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Afforestation of *Imperata* Grasslands in Indonesia

Results of Industrial Tree Plantation Research Trials at Teluk Sirih on Pulau Laut, Kalimantan Selatan

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Australian Centre for International Agricultural Research
Canberra 1995

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Summary

Objectives

THE objectives of the trials reported here were to test a range of *Eucalyptus* and *Acacia* tree species and establishment techniques for pulpwood plantations on *Imperata* grassland (alang alang) in South Kalimantan (Kalimantan Selatan), Indonesia. The trials were established in February 1992 in southern Pulau Laut, Kalimantan Selatan. The results of tree measurements taken 10 and 30 months later are reported here.

Species

At 10 months, eucalypts generally produced more wood volume than acacias, but eucalypts generally had greater insect and fungal damage. The results of this damage to the eucalypts were reduced survival rates and production volume compared with acacias. Of the acacias, *Acacia mangium* from Wipim, Papua New Guinea (PNG) had the best growth (57 m^3/ha at 30 months). At 30 months, total volume production of *A. mangium* of Wipim provenance was 70–80% (tested across two trials) greater than that of *A. mangium* of Subanjeriji provenance. This underlines the importance of selecting high performing provenances within the preferred species. Apart from *Acacia crassicarpa*, other acacias tested did not grow well and produced multiple stems even after stem pruning (singling).

An *Eucalyptus grandis* × *Eucalyptus urophylla* hybrid grew exceptionally well and produced an average of 37–46 m^3/ha of wood at 30 months. *E. urophylla* from Wetar, Indonesia produced 18–29 m^3/ha by 10 months. Fungal infections and insect damage on eucalypt foliage increased mortality and reduced total volume production at 30 months.

Cultivation

Cultivation with the large discs of a Savannah 3-in-1 plough resulted in an increase in total volume production of 1.2 m^3/ha at 10 months. The more rapid growth to 10 months due to discing also resulted in trees that were squatter and had more stems than trees growing on non-disced soil. The effect on *A. mangium* of discing and mounding with the Savannah plough was short-lived and was not evident in total volume production at 30 months. Other components of the plough (blade plough and ripping tyne) had no impact on the early growth of *A. mangium*.

Control of *Imperata*

Chemical weed control of *Imperata* grass is important for the successful establishment of *A. mangium* plantations, and can almost double total volume production at 30 months (from 26 m^3/ha without weed control to 51 m^3/ha with weed control; Wipim provenance). Effective weed control is essential for the establishment of eucalyptus plantations in *Imperata* grasslands. Without it, the plantation cannot be considered commercially viable. Effective weed control resulted in an eleven-fold increase in total volume production of *E. urophylla* from Wetar (from 1.8 m^3/ha without weed control to 21.3 m^3/ha with weed control at 30 months). Weed control also had an effect in reducing fungal damage to foliage of *E. urophylla* at 10 months.

Fertilizer

The soils in southern Pulau Laut under *Imperata* grass are moderately leached, degraded through continuous burning of grassland, and deficient in N, P and K. In industrial plantations of *A. mangium* there was a clear limit to the response of the trees at 10 months to surface applied fertilizer. For nitrogen, phosphorus and potassium treatment, this limit was 120 kg N/ha, 52 kg P/ha and 100 kg K/ha, with trees producing 4.6 m^3/ha compared with 1.5 m^3/ha without fertilizer. By 30 months, the best response was to a higher rate of NPK (180, 78, and 150 kg/ha). With this treatment, *A. mangium* produced a total volume of 61 m^3/ha, compared with 41 m^3/ha for trees which did not receive fertilizer. There was no response to additional applications of trace element fertilizer on this soil.

The slow-release fertilizer, Osmocote®, applied in the planting hole, gave growth responses in *A. mangium* similar to fertilizer applied at rates of up to 20 times higher. This was evident at 10 months and was maintained up to 30 months.

General Trends in *A. mangium*

Faster-growing provenances of *A. mangium* produced squatter trees with larger numbers of stems at 10 months. Therefore, selection of provenances of *A. mangium* for stem form and the production of single stems must be done taking into account early growth rate. If the growth of *A. mangium* is increased by silvicultural treatments, it is important to prune stems early in the growth of the tree (probably the first month after planting). Note, however, that this may create sites for the introduction of wood rot fungi into the stem.

The most important and long-lasting treatments for maximum growth rate of *A. mangium* in this environment were the selection of Wipim provenance, chemical weed control and NPK fertilizer, each of which contributed between 29 and 38% of total volume production.

Conclusions

Industrial pulpwood plantations of *A. mangium* can be established successfully on the *Imperata* grasslands of Kalimantan Selatan using techniques of provenance selection, effective weed control, cultivation, and application of NPK fertilizer. Both acacias and eucalypts performed well in the trials. *A. mangium* is the most promising acacia species, with Wipim (PNG) the best performing provenance. Amongst the eucalypts an *E. grandis* × *E. urophylla* hybrid performed exceptionally well; the Wetar (Indonesia) provenances of *E. urophylla* also performed well and warrants further study. It is very clear that effective control of *Imperata* grass with a chemical herbicide is essential for the success of eucalypt plantations. In addition, fungal diseases and insect feeding on foliage in eucalypt plantations are threats to the success of these species in this environment, and require further investigation.

CHAPTER 1

Introduction

THIS report details the results of forest plantation trials which were established near Teluk Sirih (3°48'S, 116°06'E) on Pulau Laut, Kalimantan Selatan, Indonesia in February 1992. The trials were established as part of the feasibility study for an industrial tree plantation project under a proposed joint venture between Shell Companies in Indonesia, P.T. Inhutani II, and P.T. Astra International. The trials have subsequently been managed and maintained by staff of Inhutani II from Semaras, Kalimantan Selatan. Overall views of the trials at ages 4 months and 30 months are shown in Figures 1 and 2.

Trials and Objectives

The objectives of the trials were to test silvicultural treatments and a range of *Acacia* and *Eucalyptus* tree species and provenances for their suitability for growing in plantations for pulpwood on the coastal lowlands of Kalimantan Selatan. The species were selected for their performance in plantations in similar tropical areas and included: *Eucalyptus grandis*, *Eucalyptus urophylla* and the hybrid of these species; *Eucalyptus tereticornis* and its hybrid with *E. grandis*; *Eucalyptus pellita;* and *Eucalyptus camaldulensis*. These eucalypt species represent some of the most widely planted hardwood species in the tropics (Eldridge et al. 1994). *Acacia* species selected focused on *Acacia mangium* provenances, but also included *Acacia crassicarpa* and *Acacia auriculiformis* which had performed well in trials at nearby Riam Kiwa (Vuokko 1991, Vuokko et al. 1992), and *Acacia aulacocarpa*, *Acacia cincinnata*, *Acacia polystachya* and *Acacia leptocarpa*. These represent the range of *Acacia* species which have shown some promise in the Southeast Asian region (Turnbull 1986, 1991).

Two cultivation trials, a herbicide trial and a fertilizer trial were established with *A. mangium* in order to examine techniques of establishment and silviculture and extend further the body of knowledge for this species which, although widely planted in Southeast Asia, is in its relative infancy as a plantation species (Awang and Taylor 1993). *E. urophylla* and *E. camaldulensis* were also included in trials which controlled the growth of *Imperata* grass, since failure of plantations of eucalypts in lowland grassy sites has been attributed primarily to grass competition. The individual objectives, designs and results from these trials follow.

Because of differences in time to germination and growth rate, seedlings varied in height between 60 and 120 mm at time of planting out. The acacia seedlings were generally 100–120 mm tall.

Environment

Landscape and soils

The area chosen for the trials was gently rolling *Imperata cylindrica* (alang alang) grassland. Tall forest formerly covered the area; residual pockets of this forest had been progressively removed over the previous 10 years. *Imperata* was maintained as the dominant vegetation by intermittent burning by the local landholders to provide fresh shoots for buffalo grazing.

The landscape of southern Pulau Laut is formed on soft sedimentary parent rocks (mudstones and clay marls) with small outcrops of weakly metamorphosed sedimentary rocks. This geology gives rise to a gently undulating 'pillow' landscape with slopes of generally less than 5° increasing to 10° in shallow incised drainage lines.

The trials were established predominantly in well-drained clay-loam soils. The soil profile is generally 1 m deep or less and grades from clay loam at the surface, through light and medium clays in the B1 and B2 horizons to clay loam at depth. Soil colours range from 10YR 4/2 at the surface through 7.5YR 5/8 in the B1 horizon, to 5YR 5/8 in the B2 horizon. The soil below the A1 horizon is moderately well structured clay loam and is moderately leached, providing a paler A2 horizon in some places, and underlying small quantities of ironstone gravels. The underlying soft rock is permeable and penetrated by tree roots. The soil has a very shallow A1 horizon due to burning of the *Imperata* grassland. Some surface crusting may occur and permeability is greatly improved after cultivation. The range of soil profiles present may be classified as Tropudults or Paleudults (Soil Survey Staff 1975).

The indicative soil chemical parameters in Table 1 show a soil profile low in organic matter and nitrogen, low in available P, and with low concentrations of exchangeable K and Ca.

Rainfall

The site receives on average more than 2500 mm/year rainfall. The climate is monsoonal and seasonal, and there is a dry season from June–October (Table 2). Site preparation for the trials was carried out in November 1991 at the end of a very marked dry season, and seedlings were planted in February–March 1992 in the latter part of the wet season. The dry season that followed was wetter than average (Table 2).

Table 1. Indicative soil chemical parameters for soils of Teluk Sirih, Pulau Laut.

Depth	Total C (%)	Total N (%)	Available P (ppm)	K (meq%)	Ca (meq%)	pH
Surface	3.18	0.21	7.0	0.25	2.09	5.4
10	2.20	0.16	6.2	0.10	1.58	5.3
20	1.44	0.12	4.6	0.06	1.03	5,3
30	1.03	0.08	4.6	0.20	1.04	5.4
40	0.80	0.07	4.6	0.08	0.46	5.3
50	0.67	0.06	4.6	0.02	0.46	5.3
60	0.57	0.05	4.7	0.05	0.18	5.3
70	0.51	0.05	5.5	0.06	0.03	5.2
80	0.41	0.04	4.7	0.09	0.05	5.2
90	0.35	0.04	4.7	0.12	0.11	5.2
100	0.35	0.04	4.7	0.14	0.21	5.1
110	0.31	0.03	4.7	0.14	0.05	5.2
120	0.32	0.04	4.7	0.20	0.05	5.1

Source: Turvey and Ruhiyat (1990)

Table 2. Monthly and annual rainfall (mm) for Semaras for 1986–1992.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1986	240	116	95	108	263	204	63	34	52	329	376	190	2068
1987	225	425	225	610	610	75	10	5	0	127	593	410	3315
1988	404	215	211	234	619	473	479	734	330	162	143	319	4320
1989	302	288	146	158	194	213	251	243	13	147	230	157	2343
1990	184	434	243	122	68	51	66	41	93	32	70	180	1582
1991	331	300	299	313	211	7	4	0	0	0	242	345	2049
1992	324	126	110	299	86	208	246	29	91	179	285	155	2138
Average	287	272	190	263	293	176	160	155	83	139	277	251	2545

Source: Inhutani II, Semaras.

Figure 1. Aerial view of the trials at Teluk Sirih, Pulau Laut in June 1992. The trees are aged 4 months, and the weed control was applied 7 months before the photograph was taken. Looking east, the cultivation trial is in the centre of the photograph, the herbicide trial to the right in the middle distance, the fertilizer trial in the far distance, the Savannah trial below and to the right, and the species trial hidden to the left.

Figure 2. Looking west across the main crossroads in the trial; *A. mangium* on the left-hand side of the road is 30 months old.

CHAPTER 2

Experimental Program

Measurement Techniques

TREES in the trials were measured at 10 and 30 months after planting. The stems were pruned of lateral stems (singling) around the first measurement period; this was done later than normal, and resulted in significant biomass being removed from some *A. mangium*.

Measured variables

Height: Measured with a measuring pole.

Diameter: 10 months—measured in two directions with callipers at 10 cm height, and the mean derived, 30 months—measured with a diameter tape at breast height (1.3 m). Diameters were not measured for *Acacias* with bushy habit.

Height:Diameter: The ratio of height to diameter at 10 cm height at 10 months. A higher score indicates a more slender stem shape; a lower score a more squat stem shape.

Basal area: Cross sectional area of the stem at 10 cm height (10 months) or breast height (30 months), then summed for all trees in the plot and corrected for plot area (basal area m^2/ha).

Mean tree volume: Individual stem conical volume based on mean stem height and either mean stem diameter at 10 cm at 10 months, or breast height of 1.3 m at 30 months (mean tree volume cm^3= basal area × 0.33 × height).

Table 3 gives the program for the trials.

Table 3. Program for silvicultural trials in South Kalimantan.

Activity	Comment	Timing
Imperata burnt	Normal local burning activity	October 1991
Trials laid out		October/November 1991
Savannah plough cultivation	Very dry soil profile due to prolonged dry season	November 1991
Seeds germinated		Late November 1991
Seedlings pricked–out		Mid–December 1991
Imperata germinated in ploughed ground	Beginning of wet season	December 1991
Imperata 50 cm tall sprayed with Roundup™ herbicide at 5 L/ha	Spraying carried out in first 4 hours of daylight allowing drying before afternoon rains	January/February 1992
Seedlings planted in trials	During wet season but some dry days	February 1992
Fertilizer applied	General application 360 g/tree NPK 15:15:15 (60 kgN, 26 kgP, 50kgK/ha)	March–April 1992
Fire protection measures established	50 m wide fire breaks	June 1992
Singling (stem pruning) of *A. mangium*	Later than recommended practice	December 1992
First measurement	10 months	December 1992
Second measurement	30 months	June 1994

Total volume: Based on mean tree volume for the plot multiplied by the number of stems in the plot and corrected for plot area (total volume m^3/ha).

Stems: The number of dominant stems at breast height at 10 months (before singling), or the number of dominant stems above breast height (after singling) at 30 months.

Fungus: Score 1: no fungus on foliage; Score 2: fungus visible on foliage; Score 3: significant fungal infections on foliage, particularly in the top of the crown.

Insects: Score 1: no insect feeding on foliage; Score 2: insect feeding visible on foliage; Score 3: significant insect feeding on foliage, particularly in the top of the crown.

Survival: The number of stems alive at the time of measurement relative to the number planted (%).

Statistical Analyses

The two cultivation trials and the herbicide trial were established as full factorial designs; i.e., each treatment appeared alone and in combination with each other treatment in the trial. This allows analysis of treatment main effects. The main effect is the mean for the treatment over all the plots where it occurs (even if it occurs with other treatments) and is compared with the mean for all plots which did not contain the treatment. An interaction may occur in which the effect of two or more treatment main effects vary with one another; in this case the interaction between the treatments can be examined statistically.

The species trial and the fertilizer trial were established as randomised plot experiments with each plot containing a single treatment. In this case the mean (across blocks) for the single treatment is compared with other treatments and the control or nil treatment.

CHAPTER 3

Species Trial

Objective

TO test the performance of a range of eucalypts and acacias for pulpwood plantations in South Kalimantan under optimal conditions of cultivation, weed control and NPK fertilization.

Design

The trial was designed as a first-level screening trial where groups of species could be evaluated statistically against other groups. Restrictions in the availability of seed, germinants and eventual seedlings constrained the design of the trial. In the resulting trial design it is possible to rank, but not test statistically, the performance of individual species against each other.

The trial was laid out in three blocks with an east–west axis to each block. The blocks progressed downslope to the south; block 1 was on the ridge, block 2 was just below the ridge, and block 3 was lower down the slope from the ridge top. The slope was gentle, and the difference in elevation between blocks 1 and 3 was approximately 10 m.

Individual tree species were grouped into species groups as shown in Table 4. Species are listed in Table 5. Each block contained 10 plots which each had 60 trees of a species group in them. Each plot contained four subplots of 15 trees; each subplot contained a species belonging to the species group of the main plot. The arrangement of the species within the subplots was the same for all blocks, but the main plots were randomised separately within each block. Trees were planted at a square 3 m spacing. Subplots were 135 m^2, and main plots were 540 m^2.

Base Treatments

The area of the species trial was cultivated and the soil mounded with the Savannah 3-in-1 plough, the *Imperata* grass was killed with Roundup™, and NPK fertilizer was applied after planting.

Results

Blocks

There was a significant difference in tree growth between the blocks as they went downslope; this was most marked at 30 months when total wood volume on the plots was 29.0, 27.9, and 23.8 m^3/ha for blocks 1, 2 and 3, respectively, with trees on the ridge growing better than those downslope. This trend was evident across all species groups, and there was no significant interaction between blocks and species groups.

Species groups

All species groups were significantly different from one another for all the parameters measured at 10 months. However, in species groups 3, 4 and 5 including, *A. auriculiformis, A. aulacocarpa, A. leptocarpa, A. cincinnata and A. polystachya,* multiple branching at or below breast height at 30 months made it impossible to measure diameter on the same basis as the other species in the trial. For this reason, diameter, basal area and individual and total volume estimates are not shown for these species and their groups for 30 months in Tables 4 and 5.

At 10 months, with the exception of the *E. grandis* group 9, the eucalypts produced greater wood volumes (3.6–7.0 m^3/ha) than the acacias (1.7–3.3 m^3/ha). However, the eucalypts generally had greater insect and fungal damage. The eucalypts were predominantly single-stemmed, whereas acacias were generally multi-stemmed (Table 4). At 30 months, reduced survival amongst the eucalypts resulted in lower total volume production when compared with the acacias, amongst which *A. mangium* provenances produced an average of 45 m^3/ha.

Table 4. (a) Growth parameters at 10 months for species groups in the species trial.

Species group	Species number	Species	Mean height		Mean diameter		Mean tree volume		Basal area		Total volume		Number of stems		Survival		Fungal damage		Insect damage		Heigh:diameter	
			(m)	Rank	(cm)	Rank	(cm^3)	Rank	(m^2/ha)	Rank	(m^3/ha)	Rank		Rank	(%)	Rank		Rank		Rank	(m:m)	Rank
1	1, 2, 3, 4	*A. mangium* provenances	3.23	d	5.79	h	3138	f	2.96	h	3.33	f	2.07	h	95	h	1.10	b	1.35	f	57.3	a
2	5, 6, 7	*A. crassicarpa* provenances	3.00	b	4.29	a	1836	a	1.54	a	1.74	a	1.73	f	85	a	1.29	e	1.04	b	74.7	g
3	9, 10	*A. auriculiformis* provenances	3.27	f	5.26	d	2464	d	2.35	d	2.71	d	2.43	j	94	e	1.12	c	1.24	e	62.9	c
4	11	*A. aulacocarpa* provenances	3.25	e	5.53	g	2814	e	2.54	e	2.98	e	2.23	i	90	b	1.05	a	1.10	a	60.9	b
5	13, 15, 16	*A. leptocarpa*, *A. cincinnata*, *A. polystachya*	2.97	a	4.60	b	1933	b	1.88	b	2.05	b	2.02	g	93	d	1.15	d	1.20	c	66.7	d
6	17, 19, 20, 23	*E. urophylla*, *E. pellita*	3.97	h	5.82	i	3893	i	3.01	i	4.17	i	1.27	e	96	i	1.51	i	1.55	i	68.9	f
7	27, 28, 29	*E. camaldulensis* provenances	4.12	i	5.39	f	3416	g	2.63	g	3.77	h	1.06	a	99	j	1.41	h	1.45	g	77.4	j
8	30,31	*E. tereticornis* provenances	3.96	g	5.39	e	3418	h	2.55	f	3.59	g	1.06	b	95	f	1.34	f	1.47	h	75.2	h
9	33, 34, 35, 36	*E. grandis*, *E. grandis* × *E. tereticornis*	3.18	c	4.78	c	2340	c	2.03	c	2.40	c	1.18	d	93	c	1.93	j	1.22	d	67.6	e
10	37, 26	*E. grandis* × *E. urophylla*	5.13	j	6.73	j	6583	j	3.91	j	6.98	j	1.10	c	96	g	1.38	g	1.63	j	76.6	i

Common letters denote species group means not significantly different from one another at $P < 0.05$.

Table 4. (b) Growth parameters at 30 months for species groups in the species trial.

Species group	Species number	Species	Mean height (m)	Rank	Mean diameter (cm)	Rank	Mean tree volume (cm^3)	Rank	Basal area (m^2/ha)	Rank	Total volume (m^3/ha)	Rank	Number of stems	Rank	Survival (%)	Rank
1	1, 2, 3, 4	*A. mangium* provenances	11.19	h	11.58	e	42085	d	11.58	e	44.77	d	1.54	g	96	g
2	5, 6, 7	*A. crassicarpa* provenances	10.59	g	10.09	d	31796	c	10.09	cd	29.47	c	1.36	f	84	b
3	9, 10	*A. auriculiformis* provenances	11.26	i									2.12	i	98	j
4	11	*A. aulacocarpa* provenances	9.72	d									1.9	h	96	h
5	13, 15, 16	*A. leptocarpa*, *A. cincinnata*, *A. polystachya*	9.61	c									2.2	j	94	e
6	17, 19, 20, 23	*E. urophylla*, *E. pellita*	10.33	f	8.84	c	22769	b	8.84	bc	23.59	bc	1.19	c	92	d
7	27, 28, 29	*E. camaldulensis* provenances	10.29	e	7.65	b	17381	b	7.65	b	19.03	b	1.21	d	98	i
8	30,31	*E. tereticornis* provenances	9.52	b	7.75	b	18284	b	7.75	b	18.28	b	1.19	b	92	c
9	33, 34, 35, 36	*E. grandis*, *E. grandis* × *E. tereticornis*	7.11	a	6.22	a	8840	a	6.22	a	8.4	a	1.27	e	69	a
10	37, 26	*E. grandis* × *E. urophylla*	12.06	j	10.24	d	36962	cd	10.24	d	38.86	d	1.06	a	95	f

Common letters denote species group means not significantly different from one another at $P < 0.05$.

Table 5. (a) Growth parameters at 10 months for species in the species trial.

Species No.	Species	Provenance	Survival		Mean height		Mean diameter		Mean tree volume		Basal area		Total volume		Number of stems		Height:diameter		Fungal damage		Insect damage	
			(%)	**Rank**	(m)	Rank	(cm)	Rank	(cm^3)	Rank	(m^2/ha)	Rank	**(m^3/ha)**	Rank		**Rank**	(m:m)	Rank		Rank		Rank
1	*A. mangium*	Claudie River, Qld.[a]	100	1	3.22	19	5.75	9	3116	12	3.07	5	3.46	12	1.98	8	57.8	26	1.02	28	1.36	14
2	*A. mangium*	Wipim, PNG[b]	93	7	3.44	15	6.30	3	3829	7	3.35	4	3.94	8	2.07	7	56.1	28	1.14	21	1.33	17
3	*A. mangium*	Sabah Softwood SO	96	5	2.91	25	5.01	20	2178	22	2.25	20	2.34	22	1.78	10	60.0	23	1.16	20	1.40	10
4	*A. mangium*	Subanjeriji, Indonesia	98	3	3.13	21	5.60	11	2738	17	2.77	9	2.98	15	2.43	3	56.6	27	1.05	25	1.32	18
5	*A. crassicarpa*	Bimadebun, PNG	87	11	2.95	24	3.83	26	1590	26	1.32	25	1.55	26	1.81	9	80.8	2	1.27	17	1.03	25
6	*A. crassicarpa*	Dimisisi, PNG	87	11	3.26	17	4.78	23	2149	23	1.83	22	2.07	23	1.54	13	70.8	12	1.29	16	1.02	26
7	*A. crassicarpa*	Wemenever & Moorehead, PNG	87	11	2.87	26	4.17	25	1803	25	1.50	24	1.68	25	1.78	10	73.6	10	1.30	15	1.06	23
9	*A. auriculiformis*	Bensbach, PNG	99	2	3.07	23	5.26	18	2335	20	2.46	16	2.56	21	2.71	1	59.5	24	1.12	22	1.25	19
10	*A. auriculiformis*	Wenlock River, Qld	99	2	3.46	14	5.26	16	2592	18	2.44	17	2.85	17	2.14	6	66.2	18	1.12	22	1.23	20
11	*A. aulacocarpa*	Bimadebun & Arufi PNG	97	4	3.25	18	5.26	17	2814	15	2.71	11	2.98	18	2.23	4	60.9	22	1.05	25	1.01	27
13	*A. leptocarpa*	Port Douglas, Qld	92	8	3.39	16	4.95	21	2335	21	2.07	21	2.42	20	1.60	12	66.8	16	1.12	22	1.37	13
15	*A. cincinnata*	Mossman, Qld	100	1	3.09	22	5.42	13	2497	19	2.64	13	2.77	19	2.16	5	58.0	25	1.33	13	1.00	28
16	*A. polystachya*	Bridle La, Qld	93	7	2.22	28	3.03	28	564	28	0.77	27	0.58	28	2.71	1	75.4	8	1.05	25	1.07	22
17	*E. urophylla*	Mt. Egon, Flores, Indonesia	91	9	3.67	11	5.90	5	3963	6	2.96	7	4.00	6	1.29	15	62.0	20	1.66	3	1.41	9
19	*E. urophylla*	Wetar, Indonesia	98	3	4.65	3	6.20	4	5212	3	3.46	3	5.67	3	1.16	19	76.3	5	1.43	9	1.61	4
20	*E. urophylla*	Alor, Indonesia	98	3	3.74	10	5.73	10	3671	4	2.98	6	4.01	4	1.52	14	66.8	16	1.48	6	1.90	1
23	*E. pellita*	Bupul-Mutung, Indonesia	98	3	3.64	12	5.24	19	2799	16	2.43	18	3.05	14	1.10	23	70.5	14	1.48	6	1.59	5
26	*E. grandis* × *E. urophylla*	SAPPI, South Africa	100	1	5.12	2	6.47	2	6098	2	3.80	2	6.78	2	1.07	25	79.6	4	1.18	19	1.78	2
27	*E. camaldulensis*	Petford, Qld	100	1	4.25	4	5.31	15	3423	10	2.56	15	3.80	9	1.02	27	80.9	1	1.50	5	1.38	12
28	*E. camaldulensis*	Gilbert River, Qld	98	3	4.14	5	5.59	12	3659	8	2.77	9	3.97	7	1.11	21	75.4	8	1.43	9	1.63	3
29	*E. camaldulensis*	Fergusson River, N.T.[c]	100	1	3.84	8	5.38	14	3158	11	2.63	14	3.51	11	1.07	25	72.4	11	1.22	18	1.42	8
30	*E. tereticornis*	Cooktown, Qld	91	9	4.05	6	5.86	6	3980	5	2.86	8	4.03	5	1.10	23	70.6	13	1.32	14	1.53	7
31	*E. tereticornis*	Laura River, Qld	99	2	3.87	7	4.92	22	2857	14	2.32	19	3.15	13	1.01	28	79.8	3	1.36	12	1.40	10
33	*E. grandis*	S.W. Cairns, Qld	98	3	3.21	20	4.26	24	1887	24	1.70	23	2.05	24	1.23	16	75.8	6	1.98	2	1.09	21
34	*E. grandis* × *E. tereticornis*	Congo 1	90	10	3.49	13	5.76	8	3293	13	2.66	12	3.25	15	1.17	18	61.3	21	1.42	11	1.36	14
35	*E. grandis* × *E. tereticornis*	Congo 2	91	9	3.79	9	5.78	7	3440	9	2.72	10	3.49	10	1.12	20	66.0	19	1.60	4	1.36	14
36	*E. grandis* × *E. tereticornis*	Congo 3	93	7	2.32	27	3.52	27	1059	27	1.15	26	1.09	27	1.19	17	67.3	15	2.76	1	1.05	24
37	*E. grandis* × *E. urophylla*	SAPPI, South Africa (2 seedlots)	94	6	5.13	1	6.81	1	6744	1	3.94	1	7.04	1	1.11	21	75.6	7	1.45	8	1.58	6

[a]Queensland, Australia. [b]Papua New Guinea. [c]Northern Territory, Australia.

Table 5. (b) Growth parameters at 30 months for species in the species trial.

Species No.	Species	Provenance	Survival		Mean height		Mean diameter		Mean tree volume		Basal area		Total volume		Number of stems	
			(%)	Rank	(m)	Rank	(cm)	Rank	(cm^3)	Rank	(m^2/ha)	Rank	(m^3/ha)	Rank		Rank
1	*A. mangium*	Claudie River, Qld	100	1	11.34	5	11.91	2	44259	2	116.1	2	49.18	2	1.42	9
2	*A. mangium*	Wipim, PNG	93	7	11.96	3	13.04	1	54843	1	137.0	1	56.78	1	1.56	7
3	*A. mangium*	Sabah Softwood SO	96	4	10.39	15	9.81	8	28184	10	79.7	9	30.13	7	1.47	8
4	*A. mangium*	Subanjeriji, Indonesia	98	3	10.30	16	10.08	6	28294	8	82.0	7	30.97	6	1.70	6
5	*A. crassicarpa*	Bimadebun, PNG	84	11	10.59	11	10.12	5	31739	6	85.9	5	30.10	8	1.32	12
6	*A. crassicarpa*	Dimisisi, PNG	84	11	10.73	10	10.85	4	34262	5	94.2	4	32.27	5	1.42	9
7	*A. crassicarpa*	Wemenever & Moorehead, PNG	83	12	10.53	12	9.70	9	30592	7	81.1	8	27.75	10	1.34	11
9	*A. auriculiformis*	Bensbach, PNG	98	3	10.73	9									2.31	2
10	*A. auriculiformis*	Wenlock River, Qld	99	2	11.80	4									1.92	4
11	*A. aulacocarpa*	Bimadebun & Arufi PNG	96	4	9.72	20									1.90	5
13	*A. leptocarpa*	Port Douglas, Qld	91	8	10.46	13									2.00	3
15	*A. cincinnata*	Mossman, Qld	100	1	10.91	7									1.90	5
16	*A. polystachya*	Bridle La. Qld	93	7	6.60	27									2.93	1
17	*E. urophylla*	Mt. Egon, Flores, Indonesia	82	13	9.62	21	8.58	12	19057	14	55.1	14	17.86	15	1.24	14
19	*E. urophylla*	Wetar, Indonesia	93	7	11.33	6	9.48	10	28280	9	71.2	10	29.31	9	1.07	18
20	*E. urophylla*	Alor, Indonesia	95	5	10.01	19	8.36	14	20439	13	57.0	13	21.67	12	1.35	10
23	*E. pellita*	Bupul-Mutung, Indonesia	98	3	10.45	14	9.09	11	23977	11	67.0	11	26.16	11	1.02	21
26	*E. grandis* × *E. urophylla*	SAPPI, South Africa	100	1	12.09	1	10.91	3	40954	3	97.7	3	45.50	3	1.04	20
27	*E. camaldulensis*	Petford, Qld	99	2	10.77	8	7.78	15	18602	15	49.5	15	20.44	14	1.06	19
28	*E. camaldulensis*	Gilbert River, Qld	96	4	10.27	17	7.48	18	16348	16	45.1	18	17.48	17	1.25	13
29	*E. camaldulensis*	Fergusson River, N.T.	100	1	9.36	22	7.58	17	15973	17	48.1	16	17.75	16	1.47	8
30	*E. tereticornis*	Cooktown, Qld	89	10	10.05	18	8.46	13	21847	12	60.2	12	21.07	13	1.14	16
31	*E. tereticornis*	Laura River, Qld	94	6	8.98	24	7.04	19	14721	19	42.1	19	15.49	19	1.11	17
33	*E. grandis*	S.W. Cairns, Qld	78	14	7.99	25	6.50	21	9467	21	30.5	21	8.39	21	1.34	11
34	*E. grandis* × *E. tereticornis*	Congo 1	90	9	7.58	26	6.57	20	10160	20	36.3	20	9.96	20	1.22	15
35	*E. grandis* × *E. tereticornis*	Congo 2	89	10	9.15	23	7.61	16	15618	18	47.5	17	15.59	18	1.35	10
36	*E. grandis* × *E. tereticornis*	Congo 3	27	15	3.89	28	4.33	22	556	22	4.6	22	0.19	22	1.14	16
37	*E. grandis* × *E. urophylla*	SAPPI, South Africa (2 seedlots)	93	7	12.06	2	10.02	7	35631	4	84.2	6	36.65	4	1.07	18

Species and provenances

Amongst the acacias, *A. mangium* provenances produced the greatest wood volume, with the Wipim (PNG) provenance the top producer (3.9 and 57 m^3/ha ages 10 and 30 months), followed by Claudie River, (Qld) (3.5 and 49 m^3/ha ages 10 and 30 months). These better performing provenances tended to have the lowest height:diameter ratios indicating a squatter stem form. Wipim provenance also had better form and less branching than Subanjeriji provenance, as shown in Figures 3 and 4.

In this trial, all provenances of *A. crassicarpa* performed less well than those of *A. mangium*, despite promising growth of this species at Riam Kiwa in South Kalimantan (Vuokko et al. 1992). However, there appears to be adequate scope for selection of families from within provenances of *A. crassicarpa* such as Dimisisi, PNG (Fig. 5). *A. auriculiformis* and *A. aulacocarpa* were smaller than *A. mangium* and *A. crassicarpa*, and in this trial these species produced greater numbers of multiple stems than *A. mangium* and *A. crassicarpa*, with the exception of *A. mangium* from Subanjeriji. *A. polystachya* (Fig. 6), *A. leptocarpa* and *A. cincinnata* performed poorly.

Amongst the eucalypts, the hybrid of *E. grandis* × *E. urophylla* (Figs 7 and 8) produced the greatest wood volumes (6.8–7.0 and 37–46 m^3/ha at ages 10 and 30 months). This hybrid showed significant but moderate levels of insect damage at 10 months (Table 5). The Indonesian provenances of *E. urophylla* showed good growth (4.0–5.7 and 18–29 m^3/ha at ages 10 and 30 months) and should be investigated further in more detailed provenance trials. There was little difference in growth between the *E. camaldulensis* provenances (3.5–3.8 and 17–20 m^3/ha at ages 10 and 30 months). *E. grandis* performed poorly and suffered fungal damage. Heavy fungal infection was also associated with very poor growth and low survival amongst *E. tereticornis* and the *E. grandis* × *E. tereticornis* hybrid.

Conclusions

Up to 30 months, the two most promising species for these sites in South Kalimantan were *A. mangium* from Wipim, PNG, and the hybrid *E. grandis* × *E. urophylla*.

Amongst *A. mangium* provenances, Wipim (PNG) and Claudie River (Qld) provenances stood out as markedly superior to Subanjeriji (Indonesia) and Sabah seed orchard provenances. *A. crassicarpa* from Dimisisi (PNG) showed promise for further selection, but other acacias tested showed multiple branching and generally poorer growth.

E. urophylla and *E. pellita* provenances from Indonesia performed moderately well, and show potential for further improvement through selection. The primary concern in eucalypts is fungal infections and insect damage, which markedly suppressed the growth of *E. grandis*, *E. tereticornis* and the *E. grandis* × *E. tereticornis* hybrid.

When comparisons are made between the growth of species in this trial and growth in other locations, the importance in this trial of effective control of *Imperata* with Roundup™, soil cultivation and NPK fertilizer must be taken into account.

Figure 3. *A. mangium* from Wipim (PNG) showing fair form at 30 months.

Figure 4. *A. mangium* from Subanjeriji (Indonesia) showing multiple branching at 30 months.

Figure 5. *A. crassicarpa* from Dimisisi (PNG) showing fair form and growth at 30 months.

Figure 6. *A. polystachya* from Bridle LA, Queensland showing multiple branching at 30 months.

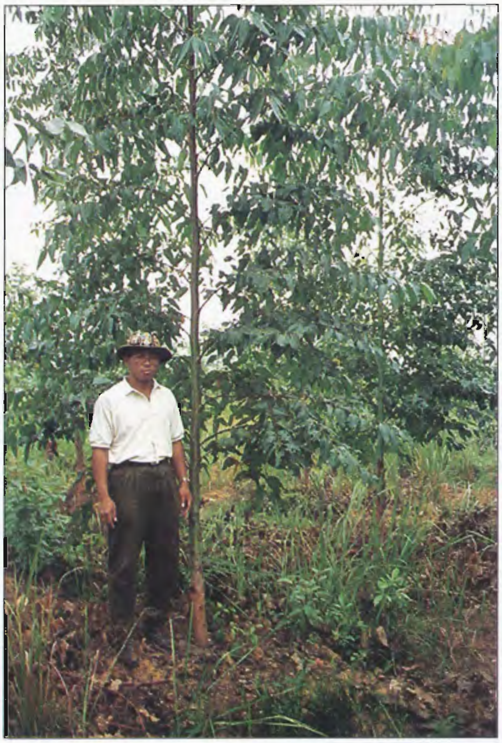

Figure 7. *E. grandis* × *E. urophylla* from SAPPI (South Africa) at 10 months.

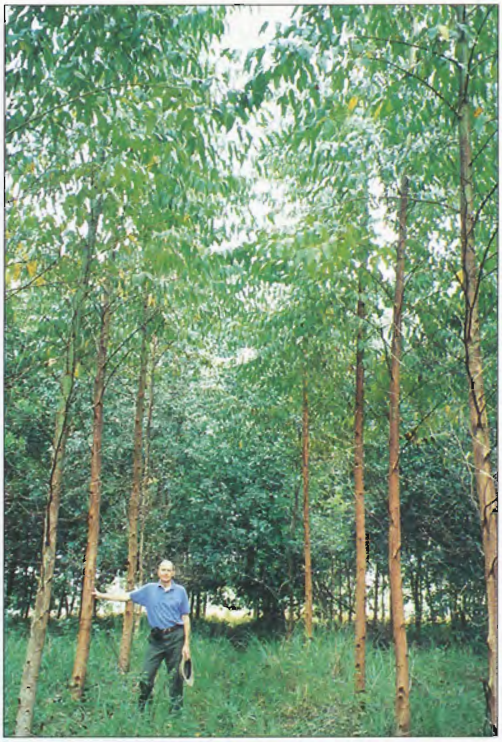

Figure 8. *E. grandis* × *E. urophylla* from SAPPI (South Africa) at 30 months.

CHAPTER 4

Cultivation Trial

Objective

TO demonstrate and evaluate the effects of weed control and different cultivation techniques on the growth of *A. mangium.*

Design

The trial was designed to compare the effects of cultivation with a Savannah 3-in-1 plough, the current technique of three passes with disc harrows, and manual cultivation at the planting site with a mattock (cankul). The Savannah 3-in-1 plough consists of a combination of cultivation implements: a blade plough followed by a deep winged ripping tyne, followed by hydraulically damped multiple offset discs (Fig. 9). This plough provides cultivation up to 1 m deep with surface cultivation and mounding 2 to 2.5 m wide (Fig. 10). The trial was also designed to measure the effects of chemical weed control. Cultivation with multiple passes with a disc harrow is also considered by some plantation managers to be a form of mechanical control of *Imperata* grass.

The trial was a factorial design with chemical weed control at two levels (Roundup™ and nil), and cultivation at three levels (Savannah 3-in-1, multiple harrowing, and manual). The trial was laid out in four blocks on a generally flat site with a slight slope to the east to an elevation of about 3 m. Each block contained six plots of approximately 100 trees. The measured plot within the main plot consisted of 36 trees, leaving two buffer rows around the measured plot. The trial was planted with *A. mangium* from Wipim (PNG) planted at a square spacing of 3 × 3 m.

Base Treatments

NPK fertilizer was applied after planting.

Results

The main effect evident in the trial at both ages 10 and 30 months was the effect of chemical weed control. Roundup™ treatment significantly improved tree growth, particularly total volume which increased more than 3-fold at 10 months (from 1.1 to 3.7 m^3/ha) and 2-fold at 30 months (from 26.1 to 51.2 m^3/ha). Roundup™ treatment also increased the number of stems produced by *A. mangium*, made tree form more squat, and reduced the incidence of fungal damage (Table 6).

Table 6. Growth response of *A. mangium* to weed control in the cultivation trial at 10 and 30 months.

Weed control	Mean height (m)	Mean diameter (cm)	Mean tree volume (cm^3)	Basal area (m^2/ha)	Total volume (m^3/ha)	Number of stems	Height:diameter (m:m)	Fungal damage	Survival (%)
					10 months				
Nil	3.01	3.26	1036	1	1.1	1.03	99.52	1.77	95.6
Roundup™	3.56	5.75	3339	2.99	3.66	1.79	64.28	1.34	98.6
P[a]	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.044
					30 months				
Nil	9.43	9.35	24536	7.87	26.08	1.04	100.95	1.03	95.4
Roundup™	11.52	12.32	47160	13.21	51.24	1.16	93.49	1.06	97.7
P[a]	0.0001	0.0001	0.0001	0.0001	0.0001	0.0008	0.0001	NS	NS

[a] P indicates the level of statistical significance of the difference between the treatments

There was no significant difference between the cultivation treatments in growth at either 10 or 30 months. Neither was there any significant interaction between cultivation and weed control treatments on the growth of *A. mangium* (Table 7). Growth in the control plots and plots treated with the Savannah plough and weed control is shown in Figures 11–14.

Table 7. Total volume of *A. mangium* in response to cultivation and weed control treatments in the cultivation trial.

Weed control	Cultivation	Total volume (m^3/ha)	
		10 months	30 months
Nil	Pit	1.06	23.25
Nil	Disc harrow	0.91	27.71
Nil	Savannah plough	1.35	27.30
Roundup™	Pit	3.71	51.66
Roundup™	Disc harrow	3.76	54.00
Roundup™	Savannah plough	3.51	48.06

Note: there are no statistically significant interactions between weed control and cultivation. Main effect due to weed control is statistically significant (see Table 6).

Conclusions

The benefit to *A. mangium* of control of ***Imperata*** grass with Roundup™ was clear at 10 months and was maintained to 30 months. This resulted in a doubling of wood production to 51 m^3/ha at 30 months. Cultivation treatments had no additional effects on tree growth.

Figure 9. The Savannah 3-in-1 plough. Looking towards the rear of the plough can be seen in sequence the wide winged tip of the blade plough, the tip of the winged deep ripping tyne, the offset discs, and the following tritter wheel.

Figure 10. Contour ploughed mounds produced with the Savannah 3-in-1 plough.

Figure 11. *A. mangium* in a control plot in the cultivation trial at 10 months. These trees received fertilizer at planting only.

Figure 12. *A. mangium* in a control plot in the cultivation trial at 30 months. These trees received fertilizer at planting only.

Figure 13. *A. mangium* in a treatment plot of Savannah plough and weed control in the cultivation trial at 10 months. These trees received fertilizer at planting.

Figure 14. *A. mangium* in a treatment plot of Savannah plough and weed control in the cultivation trial at 30 months. These trees received fertilizer at planting.

CHAPTER 5

Savannah Plough Trial

Objective

THE objective of this trial was to demonstrate and evaluate the effects of the component parts of the Savannah 3-in-1 plough on tree growth. The component parts of the Savannah 3-in-1 plough include a blade plough cultivating to 40–50 cm depth, a winged ripper cultivating to 90–100 cm depth, and four large discs cultivating the surface 30 cm of soil over a width of 2–2.5 m.

Design

The trial was laid out in three blocks in a NE–SW direction on an almost flat piece of land. Each block contained 16 plots. The treatments were applied as a full factorial design with each of the three plough components (blade plough, ripping tyne and mounding discs) being tested alone and in combination with the other two components. Each block was planted with two species, but the shortage of seedlings allowed only one species (*A. mangium* from Wipim, PNG) to be represented across each of the three blocks. *A. mangium* from Lake Murray (PNG) was also planted in one block; this allowed for a comparison between the Wipim and Lake Murray provenances of *A. mangium*. The other species planted are not analysed here.

Base Treatments

Imperata grass was killed with Roundup™, and NPK fertilizer was applied after planting.

Results

Block effects

The cultivation effects in this trial were analysed across only two of the three blocks due to a significant block by treatment interaction which caused the elimination of one block from the statistical analysis.

Cultivation effects

The only statistically significant main effect at 10 months was due to discing, which significantly increased tree size and total volume (from 2.7 to 3.9 m^3/ha). However, by 30 months the only significant difference between the disc and no-disc treatments was an increase in height due to discing, and fewer stems above breast height (Table 8). Discing also changed tree form at 10 months, making the faster-growing *A. mangium* trees squatter than the trees growing on soil that had not been disc ploughed (Table 8).

Table 8. Growth response of *A. mangium* at 10 and 30 months to cultivation with Savannah discs in the Savannah trial.

Treatment	Height (m)	Diameter (cm)	Mean tree volume (cm^3)	Basal area (m^2/ha)	Total volume (m^3/ha)	Stems	Height:diameter
			10 months				
Without Savannah discs	3.38	5.30	2717	2.30	2.7	1.99	65.60
With Savannah discs	3.51	5.98	3693	3.19	3.93	2.08	60.79
P[a]	NS	0.031	0.029	0.006	0.011	NS	0.01
			30 months				
Without Savannah discs	11.39	12.48	48059	12.34	47.24	1.15	
With Savannah discs	11.82	12.80	50645	13.36	52.75	1.06	
P	0.038	NS	NS	NS	NS	0.039	

[a] P indicates the level of statistical significance of the difference between the treatments.

A. mangium provenances

At 10 months there was no significant difference in growth between Wipim and Lake Murray provenances. However, by 30 months, the Wipim provenance of *A. mangium* had produced significantly more wood volume (57 m^3/ha) than the Lake Murray provenance (50 m^3/ha) (Table 9).

Conclusions

Discs were the only component of the Savannah 3-in-1 plough which improved the growth of *A. mangium* on this soil type in South Kalimantan. There was no apparent benefit to *A. mangium* from deep ripping in this clay-loam soil type with a soft parent rock and deep C horizon. Discing had a marked effect on early tree growth, and the more rapid growth due to discing also resulted in trees which were relatively more squat and had more stems than those which were growing on soil that had not been disced.

Table 9. Growth response at 10 and 30 months of *A. mangium* provenances from Wipim (PNG) and Lake Murray (PNG) in the Savannah trial.

Provenance	Height (m)	Diameter (cm)	Mean tree volume (cm^3)	Basal area (m^2/ha)	Total volume (m^3/ha)
			10 months		
Wipim	3.80	6.12	4006	3.31	4.30
Lake Murray	3.69	6.08	4645	3.76	4.89
P[a]	NS	NS	NS	NS	NS
			30 months		
Wipim	12.00	12.91	52983	14.25	57.00
Lake Murray	11.84	12.21	47737	12.44	49.68
P	NS	0.043	0.049	0.005	0.012

[a] P indicates the level of statistical significance of the difference between the treatments.

CHAPTER 6

Herbicide Trial

Objective

TO demonstrate and measure the effects of chemical control of *Imperata* grass and other weeds on the growth of selected acacias and eucalypts.

Design

The trial was a factorial design with chemical weed control at two levels (Roundup™ and nil), and species at four levels (*A. mangium* from Wipim, PNG, *A. mangium* from Subanjeriji, Indonesia, *E. urophylla* from Wetar, Indonesia, and *E. camaldulensis* from Fergusson River, N.T.). The species were selected to test provenance variation in *A. mangium* to weed control, and to test two contrasting forms of eucalypts.

The trial was laid out in four blocks on a relatively flat site. Each block comprised eight plots each containing 49 trees. The internal measured plot contained 25 trees. Trees were planted in a square 3 × 3 m spacing.

Base Treatments

The area of the herbicide trial was cultivated with the Savannah 3-in-1 plough, and NPK fertilizer was applied after planting.

Results

Weed control

The main effect of chemical weed control with Roundup™ across all species was to significantly improve tree growth, with a marked increase in wood volume production across all four tree species (Table 10). The difference in tree growth due to control of *Imperata* grass was very marked at 10 months, and the effect was maintained at 30 months. Weed control also reduced the incidence of fungal and insect damage at 10 months.

Species × weed control interaction

In general, growth of eucalypts was more affected by grass competition than was the growth of *A. mangium*. Weed control increased wood volume production at 10 months in eucalypts by 7 to 11 times, whereas the increase in *A. mangium* was 2 to 3 times (Table 10). At 30 months the difference in wood production for the eucalypts had increased to approximately 12-fold, while that in *A. mangium* had fallen to 1.3 to 1.5-fold (Table 10).

By 30 months there was clearly much better growth of *A. mangium* from Wipim (64 m^3/ha) than of *A. mangium* from Subanjeriji (37 m^3/ha). With weed control, *A. mangium* from Wipim produced 72% more wood than from Subanjeriji. The number of stems produced by both provenances of *A. mangium* was increased significantly by weed control.

In the absence of weed control, both species of eucalypts grew very poorly and there was no significant difference between them. With weed control *E. urophylla* grew significantly better than *E. camaldulensis* in height, diameter, and total volume to 10 months. A similar difference in productivity at 30 months was not statistically significant.

Without weed control *E. urophylla* from Wetar produced only 1 m^3/ha at 30 months, and had carried quite high levels of fungal damage at 10 months (Figs 15 and 16). By comparison, with weed control *E. urophylla* from Wetar produced 21 m^3/ha at 30 months (Table 10) (Figs 17 and 18).

Table 10. (a) The main effect at 10 months of weed control and interactions between species and weed control on the growth of *A. mangium*.

	Weed control	Height (m)		Diameter (cm)		Mean tree volume (cm^3)		Basal area (m^2/ha)		Total volume (m^3/ha)		Height: diameter (m:m)		Number of stems		Fungal damage		Insect damage	
Weed control main effect	Nil	2.94		3.27		1059		0.98		1.08		97.8		1.07		1.68		4.17	
	Roundup™	4.14		5.82		4144		3.02		4.13		72.5		1.48		1.34		4.05	
	P[a]	0.0001		0.0001		0.0001		0.0001		0.0001		0.0001		0.0001		0.0001		0.0022	
Species × weed control interaction			Rank		Rank		Rank		Rank		Rank		Rank		Rank		Rank		Rank
A. mangium, Wipim	Nil	3.22	ab	3.87	b	1457	a	1.29	ab	1.5	a	87.6	a	1.01	a	1.49	a	4	a
A. mangium, Subanjeriji	Nil	3.34	abc	3.94	b	1547	a	1.46	b	1.7	ab	90.5	a	1.24	a	1.49	a	4.02	a
E. urophylla, Wetar	Nil	2.63	a	2.76	a	737	a	0.58	a	0.6	a	104.5	a	1.01	a	2.22	b	4.23	b
E. camaldulensis, N. T.	Nil	2.57	a	2.52	a	498	a	0.59	a	0.5	a	108.7	a	1.02	a	1.51	a	4.42	c
A. mangium, Wipim	Roundup™	3.83	bc	6.16	cd	4184	c	3.48	d	4.6	d	64.9	a	1.81	b	1.33	a	4.01	a
A. mangium, Subanjeriji	Roundup™	3.61	bc	5.25	c	2822	b	2.48	c	3.1	bc	70.7	a	1.95	b	1.29	a	4.02	a
E. urophylla, Wetar	Roundup™	5	d	6.51	d	6269	d	3.53	d	6.4	e	77.7	a	1.10	a	1.41	a	4.12	ab
E. camaldulensis, N. T.	Roundup™	4.11	c	5.37	c	3300	bc	2.61	c	3.7	c	76.4	a	1.06	a	1.31	a	4.03	a

[a] P indicates the level of statistical significance of the difference between the treatments.

Rank: common letters indicate means which are not significantly different from one another at 5% significance level.

Table 10. (b) The main effect at 30 months of weed control and interactions between species and weed control on the growth of *A. mangium*.

	Weed control	Height (m)		Diameter (cm)		Mean tree volume (m^3)		Basal area (m^2/ha)		Total volume (m^3/ha)	
Weed control main effect	Nil	7.96		6.93		17837		5.22		18.51	
	Roundup™	10.18		9.84		31301		8.88		33.80	
	P[a]	0.0001		0.0001		0.0001		0.0001		0.0001	
Species × weed control interaction			Rank		Rank		Rank		Rank		Rank
A. mangium, Wipim	Nil	11.14	de	11.20	e	41208	e	10.39	c	41.48	e
A. mangium, Subanjeriji	Nil	10.30	cd	9.78	cd	27057	cd	8.58	c	29.73	cd
E. urophylla, Wetar	Nil	5.39	a	3.68	a	2077	a	1.07	a	1.79	a
E. camaldulensis, N.T.	Nil	5.01	a	3.08	a	1008	a	0.83	a	1.05	a
A. mangium, Wipim	Roundup™	12.19	e	12.70	f	58276	f	14.40	d	64.09	f
A. mangium, Subanjeriji	Roundup™	10.46	cd	10.70	de	34126	de	10.05	c	37.25	de
E. urophylla, Wetar	Roundup™	9.70	c	8.70	c	21391	c	6.30	b	21.28	bc
E. camaldulensis, N.T.	Roundup™	8.35	b	7.25	b	11410	b	4.77	b	12.59	b

[a] P indicates the level of statistical significance of the difference between the treatments.

Rank: common letters indicate means which are not significantly different from one another at 5% significance level.

Figure 15. *E. urophylla* in a control plot in the herbicide trial at 10 months. These trees received only fertilizer at planting.

Figure 16. *E. urophylla* in a control plot in the herbicide trial at 30 months. These trees received only fertilizer at planting.

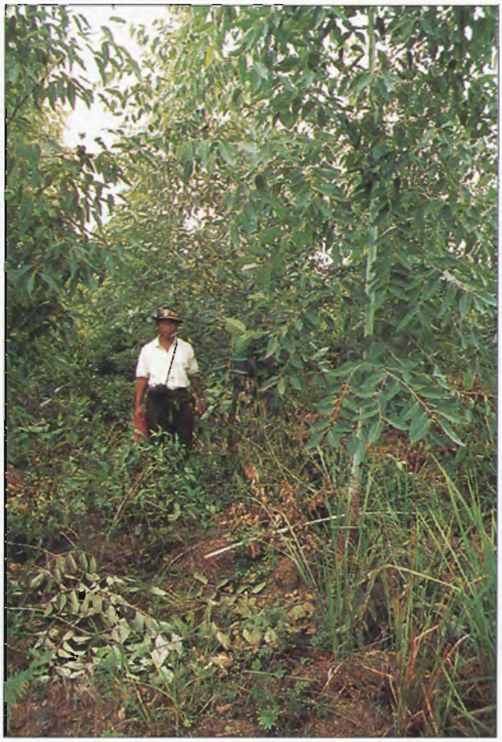

Figure 17. *E. urophylla* in a herbicide plot in the herbicide trial at 10 months. These trees received fertilizer at planting.

Figure 18. *E. urophylla* in a herbicide plot in the herbicide trial 30 months. These trees received fertilizer at planting.

Conclusions

Weed control is important to the success of *A. mangium* plantation establishment and can treble early volume production up to 64 m^3/ha at 30 months Provenance differences were maintained across weed control treatments, indicating that growth differences due to provenances did not primarily arise from a capacity to cope with weed competition.

Effective weed control is essential for the establishment of eucalypt plantations in *Imperata* grass areas where, without effective weed control, the plantation cannot be considered commercially viable. Effective weed control in eucalypt plantations can result in an eleven-fold increase in early volume production and reduced fungal damage to foliage. The Wetar provenance of *E. urophylla* grew well, producing 21 m^3/ha at 30 months on this monsoonal and coastal site, indicating potential for further selection and improvement in this provenance.

CHAPTER 7

Fertilizer Trial

Objective

To examine the requirements of *A. mangium*, growing on moderately leached and degraded clay loam soils, for NPK and trace elements, and to compare the response to fertilizer applied to the surface after planting with the response to slow-release fertilizer applied in the soil at planting.

Design

The trial used a 9 × 4 randomised block design of eight fertilizer treatments and a control (nil) treatment. Phosphorus was tested at three rates, and NPK at three rates with the P rate the same as in the P alone treatments (Table 11). By comparing the effect of P alone with the effect of NPK treatments, the additional effect of NK fertilizer can be estimated. The effect of N alone or K alone cannot be estimated from this trial. Trace elements were also applied in combination with a parallel high NPK treatment. Growth response to the slow-release fertilizer Osmocote™ was also tested. Table 12 gives the elemental contents used in the trial.

The F1 treatment is the fertilizer rate which was applied over all trees in the other trials.

Table 12. Elemental contents of fertilizers used in the fertilizer trial.

Product	Elemental content (%)		
	N	P	K
TSP	0	20	0
15:15:15	15	6.6	12.5
Osmocote™	10	26	10

The trial was laid out in four blocks with each block containing one each of the nine treatments, randomly located. The plots contained 49 trees with an internal measurement plot of 25 trees. The trial was planted with *A. mangium* from Wipim (PNG) in a square 3 × 3 m spacing.

Base Treatments

The area of the fertilizer trial was cultivated with the Savannah 3-in-1 plough, and the *Imperata* grass was killed with Roundup™.

Table 11. Treatments in the fertilizer trial.

Treatment	Treatment level[a]	Product	Product (kg/ha)	N (kg/ha)	P (kg/ha)	K (kg/ha)
Control	1	None	Nil	Nil	Nil	Nil
P1	2	TSP[b]	130	0	26	0
P2	3	TSP	261	0	52	0
P3	4	TSP	391	0	78	0
Osmocote™	–	Osmocote™	31	3.1	8	3
F1	2	15:15:15	400	60	26	50
F2	3	15:15:15	800	120	52	100
F3	4	15:15:15	1200	180	78	150
F3 + Trace elements	–	15:15:15 + Librel[c]	1200 + 5	180	78	150

[a] Refers to levels 1–4 in Figure 19
[b] TSP = triple superphosphate 46% P_2O_5
[c] Librel = proprietary trace element fertilizer mix

Results

At 10 months there were two main response groups; the nil fertilizer and P fertilizers, and the Osmocote™ and NPK fertilizers. There was some overlap between these groups. Within these groups at 10 months there was no statistically significant difference between means from different rates of fertilizer. At 30 months, there was an indication of a response to the higher levels of NPK fertilizer which was not evident at 10 months (Fig. 19).

At 10 months, maximum tree growth in the P treatments occurred at 52 kg P/ha, and in the NPK treatments at 52 kg P/ha, 120 kg N/ha, and 100 kg K/ha (Table 13, Fig. 19). Further application of P and NPK did not improve growth at this age. There was no additional growth response to the application of trace elements; this indicates that lack of trace elements is not limiting growth of *A. mangium* in this soil.

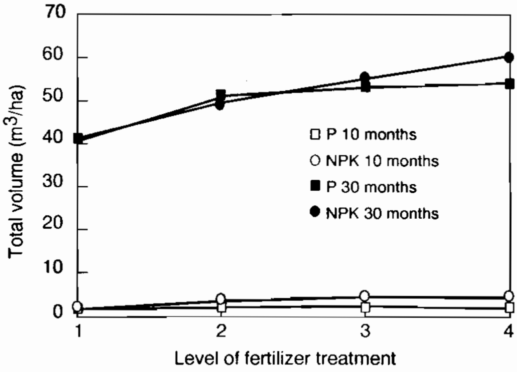

Figure 19. Total wood volume production of *A. mangium* across fertilizer treatments and time. Details of fertilizer treatment levels are given in Table 11.

At 30 months the effect of P was very evident, as was the additional effect on tree growth of N and K applied with P fertilizer. At 30 months the maximum application of NPK produced the greatest total volume of wood, but this was significantly different only from total volume production in the nil fertilizer treatment and low applications of P and NPK. The additional effect of N and K over that of P fertilizer is shown in Table 14. NK increased total volume of *A. mangium* by about 2 m^3/ha at 10 months, but the highest rate of NPK increased growth by 6 m^3/ha over P alone at 30 months.

Figures 20 and 21 show growth at 10 months in an untreated control plot and a plot receiving high NPK fertilizer treatment.

The soils appear to be deficient in phosphorus; this is consistent with the presence of leaching in the soil profile (a pale A2 horizon and some ironstone gravel concretions in the B horizon). Intermittent burning of the *Imperata* grassland has left the soil with a very thin A1 horizon, and it is likely that the response to N and K is due to low organic matter in the surface soil.

The slow-release fertilizer, Osmocote™, was applied at rates of 3.1, 8, and 3 kg /ha NPK respectively. This was applied in the planting zone at the time of planting. The response in tree growth at 10 months was similar to that of the surface applied 60, 26, and 50 kg /ha NPK treatment (F1).

Table 14. Difference in total volume production between fertilizer treatments with the same rates of P, to demonstrate the additional effect of N with K fertilizer at 10 and 30 months. Treatment details are given in Table 11.

Treatments	Difference at 10 months (m^3/ha)	Difference at 30 months (m^3/ha)
F1-P1	1.02	–0.75
F2-P2	2.06	1.69
F3-P3	2.35	6.20

The number of stems at breast height was related directly to the total volume production in each treatment and is shown in Figure 22. There was also a strongly negative correlation between total volume production and stem form, expressed as height:diameter, at 10 months, as shown in Figure 23. These two relationships between total volume production and the form of the tree indicate that the increased branching and squat stem form in *A. mangium* are due primarily to early rapid growth rates.

Table 13. Growth response of *A. mangium* at 10 and 30 months to P and NPK fertilizers in the fertilizer trial.

	Mean height		Mean diameter		Basal area		Mean tree volume		Total volume		Stems		Height:Diameter	
Treatment	(m)	Rank[a]	(cm)	Rank	(m^2/ha)	Rank	(cm^3)	Rank	(m^3/ha)	Rank	(Number)	Rank	(m:m)	Rank
Control	2.60	a	3.83	a	1.44	a	1353	a	1.46	a	1.42	a	71.94	d
10 months														
P1	2.73	ab	4.21	ab	1.79	a	1722	a	1.90	a	1.55	ab	69.54	cd
P2	3.07	abcd	4.73	ab	2.14	a	2377	a	2.52	a	1.60	ab	69.21	cd
P3	2.81	abc	4.37	ab	1.89	a	1989	a	2.10	a	1.40	a	72.11	d
Osmocote	3.19	abcd	5.22	abc	2.51	ab	2739	ab	2.91	ab	1.74	ab	64.20	bc
F1	3.11	abcd	5.28	bc	2.58	abc	2757	ab	2.92	ab	1.87	ab	63.20	bc
F2	3.69	d	6.48	c	3.52	bc	4602	c	4.58	b	2.04	b	60.00	ab
F3	3.37	bcd	6.55	c	3.72	c	4407	bc	4.45	b	2.00	b	54.40	a
F3 + Te[b]	3.53	cd	6.50	c	3.51	bc	4595	c	4.37	b	1.99	b	57.20	ab
30 months														
Control	11.25	a	10.95	a	10.63	a	38485	a	41.22	a				
P1	11.30	a	12.02	ab	13.23	bc	46174	ab	50.80	ab				
P2	11.75	a	12.67	bcde	13.61	bc	50574	bcd	53.38	bc				
P3	11.53	a	12.72	bcde	13.98	bc	52231	bcd	54.60	bc				
Osmocote	11.50	a	12.42	bcd	13.06	bc	47687	abc	50.35	abc				
F1	11.81	a	12.25	bc	12.67	b	47934	abc	50.05	ab				
F2	12.02	a	13.63	de	13.79	bc	57959	cd	55.07	bc				
F3	11.95	a	13.80	e	15.15	c	60823	d	60.80	c				
F3+Te	11.87	a	13.48	cde	14.03	bc	58145	cd	56.19	bc				

[a] Common letters denote differences between means not significant at the 5% level.

[b] Te = trace elements

Figure 20. *A. mangium* in an untreated control plot (foreground) in the fertilizer trial at 10 months. The plot had been cultivated with the Savannah plough and received herbicide treatment.

Figure 21. *A. mangium* in a high NPK fertilizer treatment (180 kg N/ha, 78 kg P/ha and 150 kg K/ha) in the fertilizer trial at 10 months. The plot had been cultivated with the Savannah plough and received herbicide treatment.

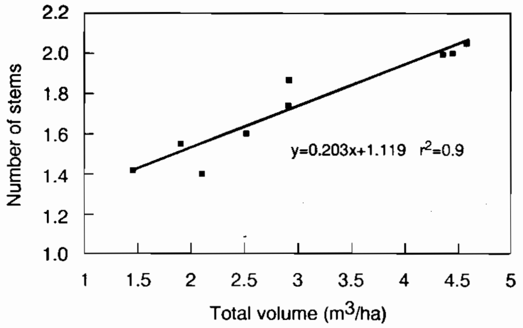

Figure 22. Relationship between growth of *A. mangium* and stems produced in the fertilizer trial at 10 months.

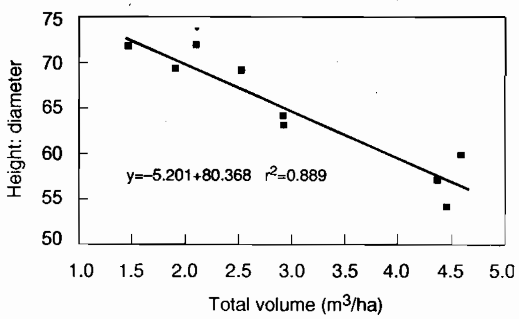

Figure 23. Relationship between height:diameter ratio and total volume of *A. mangium* in the fertilizer trial at 10 months.

Conclusions

At 10 months there was a clear limit to the response of *A. mangium* to surface applied fertilizer; this limit was at the 52 kg P/ha treatment, and 120 kg N/ha, 52 kg P/ha and 100 kg K/ha treatment. There was no response to additional applications of trace element fertilizer to this soil. At 30 months the main response to the fertilizer treatments was increased volume growth at the higher rate of 180 kg N/ha, 78 kg P/ha and 150 kgK/ha. This suggests that there may be responses to higher rates of NPK fertilizer if applied incrementally over time to the trees.

At 10 months, the slow-release fertilizer, Osmocote™, gave growth responses similar to fertilizer applied to the surface at rates of up to 20 times greater i.e. lower rate of NPK application, and this relativity was maintained at 30 months.

Across all fertilizer treatments it was clear that increased total volume production at 10 months was concomitant with changes in stem form (becoming more squat), and increased numbers of stems at breast height. Thus, although additional fertilizer created increased volume production, it was directly responsible for a change in the stem form of the tree.

CHAPTER 8

General Trends in *A. mangium*

TWO trends in the early growth of *A. mangium* (10 months) became clear when data from all the trials were put together; these trends are in the number of stems produced by the tree, and the shape of the stem. The means at 10 months for *A. mangium* (Wipim provenance) from the species trial, together with all treatment means for *A. mangium* (Wipim provenance) from the other trials, were combined to investigate these general trends.

Number of Stems

The number of dominant stems at 10 months increased as mean tree volume increased, as shown in Figure 24. The relationship was best described statistically by the 'number of stems' and a natural logarithm transformation of mean tree volume, 'ln mean tree volume'.

Stem Form

As mean tree volume increased at 10 months, the ratio of height:diameter of the stem decreased, i.e., as tree volume increased the shape of the stem became more squat. Conversely, in trees of smaller size, stem form was more slender (Fig. 25). The relationship was best described statistically by 'height:diameter' and a reciprocal transformation (1/x) of mean tree volume.

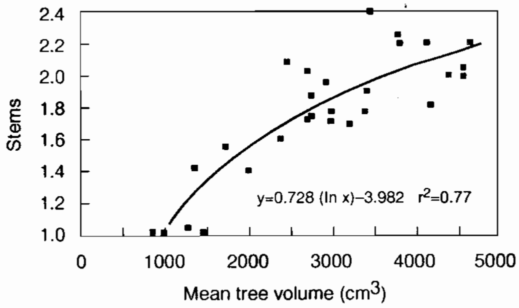

Figure 24. Relationship between stems and mean tree volume of *A. mangium* (Wipim) at 10 months.

Proportional Contribution of Treatments

The range of treatments in this series of trials allows for an estimate of the proportional contribution of each treatment to total volume production of *A. mangium*. The proportional contribution of treatments was estimated by comparing the difference in growth between treatments for cultivation (Savannah discs), P and NK fertilizer, chemical weed control, and the effect of using either Wipim or Subanjeriji provenances of *A. mangium*..

The estimated proportional contribution of treatments to total volume production of *A. mangium* are shown in Figure 26. Early growth of *A. mangium* at 10 months was affected most by chemical weed control (33%), followed by NK fertilizer (26%), cultivation (16%), P fertilizer (14%) and Wipim provenance (12%). However, at 30 months, the effects of the provenance (38%) and chemical weed control (33%) were most persistent, followed by the effects of P fertilizer (19%) and NK fertilizer (10%); the effect of cultivation did not persist to 30 months.

This analysis clearly shows the importance of chemical weed control in contributing to the successful establishment of *A. mangium* plantations in *Imperata* grassland, and the importance of fertilizer and cultivation in ensuring good early growth of the

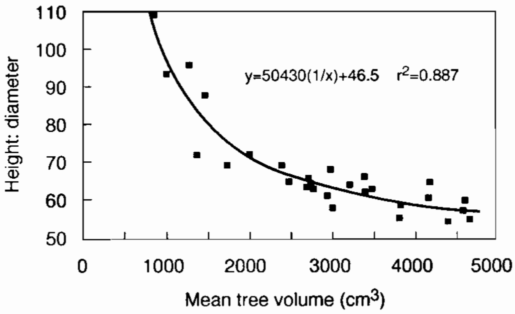

Figure 25. Relationship between height:diameter and mean tree volume of *A. mangium* (Wipim) at 10 months.

plantation. However, the enduring and most important treatments with respect to growth rate in this environment were the selection of a provenance with a high performance, and application of chemical weed control and NPK fertilizer.

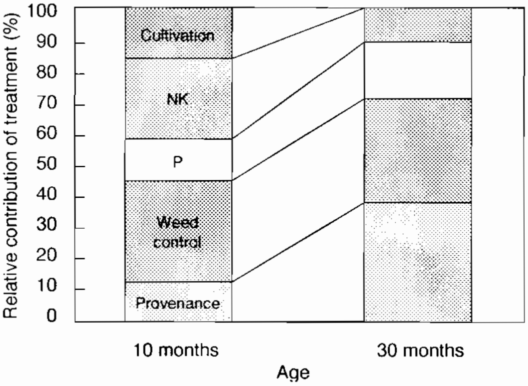

Figure 26. Proportional contribution of treatments to total volume production of *A. mangium*.

Conclusions

At 10 months, a more rapid growth rate of *A. mangium* resulted in squatter stems and increased stem branching. Selection of provenances of *A. mangium* for stem form and the production of single stems must be done by taking into account early growth rate. The more the growth of *A. mangium* is increased by silvicultural treatments such as weed control, cultivation and fertilizer, the more important it is to prune stems (singling) early in the growth of the tree (probably the first month). However, singling stems of *A. mangium* may create the added problem of establishing sites for the possible introduction of wood rot fungi into the stem.

The most important and long-lasting treatments for improved growth rate in this environment were the selection of Wipim provenance, chemical weed control and NPK fertilizers, each of which contributed between 29 and 38% of the total volume production of *A. mangium*.

CHAPTER 9

General Conclusions

THESE trials have shown the great potential for tropical acacias to be used on poor *Imperata* grassland for the purpose of industrial pulpwood plantations. *A. mangium* showed particular promise because of its rapid growth rate, particularly when assisted with effective weed control and fertilizers. These trials also showed the importance of provenance selection in this species. The Wipim and Lake Murray (PNG) provenances and Claudie River (Qld) provenance performed better than the Subanjeriji (Indonesia) provenance in terms of both growth rate and tree form. The Subanjeriji provenance has developed from a local land race of *A. mangium* and as a result it has a narrow genetic base. Vuokko et al. (1992) also recommended that the Subanjeriji provenance should be avoided for the reasons confirmed by these trials.

A. crassicarpa showed promise as a species which has better form and higher wood density than *A. mangium* (Clark et al. 1991). *A. crassicarpa* has also been found to grow faster than *A. mangium* on poor sites in South Kalimantan (Vuokko 1991) and in Sabah (Sim 1992). The other species of acacias used in the trials showed either poorer growth or multi-stemmed form. In trials at Riam Kiwa in South Kalimantan it was also found that *A. auriculiformis* and *A. aulacocarpa* had poor form (Vuokko 1991, Vuokko et al. 1992).

The results of the silviculture trials (weed control and fertilizer) confirm the importance of effective chemical weed control and NPK fertilizer for the rapid growth of *A. mangium* on poor sites. In trials at Bengkoka, Mead and Miller (1991) demonstrated the importance of NPK fertilizer, and stressed the importance of P and N fertilizer on poor sites. At Riam Kiwa in South Kalimantan, Simpson (cited in Srivastava 1993) demonstrated the importance of K nutrition in explaining the growth of *A. mangium*. It is important to stress the requirement of adequate nutrition for acacias in plantations; although they are nitrogen-fixing species, acacias still require adequate nutrition in order to grow and further fix nitrogen (Ryan et al. 1991).

The form of *A. mangium* was shown here to be directly related to growth rate; with faster growth rates resulting in increased branching and squat stem formation. Anecdotal evidence of this was found in Bengkoka, Sabah, by Mead and Miller (1991). Lim (1993) also reported that 57% of the biomass of open-grown *A. mangium* was in branches and phyllodes, compared with 27% in plantation-grown trees. These trends indicate the importance of singling, pruning, and optimising stocking if *A. mangium* is to be used for mechanically-harvested pulpwood plantations.

The success at 30 months of the hybrid *E. grandis* × *E. urophylla* is in marked contrast to the poor success of its parent *E. grandis*. This hybrid was developed from land race parents at Aracruz in Brazil, and has been further developed by controlled crossing in Brazil, southern China and South Africa (Eldridge et al. 1994). Its success in this monsoonal wet/dry environment in South Kalimantan reflects the origins of *E. urophylla*, the Wetar (Indonesia) provenance of which also performed well in these trials to 30 months. The overriding conclusion from the success of these eucalypt species is that there is greater potential for growing industrial plantations of eucalypts on poor lowland *Imperata* grassland sites than previously considered, though the sometimes rapid decline of eucalypt plantations which have shown early promise (Eldridge et al. 1994) remains of concern.

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Company (London) provided advice on the design of the species trial and provided seedlots of hybrid eucalypts. The main seedlots were purchased from the Australian Tree Seed Centre of the CSIRO in Canberra, Australia. Seedlings were grown by Inhutani II at Semaras under the supervision of Ir. Totok and Ir. Nofi. Assistance with supervision of planting the trials was provided by ENSO Forest Development staff from Banjarbaru, Kalimantan Selatan (Mr Goran Adjers and Mr Markku Temmes).

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