EARLY PERFORMANCE OF 12 SHADE TOLERANT TREE SPECIES INTERPLANTED WITH *PARASERIANTHES FALCATARIA* ON *IMPERATA CYLINDRICA* GRASSLAND

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OTSAMO, R., ÅDJERS, G., HADI, T. S., KUUSIPALO, J. & OTSAMO, A. 1996. Early performance of 12 shade tolerant tree species interplanted with *Paraserianthes falcataria* on *Imperata cylindrica* grassland. Performance of 12 slow-growing shade tolerant tree species on *Imperata cylindrica* dominated grassland interplanted with *Paraserianthes falcataria* was studied for five years in South Kalimantan, Indonesia. The seedlings were planted under a two-year-old plantation in a randomized complete block design with eight replications. All the species had high survival until the third year, when the mortality of several *Shorea* species as well as *Durio zibethinus* increased considerably as a result of a severe dry season. Non-dipterocarp species, *Podocarpus polystachyus, Agathis borneensis* and *Pericopsis mooniana,* had the best performance in the trial with survival rates of 82-95% and height of 3.2-3.5 m at the age of five years. The best dipterocarps were *Vatica* sp., *S. leprosula* and *Hopea sangal* with survival rates of 49-

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83% and height of 2.9-3.4 m. The results suggest that rehabilitation of *Imperata* grasslands by interplanting shade tolerant species with fast-growing species is possible with proper species selection. Despite the long time period needed, the method will provide alternatives for monoculture plantations both in terms of wood production and restoration of natural forest ecosystem.

Key words: Dipterocarps - non-dipterocarps - nurse tree - shade tree - *Imperata cylindrica* - grassland - reforestation - rehabilitation - *Paraserianthes falcataria*

OTSAMO, R., ÅDJERS, G., HADI, T. S., KUUSIPALO, J. & OTSAMO, A. 1996. Prestasi awal 12 spesies pokok toleran naungan yang ditanam selang dengan *Paraserianthes falcataria* di atas padang rumput *Imperata cylindrica.* Prestasi 12 spesies pokok toleran naungan yang lambat tumbuh ke atas padang rumput utama *Imperata cylindrica* ditanam selang dengan *Paraserianthes falcataria* telah dikaji selama lima tahun di Kalimantan Selatan, Indonesia. Biji benih tersebut ditanam di bawah ladang berumur dua tahun di dalam reka bentuk blok yang lengkap secara rawak dengan lapan pereplikaan. Kesemua spesies mempunyai kemandirian yang tinggi sehingga tahun ketiga, bila kematian beberapa spesies *Shorea* serta *Durio zibethinus* bertambah dengan banyaknya akibat musim kering yang teruk. Spesies bukan-dipterokarpa, *Podocarpus polystachyus, Agathis borneensis* dan *Pericopsis mooniana,* menunjukkan prestasi di tapak percubaan dengan kadar kemandirian 82-95% dan ketinggian 3.2 - 3.5 m ketika berumur lima tahun. Dipterokarpa terbaik adalah *Vatica* sp., S. *leprosula* dan *Hopea sangal* dengan kadar kemandirian 49-83% dan ketinggian 2.9 - 3.4 m. Keputusan menunjukkan bahawa pemulihan padang rumput *Imperata* dengan cara menanam selang spesies toleran naungan dengan spesies yang cepat tumbuh adalah baik melalui pemilihan spesies yang betul. Sungguhpun jangka masa yang lama diperlukan, kaedah ini akan menyediakan alternatif kepada ladang-ladang monokultur baik dari segi pengeluaran kayu mahupun pemulihan ekosistem hutan semulajadi.

Introduction

The forest resources in tropical Asia are declining at an alarming rate. In Indonesia, there will be a severe lack of wood raw material by the year 2000, if the utilization efficiency and forest management do not significantly improve [Indonesian Tropical Forestry Action Programme (ITFAP) 1991]. Direct causes of forest loss and degradation include unsustainable large-scale commercial logging of valuable timbers particularly of Dipterocarpaceae family, and the subsequent encroachment of shifting cultivation and illegal logging to the logged-over forests.

Heavy logging destroys the structure of forest and, by removing seed trees, reduces the regeneration potential of trees (ITFAP 1991). Rehabilitation of these logged-over and secondary forests is considered possible through enrichment planting, assisted natural regeneration and maintenance of existing natural stands (ITTO 1990). However, secondary forests burned, cultivated and abandoned by shifting cultivators are most often converted to grasslands dominated by *Imperata cylindrica* (alang-alang). Annual fires promote the spread of *I. cylindrica* and prevent the grassland from being reforested by pioneer species (Eussen & Wirjahardja 1973).

Imperata cylindrica covers large areas of former forest land throughout moist tropical regions in Southeast Asia. In Indonesia alone, the estimated total area of *Imperata* grassland varies from 20 million ha (ITTO 1990) to 64.5 million ha (Suryatna & McIntosh 1980). Grasslands are difficult to reforest owing to harsh environmental conditions, grass competition and allelopathy, fire susceptibility of the grass, and soil degradation (Dela Cruz 1986, Ohta 1992).

The main interest in reforestation of *Imperata* grasslands has been in fast-growing and light-demanding exotic species, which are able to suppress the grass. *Gmelina arborea, Paraserianthes falcataria* and *Acacia* species, especially *Acacia mangium* have given promising results, and are widely used plantation species in Indonesia (Dela Cruz 1986, Awang & Taylor 1993). On the other hand, planting of dipterocarps and other primary forest tree species directly on *Imperata* grassland has failed almost completely. Due to their slow growth as well as shade and moisture requirements, these species are not able to compete with the grass.

Fast-growing plantations provide alternative sources for a wide variety of raw material extracted from natural forests. From an ecological point of view, they are capable of restoring a microclimate, as well as soil physical and chemical properties more suitable for a wide variety of forest flora and fauna, e.g. for the shade demanding primary forest species (Lugo *et al.* 1993). In cleared logged-over and secondary forest lands, fast-growing trees have been used as shade trees for slow-growing dipterocarps (Kustiawan & Unger 1991, Priasukmana 1991, Appanah & Weinland 1993, Mok undated).

Imperata cylindrica grasslands are regarded as unproductive wastelands and the need for their reforestation is widely acknowledged (Dela Cruz 1986). In the future, if large-scale reforestation on *Imperata* grasslands becomes essential to industrial wood production, there will be a need to diversify the species selection and to search for alternatives to monocultures. Since slow-growing species cannot be used as primary species on grasslands, one possibility is to introduce dipterocarps and other primary species under fast-growing plantations established on *Imperata* grassland. Enrichment planting with indigenous species would also be a step in converting these monocultures towards more diverse natural ecosystems.

However, our knowledge of interplanting dipterocarps on *Imperata* grassland is very limited. The available scarce information is obtained from cleared logged-over and secondary forests, where the site conditions, especially the physical soil properties, may be more favorable. In spite of the differences, the species and silvicultural practices may be applicable for grassland reforestation.

The aim of this study was to examine the performance of slow-growing valuable timber trees under a temporary shade cover provided by a fast-growing tree, *Paraserianthes falcataria*, and to assess the possibility of using the method for a gradual rehabilitation of plantations towards mixed rain forest ecosystem.

Materials and methods

Study area

The Riam Kiwa trial and demonstration area is located in South Kalimantan, Indonesia (3° 30'S, 115°E, 100-200 m a.s.l.), and lies on the undulating basin of the Riam Kiwa river. The mean annual precipitation measured throughout the study period was 2103 mm (Table 1). A pronounced dry season with 17% of the total annual precipitation occurred from May to September.

Table 1. Rainfall distribution during the study period in Riam Kiwa, South Kalimantan, Indonesia

Year	Total rainfall		Dry season rainfall		
	Amount (mm)	Rainy days (N)	Amount (mm)	Of total (%)	Rainy days (N)
1	2547	149	593	23	35
2	1898	122	353	19	27
3	1599	110	225	14	13
4	2348	152	438	19	43
5	2123	144	167	8	22
Mean	2103	135	355	17	28

The soils are deeply weathered, heavily textured acidic soils which have suffered various degrees of degradation. The soil in the trial site is fine-textured (50-60% of clay) and belongs to the red podzolic type (Simpson 1992). Soil analyses from the experimental site, at the time of planting *Paraserianthes falcataria*, indicate low pH values, comparatively low levels of nutrients and low cation exchange capacity (Table 2). On undisturbed land the height of *I. cylindrica* varies between 1.0 and 1.5 m and the above ground dry biomass between 10 and 20 t ha^{-1}. Compared to some other former *Imperata* grasslands the soil is well suited for tree plantation (Awang *et al.* 1994). The vegetation has been dominated by *Imperata* grass since the Second World War, possibly even longer. There are no records of the original tree species composition in the area.

Planting material

Species and their origins are listed in Table 3. All the species are valuable timber species used by both local and large-scale industries (Whitmore 1977, Martawijaya *et al.* 1992, Appanah & Weinland 1993). In addition, *Durio zibethinus* is an important fruit tree. For more detailed species description, see Symington (1974) and Whitmore (1977). Because of the difficulty of obtaining seeds for all the species, seedlings were raised from seeds or wildings (Table 3).

The seeds were sown in sand and transplanted to black polythene tubes (8 × 15 cm, volume 750 cm^3) with peat and rice husk (70:30%) as substrate. The seedlings were watered according to normal nursery practices and fertilized with NPK fertilizer (15:15:15) twice weekly for a total dose of 225 g m^{-2}. At the time of planting the seedlings were 5-7 months old.

Table 2. Soil characteristics on the experimental site in Riam Kiwa, South Kalimantan, Indonesia

Depth (cm)	pH 1	pH 2	pH 3	C-org (%)	N-tot (%)	P-avl	P-tot (ppm)	Mn	CEC	K	Na	Ca	Mg	Al (meq)	N+	Fe^{2+}	Fe^{3+}	S-avl	K-tot	Clay (%)	Silt (%)	Sand (%)
0-30	3.6	4.4	5.2	0.9	0.009	3.46	6.70	3.5	17.37	0.02	0.12	0.22	0.26	0.21	0.47	0.006	0.247	1.489	0.07	49.6	16.4	35.0
31-45	4.1	5.2	5.0	0.7	0.020	tr	13.40	23.5	13.62	0.03	0.55	0.27	0.35	0.05	0.22	0.004	0.048	2.029	0.11	58.5	13.8	27.7

tr	trace
avl	available
tot	total
CEC	cation exchange capacity
meq	meq/100 g of soil
pH 1	in H_2O
pH 2	in KCl
pH 3	in K_2SO_4

Table 3. Species, families, type and origin of planting material used in Riam Kiwa South Kalimantan, Indonesia

Species	Family	Planting material from	Origin
Agathis borneensis	Araucariaceae	Seed	ITCI Arboretum, Balikpapan, East Kalimantan
A. loranthifolia	Araucariaceae	Seed	Baturaden, Central Jawa
Hopea sangal	Dipterocarpaceae	Wilding	Kintap, South Kalimantan
Durio zibethinus	Bombacaceae	Seed	Kintap, South Kalimantan
Pericopsis mooniana	Leguminosae	Seed	Kolaka, South East Kalimantan
Podocarpus polystachyus	Podocarpaceae	Seed	Unknown (UGM, Yogyakarta)
Shorea hopeifolia	Dipterocarpaceae	Wilding	Kintap, South Kalimantan
S. johorensis	Dipterocarpaceae	Wilding	Kintap, South Kalimantan
S. leprosula	Dipterocarpaceae	Wilding	Kintap, South Kalimantan
S. macroptera	Dipterocarpaceae	Seed	East Kalimantan
S. parvifolia	Dipterocarpaceae	Wilding	Kintap, South Kalimantan
Vatica sp.	Dipterocarpaceae	Wilding	Kintap, South Kalimantan

Key: ITCI: International Timber Company of Indonesia
UGM: Universitas Gadjah Mada, Yogyakarta

The wildings, 25-40 cm in height and 0.2-0.5 cm in diameter at root collar, were collected from the secondary dipterocarp forest in Kintap trial area located 170 km southeast of Riam Kiwa (latitude 03°42'S, longitude 115° 09'E, altitude 100-200 m.a.s.l., mean annual rainfall 3000 mm). The wildings were pulled up and brought to the nursery in moist gunny sacks. They were potted in polythene tubes (8 × 15 cm, volume 750 cm^3) with a substrate of peat and rice husk (70:30%). They were kept inside the greenhouse for four weeks and thereafter transferred to the shaded area for three months.

Experimental design

Before planting the shade tree stand of the *Paraserianthes falcataria*, the soil was disc-plowed twice and rotavated once. The stand was planted at the spacing of 4 x 4 m in November 1986.

The trial was established on 24 October 1988 under a closed canopy of the *Paraserianthes falcataria* stand. Before planting the shade tolerant species, the area was sprayed with glyphosate (Roundup, 6 l ha^{-1}) in order to reduce competition of *Imperata cylindrica* and *Eupatorium palescens* vegetation. The trial was regularly maintained by removing the disturbing grasses and climbers. At the time of the last measurement, mean height of the *P. falcataria* stand was 17 m and basal area 12 m^2 ha^{-1}. The stand was partly uneven in terms of health and growth.

Randomized complete block design with eight replications was used. Each plot consisted of five trees planted in lines between *P. falcataria*. The spacing of 4 × 2 m (1250 seedlings ha^{-1}) was used for the shade tolerant species.

Measurement and analysis

Survival, height and diameter at breast height (DBH) were measured 1, 2, 3, 4 and 5 years after planting. For survival percentages an arcsin transformation was applied. A two-way Anova and Tukey's HSD-test (SYSTAT 1992) of means were carried out for DBH, height and survival. *Shorea johorensis* and *S. macroptera* were not included in the analysis of variance due to their poor survival, and subsequent low number of replications for height and DBH. Composite ranking based on the means of survival, height and DBH was calculated. Total annual rainfall and dry season rainfall were compared with the development of survival rates.

Results

Five years after the establishment of the trial there were significant differences in survival between species ($F = 16.11$; $p < 0.001$). *Podocarpus polystachyus* and *Agathis borneensis* had the highest survival rates and differed significantly from other species except *Pericopsis mooniana*, *Vatica* sp. and *Agathis loranthifolia* (Table 4). *Vatica* sp. was the best species in the Dipterocarpaceae family, followed by *Shorea leprosula* and *Hopea sangal*. Other *Shorea* species had survival rates less than 30%.

Table 4. Survival, height, diameter at breast height (DBH) and ranking of the 12 shade tolerant species 5 years after planting under *Paraserianthes falcataria* stand in Riam Kiwa, South Kalimantan, Indonesia.

Species	Survival* (%)	Height* (m)	DBH* (cm)	Ranking
Podocarpus polystachyus	95.0 (3.3) a	3.4 (0.1) a	3.2 (0.1) a	1
Agathis borneensis	87.5 (8.4) a	3.5 (0.2) a	2.8 (0.3) ab	2
Pericopsis mooniana	82.5 (5.9) ab	3.2 (0.3) a	2.5 (0.4) abc	3
Vatica sp.	82.5 (8.0) ab	2.9 (0.2) ab	1.8 (0.1) bcd	5
A. loranthifolia	77.5 (8.0) ab	2.5 (0.1) ab	2.0 (0.2) bcd	5
Shorea leprosula	52.5 (12.5) bc	3.4 (0.3) a	2.8 (0.4) abc	4
Hopea sangal	48.6 (8.6) bcd	3.0 (0.3) ab	2.0 (0.3) bcd	7
Durio zibethinus	30.0 (10.7) cd	2.4 (0.3) ab	1.3 (0.3) d	9
Shorea hopeifolia	27.5 (7.5) cd	1.9 (0.3) b	1.5 (0.3) cd	10
S. parvifolia	15.0 (6.3) cd	3.1 (0.4) ab	1.7 (0.3) bcd	8
S. macroptera	10.0 (5.3) cd	1.0 (0.2)	0.5 (-)	-
S. johorensis	5.0 (3.3) d	3.9 (0.6)	3.4 (0.7)	-
F-value	16.11	4.24	5.55	

Standard error of mean presented in parentheses. Means followed by the same letter are not significantly different ($p<0.05$).

One year after the establishment of the trial the survival of all species was greater than 60% (Figure 1). The mortality of most of the species increased during the third year, which had the lowest amount of total rainfall (Figure 1, Table 1).

Another decrease of survival rates was detected during the fifth year, which in spite of above average total rainfall, had very low dry season precipitation. Species with decreasing survival rates after successful initial development were *Shorea hopeifolia, S. johorensis, S. parvifolia* and *Durio zibethinus.* Only the best performing species as well as *S. leprosula* and *Hopea sangal* had low mortality rates (Figure 1).

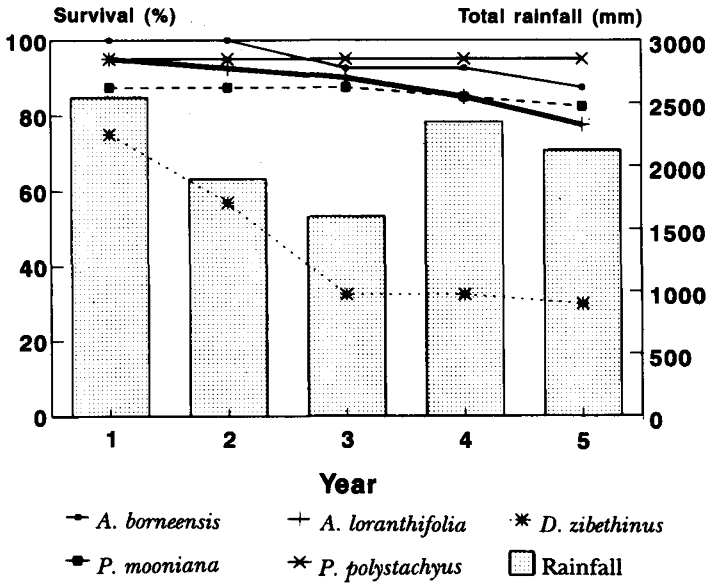

Figure 1a. Survival of 12 shade tolerant tree species in relation to total and dry season rainfall 1-5 years after planting in Riam Kiwa, South Kalimantan, Indonesia: Non-dipterocarps with total annual rainfall

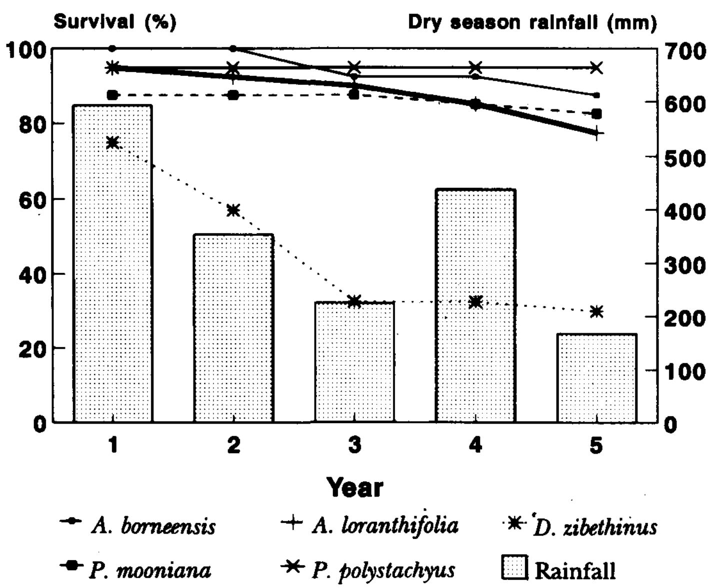

Figure 1b. Survival of 12 shade tolerant tree species in relation to total and dry season rainfall 1-5 years after planting in Riam Kiwa, South Kalimantan, Indonesia: Non-dipterocarps with dry season rainfall

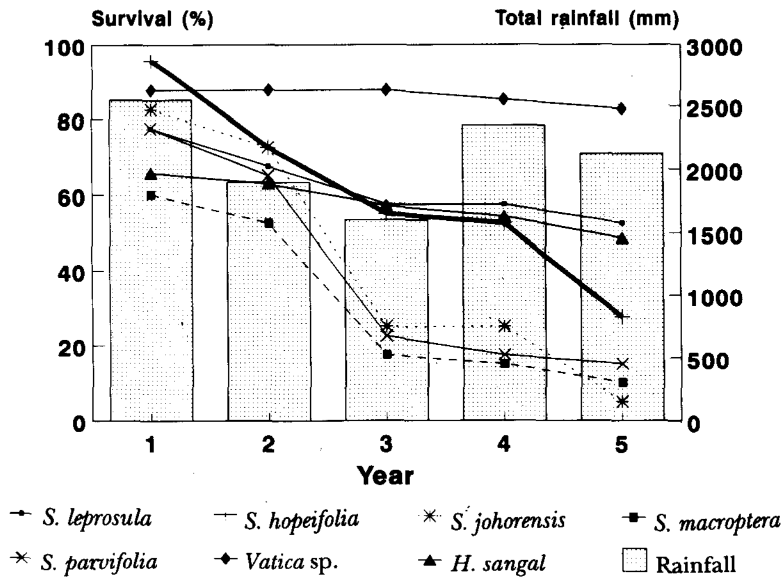

Figure 1c. Survival of 12 shade tolerant tree species in relation to total and dry season rainfall 1-5 years after planting in Riam Kiwa, South Kalimantan, Indonesia: Dipterocarps with total annual rainfall

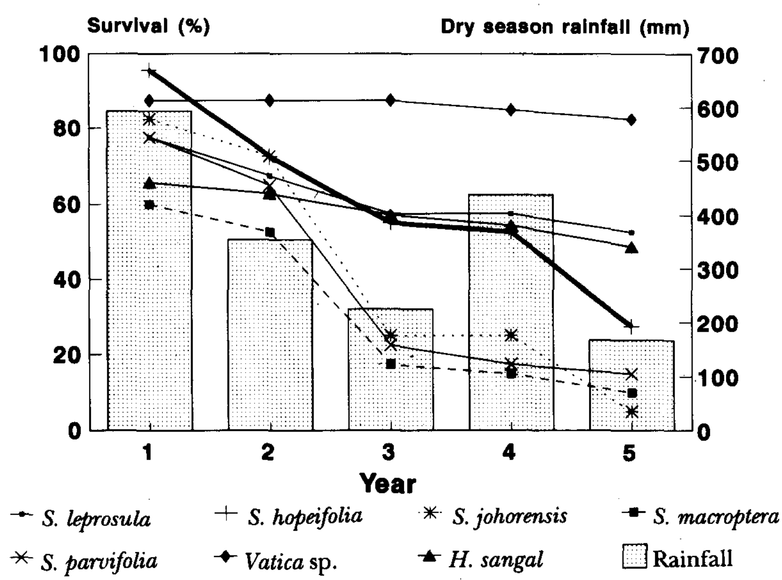

Figure 1d. Survival of 12 shade tolerant tree species in relation to total and dry season rainfall 1-5 years after planting in Riam Kiwa, South Kalimantan, Indonesia: Dipterocarps with dry season rainfall

Five years after the establishment of the trial there were significant differences in height (F= 4.24; p<0.001) and DBH (F= 5.55; p<0.001) (Table 4). The tallest trees were *Agathis borneensis, Podocarpus polystachyus, Shorea leprosula* and *Pericopsis mooniana,* although statistically only *S. hopeifolia* was inferior to these species. *Podocarpus polystachyus* had the highest DBH, which differed significantly from other species than *Agathis borneensis, Shorea leprosula* and *Podocarpus mooniana*. *Podocarpus polystachyus, A. borneensis* and *P. mooniana* had the highest composite ranking. The highest ranking dipterocarps were *S. leprosula* and *Vatica* sp. (Table 4). There were no statistically significant differences for any of the variables between the replications.

Discussion

The non-dipterocarps *Podocarpus polystachyus, Agathis borneensis* and *Pericopsis mooniana* performed best. They had high survival rates and considerable height and diameter growths. In the same area, when planted on open *Imperata cylindrica* grassland, *Podocarpus polystachyus* and *Pericopsis mooniana* had survival rates over 90% at the age of two years, whereas *Agathis borneensis* failed completely and *A. loranthifolia* had a survival of 33% (unpublished data).

Podocarpus polystachyus and *Agathis borneensis* are moderately shade-demanding species at seedling stage but require open conditions for successional growth (Martawijaya *et al.* 1992, Appanah & Weinland 1993). *Agathis borneensis* has a wide ecological amplitude and it can tolerate a more severe dry season than *A. loranthifolia*, which is more sensitive to site fertility and to high light intensities during the establishment phase (Bowen & Whitmore 1980). However, planting of *Agathis* species on a large-scale has been limited by shortage of planting material (Bowen & Whitmore 1980). *Podocarpus polystachyus* and *Pericopsis mooniana* have been planted only on a small-scale and very little information concerning their silvicultural practices exists.

The early survival of dipterocarp species was fairly good. At the age of two years, the survival rates of *Shorea johorensis, S. leprosula* and *S. parvifolia* were higher than obtained by line planting in a secondary pioneer forest in South Kalimantan (Ådjers *et al.* 1994). However, the mortality of other dipterocarp species than *Hopea sangal, Shorea leprosula* and *Vatica* sp. increased rapidly during the third year, which had the lowest amount of precipitation.

Despite the high survival rate, early growth of *Vatica* sp. was slow. This genus has not been widely planted, and is little known. It grows on higher elevation than *Shorea* species, which may indicate its tolerance to poorer and drier sites. Performance of *Hopea sangal* was not good even though it is reported to tolerate high light intensities and survive remarkably well on *Imperata* grassland (Symington 1974).

Stable survival rates and fairly good growth for *Shorea leprosula* correspond well with results from interplanted plantations in cleared forest lands (Kustiawan & Unger 1991, Priasukmana 1991, Appanah & Weinland 1993, Mok undated). *Shorea leprosula* is considered the most promising *Shorea* species for artificial regeneration due to its fast initial growth and ability to benefit from full open conditions. In addition, it is reported to have high tolerance to moisture stress during periods of low precipitation and high temperature (Symington 1974, Appanah & Weinland 1993). *Shorea parvifolia* had suprisingly poor performance compared to results gained elsewhere (Appanah & Weinland 1993, Ådjers *et al.* 1994, Mok undated). *Shorea parvifolia* resembles *S. leprosula*, being more shade tolerant, and having slower early growth (Symington 1974). *Shorea johorensis*, which is reported to have fast early growth (Kustiawan & Unger 1991, Ådjers *et al.* 1994) and which had some of the biggest individual trees in this experiment, performed well at the early stages but perished almost totally during the fifth year with a severe dry season.

Variation in planting material has to be considered when the results are being interpreted. Since especially dipterocarps flower and fruit irregularly and seeds cannot be stored, the difficulty in obtaining even-aged planting material will remain a problem also in future experiments. Wildings can be used as in this study, but then the effects of the early development on the performance after planting cannot be controlled, which may add random variation to results.

Dipterocarps collected as wildings originated from a secondary pioneer forest with higher annual precipitation than the trial site. However, response to drought varied remarkably even within the closely related species, like *S. leprosula* and *S. parvifolia*. This indicates ecological differences of the species. It is evident that dry season precipitation had a more important role than total precipitation in determining the success of primary forest species.

The effect of drought was probably intensified by insufficient shading provided by the *Paraserianthes falcataria* stand, within which the health and growth varied remarkably. This may be due to soil properties and the defoliation of *P. falcataria* trees by *Eurema* sp. (Pieridae, Lepidoptera). Even though shade intensity evidently varied within the experimental area, no growth variation between replications was detected. This may indicate that even a well growing *P. falcataria* stand cannot provide enough shade for the most sensitive dipterocarps.

Generally, *Paraserianthes falcataria* has proven to be a suitable nurse tree due to its sparse foliage with a flat-topped crown high above the ground (Kustiawan & Unger 1991, Appanah & Weinland 1993). *P. falcataria* usually partly supresses the *Imperata cylindrica* grass but favours the growth of shrub species *Eupatorium palescens* and *Clibadium* sp. as well as climbers (Kuusipalo *et al.* 1995). Their occurrence under nitrogen fixing *P. falcataria* may reflect the enhanced soil properties through litterfall of the trees. Due to these favourable characteristics and the promising results gained with the best species in this trial, *P. falcataria* can be recommended as a shade tree. Other nurse tree species and establishment methods should be carefully studied as well.

Although dipterocarps are commonly regarded as shade species during their early development, remarkable differences occur between the species. *Shorea leprosula* is known to be a strong light demander after the seedling stage, and many other species are reported to require light at least after the sapling stage (Nicholson 1960, Symington 1974, Appanah & Weinland 1993). The conifers *Agathis borneensis* and *Podocarpus polystachyus* can tolerate shade in the seedling stage, but are light demanders in later stages (Whitmore 1977, Martawijaya *et al.* 1992).

The modest performance of *Shorea* species may be due to the poor site-species compatiblity and the lack of mycorrhizae which are known to be crucial for dipterocarps (Julich 1988). Wildings are normally infected by the mycorrhizal roots of the mother trees, but many mycorrhizae are sensitive to high temperatures on planting site. Evidently, the mycorrhizae may play a very important role in the performance of the dipterocarps planted on *Imperata* grassland. The good performance of *Agathis borneensis* may be due to an ubiquitous fungi, which makes the artificial inoculation unnecessary (Whitmore 1977).

Successful diversification of fast-growing plantations is a slow process and its economic impacts are not known. At young age mixed plantations need more intensive tending than monocultures of fast-growing exotics. Insufficient tending is the most common reason for failures in dipterocarp plantations (Weidelt 1976, Kustiawan & Unger 1991). Moreover, the whole management chain has to be considered before establishment of plantations in order to be able to harvest the fast-growing trees without damage to remaining stock.

Conclusion

Restoring *Imperata* grassland by using fast-growing tree species as nurse trees for slow-growing trees is possible. Even though our results were obtained on a rather fertile site, they indicate good prospects for diversifying the species composition in plantations, which are commonly regarded as monocultures. In the future, this kind of rehabilitation with high quality timber trees creates alternatives for the utilization of remaining virgin forests and the already depleted secondary forests. Despite the long time period needed, the method can be used both in terms of wood production and restoration of natural forest ecosystem.

Since *Imperata* grasslands are often relatively old, the species composition of the original forest may not be known. Hence, when rehabilitating these areas by interplanting primary forest species with fast-growing trees, species selection should be focused on species occurring in similar areas and known to be fast-growing and adaptable to degraded soils, high light intensity and high temperatures. According to our results several dipterocarp and non-dipterocarp species have potential for these conditions.

Intensive research is still needed on site-specific species selection, species-specific light intensity requirements and the role of soil characteristics and mycorrhizae. Selection of potential shade tree species and establishment methods are another area requiring major studies.

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