The objectives of this study were firstly to identify a cost-effective method of rehabilitation of logged-over forest and secondly to determine if *Hopea odorata, Azadirachta excelsa* and *Vitex pubescens* are suitable for rehabilitation of this forest.

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MATERIAL AND METHODS

Site description

The study was conducted at Compartment 121, Pasoh Forest Reserve, Jempol, latitude 3°03'N and longitude 102°21'E and approximately 80 km southeast of Seremban, Negeri Sembilan, Peninsular Malaysia. The soil, derived from acidic granites, shales and interbedded shales and sandstones, is classified as a Kaolinitic Isohypertermic Typic Palaeudult (Allbrook 1973). The area is undulating with slopes ranging from gentle to steep. The forest was selectively logged manually by chainsaw and has remained untouched since 1984. Annual rainfall ranges from 1728–3112 mm with a mean of 2054 mm, wet months with rainfall 250–350 mm month^{-1} were April–May and November–December, driest months with rainfall 30-100 mm month^{-1} were February-March and July-August. Air temperature fluctuated from 19.6 to 35.9°C, with a monthly mean of 24.8°C (Soepadmo and Kira 1977).

Experimental design

The rehabilitation methods tested were:

- *Line planting* (T1): Seedlings were planted east-west in two rows within each line, distance between lines was 10m. There were three different widths of line in each plot namely 3 m, 5 m and 10 m, each containing double rows of seedlings with row distance of 2 m, 3 m and 6 m respectively and seedling spacing within rows of 2 m. There were 102 trees per line planting or 612 trees ha^{-1} and total area planted was 3600 m^2 ha^{-1}.
- *Gap planting* (T2): Tree seedlings were grown in a gap 10 m x 10 m and each treatment plot had 5 gaps. In each gap, the seedlings were spaced 2 m x 2 m giving 16 trees per gap and 80 trees ha^{-1}.
- *Gap planting* (T3): Tree seedlings were grown in a gap 20 m x 20 m and each treatment plot had 5 gaps. In each gap, the seedlings were spaced 2 m x 2 m giving 64 trees per gap and 320 trees ha^{-1}.
- *Gap planting* (T4): Tree seedlings were grown in a gap 10 m x 10 m and each treatment plot had 9 gaps. In each gap, the seedlings were spaced 2 m x 2 m giving 16 trees per gap and 144 trees ha^{-1}.

The four methods were replicated three times in a Randomized Complete Block Design and each treatment plot was 100 m x 100 m. *Hopea odorata*, *Azadirachta excelsa* and *Vitex pubescens* were planted. Lines and gaps were cleared by sickle and chainsaw before planting and the planting pits, 15 cm diameter and 30 cm deep, were made at the time of planting. Christmas Island rock phosphate (CIRP) fertiliser at rate 30 g per seedling was applied at planting in July-August 1998.

Data collection and analysis

Survival rate of seedlings was recorded based on a census of all planted seedlings. Soil properties: bulk density, soil moisture characteristic, organic matter and pH were measured. Bulk density was measured using undisturbed core samples (4 cm long and 7.5 cm diameter). Total organic matter was determined by Walkey and Black's titration method (Piper 1950). Soil moisture characteristics at 0, 1, 10, 33 and 1500 kPa were determined by the pressure plate method (Richards 1947). Soil pH in water with 1:2.5 ratio of soil to solution was measured with a pH meter. All undergrowth (plants of less than 2m in height) in a 1 m x 1 m quadrat was collected to determine dry matter weight. A planting cost per hectare was estimated for each treatment.

RESULTS AND DISCUSSION

In this study we observed several variables, such as survival rate of seedlings, cost estimate, changes of soil properties and development of undergrowth, as indicators of successful rehabilitation treatment. Seedling growth and soil data are most of the important indices required for planning operations.

Survival of seedlings

Seedling survival of each species was measured a year after planting in July 1999 and the results are shown in Table 1.

Table 1. Survival rate of seedlings after one year

Treatment	*Hopea odorata*	*Azadirachta excelsa*	*Vitex pubescens*
	%		
T1	97a	90a	94a
T2	93a	85a	76b
T3	93a	88a	87a
T4	96a	96a	97a

Within columns, numbers followed with the same letter are not significantly different at 5% level (Duncan's Multiple Range Test)

A year after planting, the seedling survival rate *Hopea odorata, Azadiracta excelsa* and *Vitex pubescens* was high (>85%), Among treatments, there were no significant differences except for *Vitex pubescens,* whose percentage survival seedling was lower in gap planting T2 compared to other treatments. Although survival rate was high, growth performances from visual observation in the field were not homogenous in each treatment (plot). This indicates the reaction of seedlings to environmental conditions is very specific. For example, near the river seedlings grew fast but on compacted soil areas seedlings grew slowly. Evans (1992) reported that many factors affect initial survival rate, including (i) planting skill, (ii) immediate post-planting weather, (iii) condition of seedlings, (iv) poor soil condition, (v) insects, such as termites, (vi) weed competition and (vii) animal damage. It follows that the most important step in the rehabilitation of logged-over forest is to identify and minimise those factors that limit seedling growth and contribute to mortalities.

Cost estimate of rehabilitation technique

A planting cost per hectare was calculated for each treatment. For this study, a compounded rehabilitation cost was calculated from preparation of the area until the seedlings were planted using a hypothetical labour cost of Ringgit Malaysia (RM) 7.50 hour^{-1} and a seedling cost of RM 1.00. Labour cost for site preparation was RM 0.20 m^{-2} and planting seedlings RM 1.00 per seedling. The results are shown in Table 2.

Gap planting was less expensive than line planting (Table 2). Total planting area and number of seedlings per hectare were the main variable costs in the rehabilitation of logged-over forest.

Soil properties

Soil properties were measured before and a year after treatments (Table 3). The soils from all treatment plots before rehabilitation had a high bulk density, low to medium organic matter and were acidic. These conditions indicated the soils were degraded. Sanchez *et al.* (1994) reported physical and chemical degradation of forest land involves soil compaction, sheet and gully erosion, significantly increased soil acidity and decreased available nutrients.

Data in Table 3 shows that there was generally no significant changes of soil properties one year after the rehabilitation treatments. This may be due to tree felling by sickle and chainsaw during manually clearing the plot. However, significant changes in bulk density were shown in the line planting method as it decreased from 1.48 g cm^{-3} to 1.30 g cm^{-3}.

Table 2. Cost estimates (Ringgit Malaysia) of different rehabilitation techniques

Treatments	Cost			
	Preparation planting area	Seedlings	Planting	Total
T1	720	1,530	612	2862
T2	100	200	80	380
T3	400	800	320	1520
T4	180	360	144	684

Note: RM 1.00 = US $ 0.262

Table 3. Soil properties before and after rehabilitation treatments

Soil Properties	T1		T2		T3		T4	
	Before	After	Before	After	Before	After	Before	After
Bulk density (g cm^{-3})	1.48*	1.30*	1.25 ^{ns}	1.28 ^{ns}	1.38 ^{ns}	1.27 ^{ns}	1.42 ^{ns}	1.27 ^{ns}
Organic matter (%)	2.86^{ns}	3.10 ^{ns}	3.84 ^{ns}	3.92 ^{ns}	3.48 ^{ns}	3.06 ^{ns}	4.04 ^{ns}	4.02 ^{ns}
pF 0 (% v/v)	49 ^{ns}	50 ^{ns}	53 ^{ns}	40 ^{ns}	46 ^{ns}	48 ^{ns}	44 ^{ns}	40 ^{ns}
pF 1 (% v/v)	41 ^{ns}	43 ^{ns}	38*	34*	40 ^{ns}	35 ^{ns}	38 ^{ns}	34 ^{ns}
pF 2 (% v/v)	31 ^{ns}	32 ^{ns}	27 ^{ns}	27 ^{ns}	32 ^{ns}	30 ^{ns}	31 ^{ns}	28 ^{ns}
pF 2.54 (% v/v)	25 ^{ns}	29 ^{ns}	21 ^{ns}	24 ^{ns}	25 ^{ns}	26 ^{ns}	25 ^{ns}	24 ^{ns}
pF 4.19 (%v/v)	22 ^{ns}	22 ^{ns}	17 ^{ns}	19 ^{ns}	21 ^{ns}	21 ^{ns}	20 ^{ns}	20 ^{ns}
Available water (%v/v)	3 ^{ns}	7 ^{ns}	4 ^{ns}	5 ^{ns}	4 ^{ns}	5 ^{ns}	5 ^{ns}	4 ^{ns}
pH H_20 1: 2.5	4.75 ^{ns}	4.73 ^{ns}	4.79 ^{ns}	4.90 ^{ns}	4.72 ^{ns}	4.37 ^{ns}	4.66 ^{ns}	4.15 ^{ns}

ns = non significant at 5% level * = significant at 5% level

Table 4. Changes of dry undergrowth at 6 months in the rehabilitation area

Treatment	Undergrowth (t ha^{-1})		
	September 1998	February 1999	Growth rate (times)
T1	1.20	6.77	5.6
T2	1.05	4.12	3.9
T3	0.92	3.54	3.9
T4	1.13	2.99	2.7

Undergrowth

The undergrowth productivity measured on an oven-dry weight basis showed that after a period of 6 months the undergrowth increased from 1.20 to 6.77 t ha^{-1} in line planting, from 1.05 to 4.12 t ha^{-1} in gap planting 10m x 10m x 5 ha^{-1}, from 0.92 to 3.53 t ha^{-1} in gap planting 20m x 20 x 5 ha^{-1}and from 1.13 to 2.99 t ha^{-1} in gap planting 10m x 10m x 9 ha^{-1} (Table 4). It was clear that the undergrowth in line planting developed more quickly than in gap planting. This may be because the large area opened in line planting allows increased growth of undergrowth by increasing the amount of sunlight. Ochiai *et al*. (1994) also found that the undergrowth in gap planting is less than in line planting. Sometimes the undergrowth interfered with the growth of young seedlings, e.g., *Bauhinia* spp. climbing on young seedlings. To prevent competition between undergrowth and young seedlings, selective weeding around planted seedlings must be practised during the rehabilitation process.

CONCLUSION

These results suggest that technically, line planting and gap planting methods were suitable for rehabilitation of this area but in terms of economic cost and effective area planted, gap planting was more efficient and effective than line planting. *Hopea odorata, Azadirachta excelsa* and *Vitex pubescens* are suitable for rehabilitation of this forest.

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16

Rehabilitation of Tropical Rainforests Based on Indigenous Species for Degraded Areas in Sarawak, Malaysia

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Abstract

A study was conducted on forest rehabilitation based on indigenous species at the Universiti Putra Malaysia, Bintulu, Sarawak. Areas of open abandoned shifting cultivation, man-made mounds, *Macaranga* secondary forest and shrubby undergrowth were used for trial planting with different types of planting techniques. The research showed that selected species from the natural vegetation community easily adapt to the site conditions similar to their native habitat. The planted seedlings were classified as light demanding, shade tolerant and late growth species on the basis of their height growth performance in the trials. The indigenous tree species recommended for checkerboard plantations are: *Shorea ovata, S. mecistopteryx, S. macrophylla, Dryobalanops aromatica, Parashorea parvifolia, Hopea beccariana, Durio carinatus* and *Eusideroxylon zwageri.*

INTRODUCTION

The concern over depletion of the tropical rainforests has resulted in an increasing emphasis on forest rehabilitation to maintain the ecological balance within the ecosystem. Forest clearfelling in Sarawak is mainly by shifting cultivation practices. The figures based on the satellite imageries of 1990 to 1991, show the total area of land affected by shifting cultivation is about 3 million hectares. Of this, 116 121 hectares are located within the permanent forest estate while 11 404 hectares are in totally protected areas. In view of the loss, an extensive reforestation program is necessary both to sustain the forest resources and to rehabilitate the deteriorating ecosystem. Malaysian research in this area has included planting of native species on barren land and in secondary vegetation and much experience is available from research dating back to the 1920s.

Rehabilitation of forest involves re-establishment of a more intact canopy that is found in undisturbed forests (Lim 1992). It is also important to define the objective of rehabilitation so the efforts can be evaluated subsequently. This can be the restoration of the degraded forests to its original pristine stage with the use of indigenous tree species. The case for using indigenous species has often been overlooked, possibly because of a lack of information but perhaps more likely so through the biased view that exotics are better. There are problems associated with the use of indigenous species, such as the lack of ecological understanding of the requirements for growth, the inadequate collection of seeds, the relatively slow growth and the purported uneconomic proposition of using indigenous species. These problems can be overcome through research. On the other hand, there are numerous other advantages of using indigenous species. They are already adapted to the local conditions, the genetic base is easily

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accessible, and the supply of seeds may not be as difficult as anticipated previously. There is a wealth of information available locally that can be usefully exploited.

Even though the potential of using indigenous tree species for forest plantation in Malaysia has been known since 1921 (Appanah and Weinland 1993), the species were never planted on a large scale. They were planted as part of experimental research or reforestation projects. Species, such as *Shorea macrophylla, S. pinanga, S. splendica, S. palembanica* and *S. streoptera,* were planted in Sarawak mainly due to their fast growth and illipe nuts (Joseph 1992). Many rehabilitation efforts using different techniques have been carried out in Malaysia with varying degrees of success. One technique that has been successful in the warm temperate zone is dense planting (e.g. Miyawaki 1993). This technique was used in Bintulu, Sarawak to rehabilitate the degraded shifting cultivation area with indigenous tree species.

The study reported here had two objectives:

- to understand the nature of tree-environment relationships of the native species and,
- to recommend the most suitable species and the best planting techniques for different sites conditions for rehabilitation of tropical rainforest.

MATERIALS AND METHODS

The study was conducted on a 47.5 ha area within the former campus of Universiti Putra Malaysia, Bintulu, Sarawak the campus premise. It is located about 600 km northeast of Kuching, latitude 3^0 12’ N, longitude 113^0 05’ E and 50 m a.s.l. Mean annual rainfall is 2993 mm and the rainy season is November-January during the northeast monsoon. The mean daily temperature recorded is 26.7^0 C and relatively consistent throughout the year. Mean monthly relative humidity is usually above 80% but slightly lower during the rainy season. The soil belongs to Nyalau and Bekenu series and is well-drained. The Nyalau series is characterised by coarse loam, light yellowish brown topsoil 9 cm deep with brownish yellow subsoil. The Bekenu series is a fine loam, light yellowish brown top soil 4-15 cm deep and brownish yellow subsoil (Peli *et al*. 1984).

The planting methods and site preparation employed depended on the condition of the sites:

- Site A: severely eroded and compacted areas,
- Site B: man-made mounds,
- Site C: under *Macaranga* secondary forest,
- Site D: in grasses and undergrowth.

At Site A and Site B, the planting of three seedlings per metre square with a mixed and random distance was applied. For under *Macaranga* secondary forest (Site C), the seedlings were planted at 3 metres between them and oriented in line. But for Site D, the planting distance just 1 metre and the clearance of the line for planting area was 1 metre width. The distance between line were located at 3 metres each. The dense planting technique (three seedlings per metre square) shortens the time for the canopy closer and controls the weed growth.

Data on growth performance (basal diameter and total height) and survival rate of planted seedlings were recorded for 72 months (Site A and Site C) and 60 months for Site B and 66 months for Site D.

RESULTS AND DISCUSSION

Survival. In general, survival rate decreased rapidly soon after planting, especially for the shade demanding species. The strong and direct sunlight burned the leaves of newly planted seedlings. After one year, the light-demanding species had no further mortalities. The slow height growth of some species reduced survival rate, as the seedlings did not have enough sunlight for the photosynthesis process, and competition for sunlight also affected the survival rate of *Parashorea parvifolia*. The size of the newly-planted seedlings (less than 50 cm tall) also contributed to the low survival rate. Seedlings less than 50 cm in height cannot compete with the growth of weeds for nutrients, sunlight and growing space (Mohamad Azani *et al*. 1995).

Table 1. Survival rate (%) of planted species at four different planting sites

	Species	Site			
		A	B	C	D
		Survival (%)			
1	*Calophyllum ferrugenium*	24	25	-	-
2	*Cotylelobium burckii*	33	-	-	0
3	*Dryobalanops aromatica*	51	45	-	50
4	*Durio carinatus*	45	45	-	73
5	*Eugenia* sp.	25	18	-	56
6	*Eusideroxylon zwageri*	-	-	96	-
7	*Hopea beccariana*	14	14	-	-
8	*Hopea kerangasensis*	15	25	-	0
9	*Parashorea parvifolia*	10	-	-	-
10	*Pentaspodon motleyi*	-	80	69	-
11	*Shorea gibbosa*	23	20	-	-
12	*Shorea leprosula*	35	20	-	34
13	*Shorea macrophylla*	-	80	85	62
14	*Shorea materialis*	16	10	-	-
15	*Shorea mecistopteryx*	40	67	73	59
16	*Shorea ovata*	41	43	-	56
17	*Vatica nitens*	-	10	-	-
18	*Whiteodendron moultianum*	56	55	-	-

Survival rate at Site B was higher than at Site A (Table 1). The highest survival rate was 80% for *Shorea macrophylla* and *Pentaspodon motleyi,* while *Shorea mecistopteryx* and *Whiteodendron moultianum*. were above 50%. The lowest survival rate was 10% for *Vatica* sp. Better site conditions at Site B were probably responsible for the higher survival rate. These were: (a) good aeration, through using topsoil as a main material for the man-made mound, and less compaction, (b) more nutrients in the top soil, (c) good drainage and less weed competition.

The survival rates for seedlings under shade (Sites C and D) were higher than for direct sunlight (Table 1). The mortality of *Hopea kerangasensis* and *Eugenia* sp. at Site D was caused by the small seedlings which could not compete with the weed growth. The shade provided a better planting condition in terms of humidity and amount of sunlight. The sunburned effect was not found on any newly-planted seedlings under shade. The survival rate of planted seedlings at Site D was 40-80%, while for Site C it was over 60%.

Rahim (1992) reported survival rate of 44% for *E. zwageri* at the Segaliud Lokan enrichment planting by line planting under natural forest shade. The 100% mortality of *Hopea kerangasensis* and *Cotylelobium burckii* at Site D was due to the small size of the seedlings at the time of planting. *Durio carinatus* had the highest survival with 73% after 5 years. Dipterocarpaceae species (*Dryobalanops aromatica, Shorea macrophylla, S. mecistopteryx, S. ovata* and *S. leprosula*) had 34-62% survival. Anuar and Abtah (1990) reported a survival rate for *Dryobalanops lanceolata* (84%), *Shorea beccariana* (64%), *S. mecistopteryx* (72%) and *S. superba* (76%) in the enrichment planting by line planting. The survival rates suggest that planted seedlings can easily adapt to the site condition at Site D with reduced sunlight and small temperature changes.

The site conditions under *Macaranga* secondary forest (Site C), which is mesic, had low sunlight penetration (around 50% at the time of planting) and less weeds, were very suitable for *Eusideroxylon zwageri*, *Pentaspodon motleyi*, *Shorea macrophylla* and *S. mecistopteryx* to grow.

The inability of some seedlings to adapt to the site's microclimate may have attributed towards some seedling mortality especially during the first six months after planting (Mohd Zaki *et al*. 1993). Taller seedlings competed better for sunlight, water, nutrient or space and survived better than smaller trees.

Growth. In general, the species planted in severely eroded and compacted areas (Site A) had moderate growth in basal diameter and height, except *Dryobalanops aromatica* and *Whiteodendron moultianum* which showed good growth (Tables 2 and 3). On mounds (Site B), *Pentaspodon motleyi* had the highest basal diameter MAI (2.88 cm), followed by *Whiteodendron moultianum* (1.99 cm). *Calophyllum ferrugenium* had the lowest MAI (0.46 cm) at Site B but moderate (0.64 cm) at Site A. The four species planted at Site C had low MAI basal diameters (0.31-0.93 cm). Of the *Shorea* species tested, *S. leprosula* and *S. ovata* had higher MAI in height at Sites B and D. The slowest species in the trials was *S. gibbosa* (17.00 cm MAI height) at Site A (Table 3).

In direct sunlight, *Dryobalanops aromatica, Shorea ovata, S. leprosula, Whiteodendron moultianum, Pentaspodon motleyi* and *Durio carinatus* had the highest mean height growth. At Site A *Dryobalanops aromatica,* reached a height of 598 cm, followed closely by *Whiteodendron moultianum* (594 cm) and *Shorea ovata* (588 cm). *Whiteodendron moultianum* had highest diameter (9.5 cm), while *D. aromatica* was (9.2 cm). *Shorea leprosula* had only moderate growth in total height and volume and other species on this site showed less growth.

On the man-made mounds (Site B), *Pentaspodon motleyi* had the biggest height and basal diameter growth, while at Site D, in grasses and undergrowth, *Shorea leprosula* had the best growth (both height and basal diameter). At Site B, *P. motleyi, S. leprosula, S. ovata* and *W. moultianum* had good growth in total height, but only P. *motleyi* showed good growth in basal diameter. *Pentaspodon motleyii* appears to have a weak apical dominance and so needs strong lateral competition to stay erect. Its self-pruning capacity is good but not its self-thinning ability. The crowns are feathery and much light penetrates to the ground floor.

Table 2. Mean annual increment (MAI) of basal diameter of planted species at four different planting sites

Species		Sites			
		A	B	C	D
		Basal diameter MAI (cm year^{-1})			
1	*Calophyllum ferrugenium*	0.64	0.46		
2	*Cotylelobium burckii*	0.75			Dead
3	*Dryobalanops aromatica*	1.53	1.01		1.09
4	*Durio carinatus*	0.49	0.78		0.49
5	*Eugenia* sp.	0.42	0.51		0.42
6	*Eusideroxylon zwageri*			0.31	
7	*Hopea beccariana*	0.68	0.83		
8	*Hopea kerangasensis*	0.55	0.49		Dead
9	*Parashorea parvifolia*	0.78			
10	*Pentaspodon motleyi*		2.88	0.93	
11	*Shorea gibbosa*	0.90	1.17		
12	*Shorea leprosula*	1.32	1.45		1.48
13	*Shorea macrophylla*		0.86	0.44	0.70
14	*Shorea materialis*	0.97	0.63		
15	*Shorea mecistopteryx*	0.85	1.18	0.63	0.98
16	*Shorea ovata*	0.93	1.79		0.95
17	*Vatica nitens*		1.59		
18	*Whiteodendron moultianum*	1.58	1.99		

Table 3. Mean annual increment (MAI) of height of planted species at four different planting sites

Species		Sites			
		A	B	C	D
		Height MAI (cm $year^{-1}$)			
1	*Calophyllum ferrugenium*	43.0	24.0		
2	*Cotylelobium burckii*	47.3			Dead
3	*Dryobalanops aromatica*	99.7	68.0		83.2
4	*Durio carinatus*	41.8	41.6		60.9
5	*Eugenia* sp.	18.3	37.4		30.8
6	*Eusideroxylon zwageri*			31.4	
7	*Hopea beccariana*	50.3	37.0		
8	*Hopea kerangasensis*	18.3	32.0		Dead
9	*Parashorea parvifolia*	59.3			
10	*Pentaspodon motleyi*		64.0	113.3	
11	*Shorea gibbosa*	17.0	64.0		
12	*Shorea leprosula*	77.5	131.3		103.0
13	*Shorea macrophylla*		70.8	46.4	62.8
14	*Shorea materialis*	65.7	65.4		
15	*Shorea mecistopteryx*	64.0	65.6	117.5	69.0
16	*Shorea ovata*	98.0	131.1		91.2
17	*Vatica nitens*		37.4		
18	*Whiteodendron moultianum*	99.0	110.7		

The results confirm the observation of Appanah and Weinland (1993) that *Shorea parvifolia* is shade demanding and slow growing when young but later requires full sunlight to grow well. *Shorea leprosula*, when young, is less shade tolerant than *S. parvifolia*, and will die. Its self-pruning capacity was superior to *S. parvifolia*. *Shorea leprosula* is suited for planting in less competitive conditions but needs strong competition to prevent formation of wolf trees, and if early growth rates are too high, brittle heart may develop (Appanah and Weinland 1993). As a mature tree, *Shorea leprosula* forms a distinctly open and wide spreading crown, and light penetrates easily to the ground. It is therefore preferable to mix it with species having a dense crown. *Shorea leprosula* reached 73 cm in height after 1 year and 3 m after 4 years on man-made mounds (Ismail Adnan Malek and Othman 1992, Mohamad Azani 1995).

Shorea macrophylla had exceptionally fast growth and a wide spreading crown with big limbs, as shown at Site A. It needs medium shade at the early stage of planting, and under shade it grows with excellent form (Appanah and Weinland 1993). It makes an excellent species for line planting into secondary growth and on cleared sites it needs a nurse crop. *Shorea macrophylla* has a very fast diameter growth but after initial fast height growth this levels off (Azman *et al.* 1990). *Shorea ovata* performed well in the open and confirmed its classification as a light demander by Wood and Meijer (1964).

From the results, *Dryobalanops aromatica* was distinctly shade tolerant at the young stage and had excellent growth in basal diameter and height. Appanah and Weinland (1993) recommended it must be raised under strong competitive conditions to prevent formation of brittle heart. It was selected as a potential species for mixed plantations with *Shorea leprosula, Shorea ovata, Hopea odorata, Endospermum malaccense, Dyera costulata* and *Khaya ivorensis* (Appanah and Weinland 1993). Numerous other researchers have noted its good survival under shade, e.g. Barnard (1949), Mohd Zaki *et al.*

(1993). It has good potential for rapid height growth, e.g. Watson (1935) found it reached an average of 6 m height and 11.3 cm diameter in six years and Edwards and Mead (1930) estimated that it takes only 43 years to reach 50 cm diameter and 66 years to reach 70 cm diameter. At Kepong, Malaysia, plantations aged 46 years had trees over 50 cm diameter and with a mean annual increment of 8 m^3 ha^{-1}

Based on the mean total height growth of planted species under the four different conditions, three categories of species can be recognised:

- **Light demander species:** *Shorea ovata, S. mecistopteryx, Dryobalanops aromatica, Pentaspodon motleyi* and *Whiteodendron moultianum.*
- **Shade tolerant species:** *Shorea macrophylla, S. gibbosa, S. materialis, Parashorea parvifolia, Hopea beccariana, Cotylelobium burckii, Calophyllum ferrugenium, Durio carinatus* and *Eusideroxylon zwageri.*
- **Late growth species**: *Hopea kerangasensis, Eugenia* sp., and *Vatica* sp.

It is recommended that mixed and dense planting can give fast restoration results, but when the planting area is large, a checkerboard plantation design can be applied as an alternative rehabilitation technique. The cost of rehabilitation in wide areas can be reduced by using this method because less seedlings are used. The indigenous tree species recommended for checkerboard plantation were *Shorea ovata, S. mecistopteryx, S. macrophylla, Dryobalanops aromatica, Parashorea parvifolia, Hopea beccariana, Durio carinatus* and *Eusideroxylon zwageri.*

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17

Short Communication

Preliminary Results of the Effects of Different Gap Sizes on the Growth and Survival of Six Forest Tree Species in Papua New Guinea

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Forest degradation due to logging is becoming an acute problem in Papua New Guinea. Research started at two sites in 1998-1999 to develop the most effective methods to rehabilitate logged-over forest sites by applying different treatments, observing changes in the forest ecosystem and determining whether these methods are more effective than allowing natural regeneration to rehabilitate the forest. It aimed to test different size gaps (10 m x 10 m x 9, 10 m x 10 m x 5, 20 m x 20 m x 5) for planting in logged-over forest and to measure the growth and survival of three species with potential for use in rehabilitation at each site.

Gumi (site 1) is montane forest about 33 km west of Bulolo at an altitude of 2300 m. The forest is dominated by species of Fagaceae, especially *Castanopsis acuminatissima*. The species planted at Gumi are *Castanopsis acuminatissima, Phyllocladus hypophyllus* and *Euodia melicope.* Yalu (site 2) is typical lowland rainforest, about 15 km from Lae at about 100 m asl. *Pterocarpus indicus, Instia bijuga,* and *Pometia pinnata* were planted at this site. There is an 8 ha plot at each site with three gap treatments and a control in four 1 ha plots with two replications. The treated plots were planted in different gap size clearings of 10 m x 10 m x 9; 10 m x 10 m x 5 and 20 m x 20 m x 5. At 2 m x 2 m spacing, all planted trees were tagged and numbered including those residual trees within the plot with diameter breast height greater than 10 cm. Parameters were recorded on monthly basis and commercial trees regenerating naturally within the cleared gaps were recorded. Seedlings were nursery stock or directly from the forest as wildings. The parameters measured are: seedling height, branch internodes, number of branches and leaves. Mortality is also recorded and refilling carried out where necessary. Light intensity is measured within the treated plots between gaps, control and surrounding natural forest.

A preliminary analysis was made 9 months after planting at site 1 and after 3 months at site 2. It was found that at the high altitude site seedlings grew better growth in gap size 10 m x 10 m x 9 while at the low altitude best growth was in 20 m x 20 m x 5. There was high seedling mortality (35%) in the smaller (10 m x 10 m) gaps at low altitude. *Castanopsis acuminatissima* had 95% survival rate in 10 m x 10 m x 9 gap size at this stage shows the most promise for planting in the montane forest followed by *Euodia melicope*. At the low altitude site *Pterocarpus indicus* followed by *Instia bijuga* shows most potential. The trial plots will be monitored to confirm these initial observations.

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