SILVICULTURE

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SAFODA
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Authority

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Agency

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Silvicultural Text B Course

1. Forest ecology

1-1 Plant formation in the tropical region

The characteristics of plant formation in the world are made by basic factors of temperature (mean annual temperature) and annual rainfall. Whittaker classified this into 22 types, and the types in the tropics are shown in figure 1.

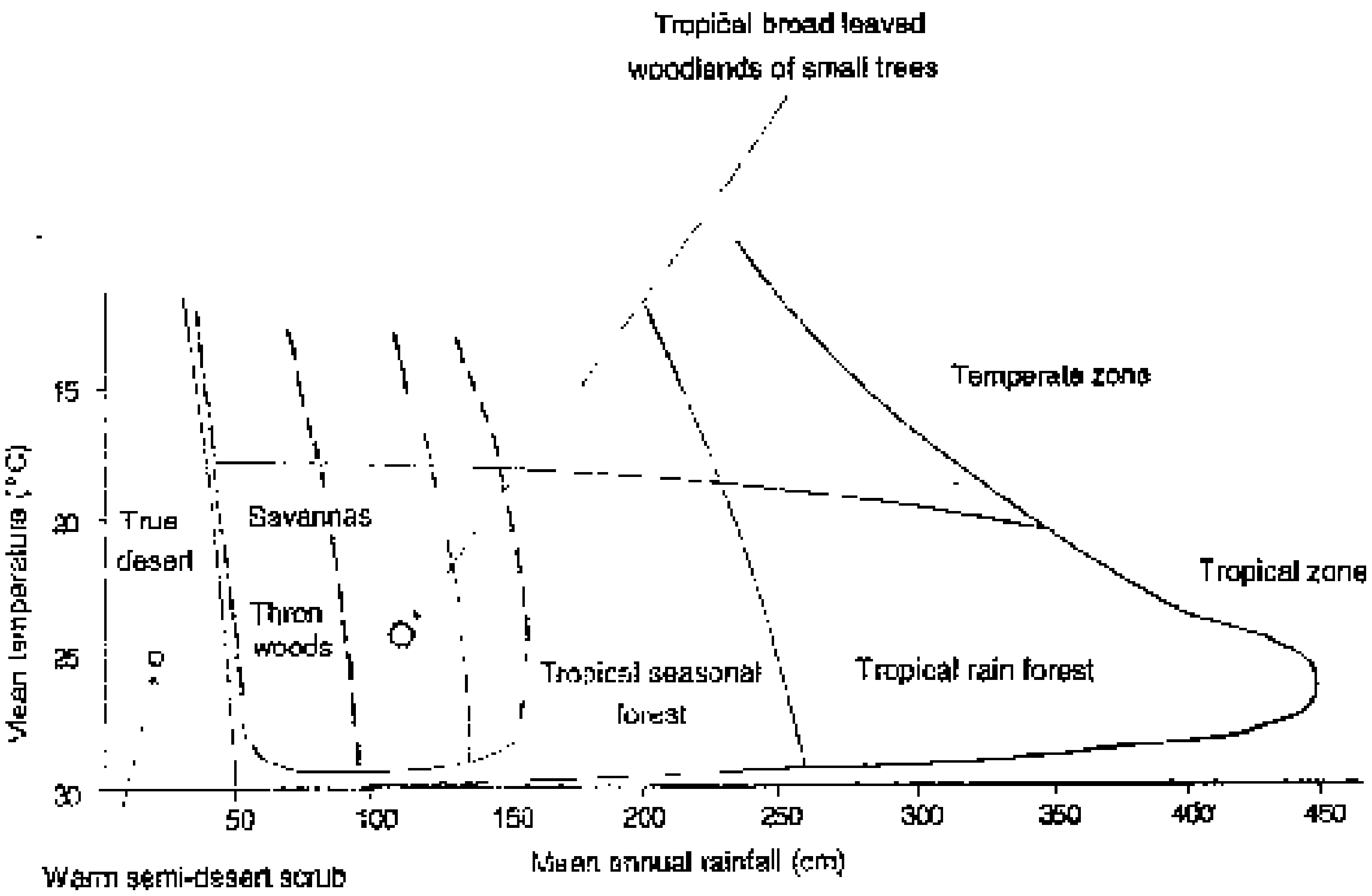


Figure 1: Plant formation in the Tropics. (Whittaker, 1975)

The period of dry season is rather important factor for organization of tropical forest types than the amount of annual rainfall. Inorder to understand this, Walter made and suggested a Climatic Diagram which consists of mean monthly temperature and rainfall in the year and give us the situation of dry, semi-dry and rainy season at certain place easily and clearly. Based on this diagram, the tropical forest was classified as shown in table 1. and figure 2 is the climatic diagrams of some types of the classified forest.

Table 1: Forest type in the tropics.

Forest type		Period of dry season (month)	Height of Forest (mean height of crown cover story)	No. of leaf layer except undergrowth grass.	The physiognomy during dry season
			(m)		
Tropical rain forest		0 - 1	45 - 65	4	ever-green
Tropical seasonal forest	ever-green	1 - 2	35 - 50	4	amount of defoliation increases in the end of dry season
	semi-deciduous	2 - 4	20 - 45	3	part or most of all leaves of crown cover story falls except lower story.
	deciduous	5 - 6	15 - 25	2	all leaves of crown cover and lower story falls.
Savanna		6 - 8	5 - 20	1	Gramineae spp. on the ground floor dries.

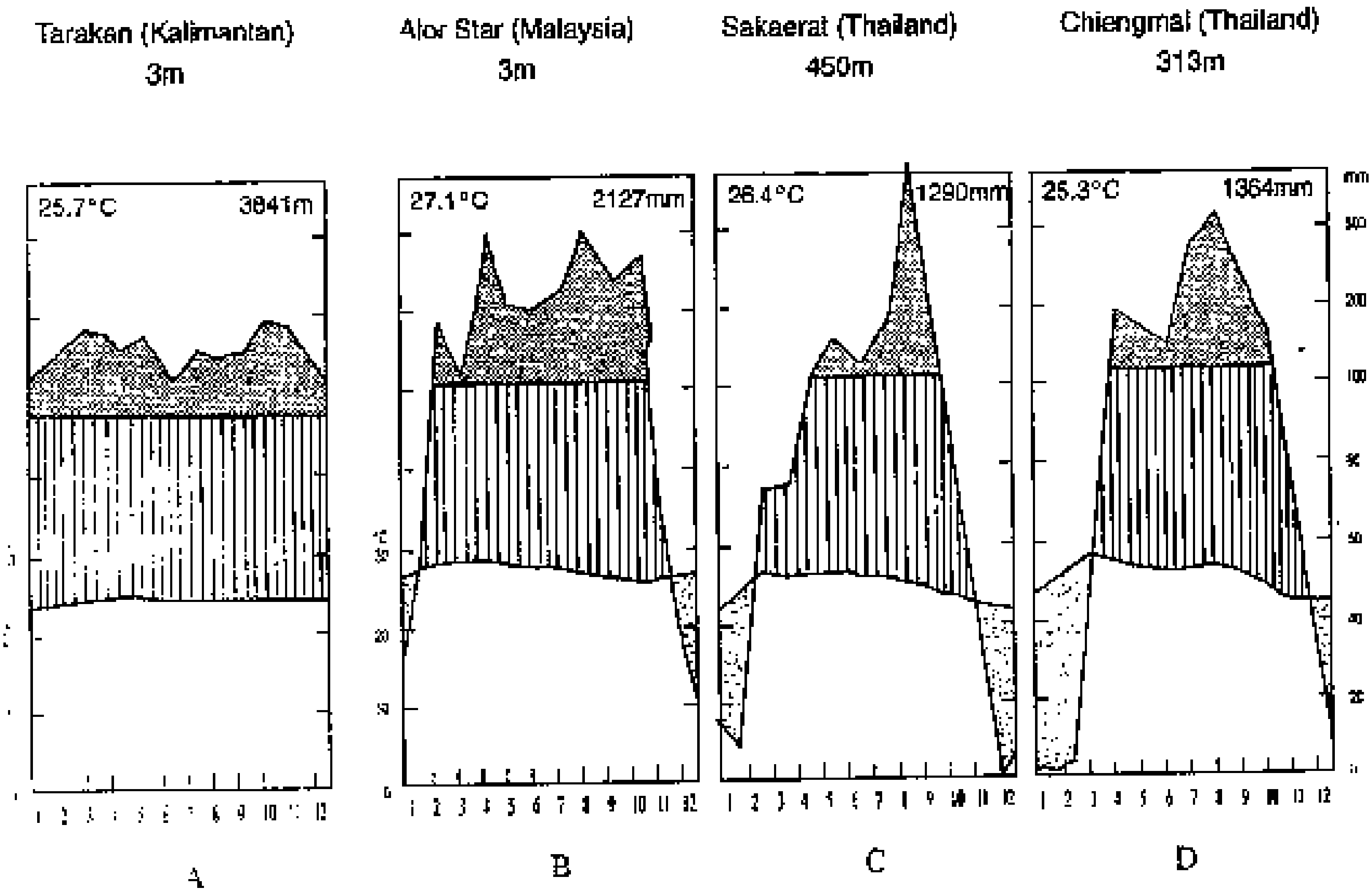


Figure 2: Climatic Diagram (kira).

A: Tropical rain forest
B: Tropical seasonal forest (ever-green)
C: Tropical seasonal forest (semi-deciduous)
D: Tropical seasonal forest (deciduous)

Table 4: Rate of nutrient cycle in tropical rain forest.

content		N	P	Ca	Mg	K
A: supply to forest by rainfall (kg/ha. year)		14	-	4.8	1.2	10
B: supply to soil by rainfall in forest (")		26	-	4.8	2.4	39
C: Supply to soil by litter fall	(")	123	3.5	89	23	38
D: amount supply to soil (A+C)	(")	138	3.5	94	24	48
D': amount supply to soil (B+C)	(")	149	3.5	94	25	77
E: amount in soil (kg/ha)	(")	6734	29.2	108	77	266
F: mean residence time (E/D)	(year)	48	8.3	1.1	3.2	5.7
F': mean residence time (E/D')	(year)	45	8.3	1.1	3.1	3.5
F: <warm temperate laurel forest>	(year)	119	-	10	18	15
F: <cool temperate deciduous broadleaved forest>	(year)	279	-	11	5.5	45

Thus tropical rain forest subsists on the rapid nutrient cycle, and in general, soil under tropical rain forest includes nutrients in small quantity; this is a notable point. After logging followed by burning or cultivation, the nutrient cycle is cut off and nutrients are washed away by much rainfall: as a result, the soil gets poorer and poorer. Lallang (*Imperata cylindrica*) grassland growth after repetition of shifting cultivation is obviously indicates infertile land.

1-4 Growth rate of tropical rain forest

Another notable point is that pioneer or secondary forest species grow terrifically fast while climax species do not grow fast and the maximum photosynthetic rate (10-15 mg $CO_2/dm^2/hour$) is as much as warm temperate laurel forest. Figure 4 shows the photosynthetic rate of tree in each category.

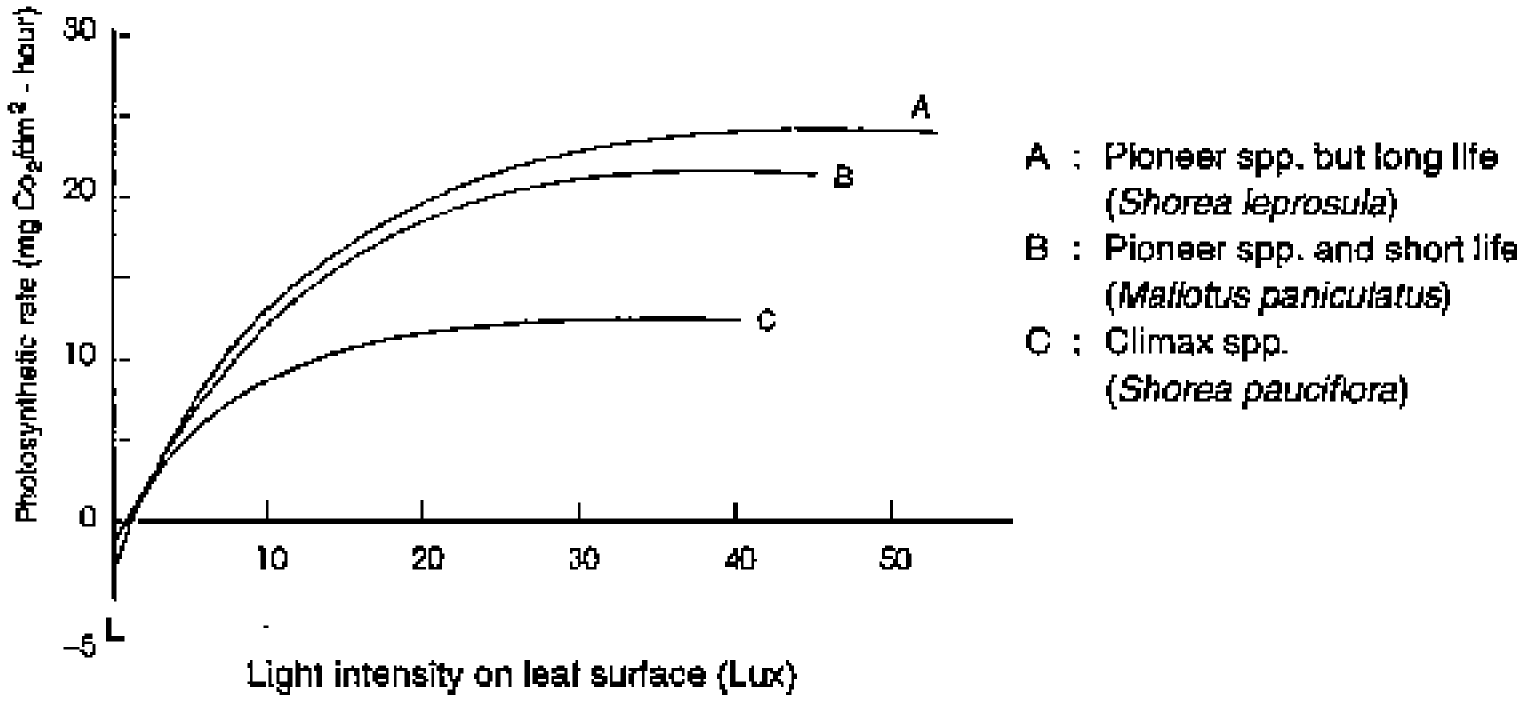


Figure 4: Light - Photosynthesis curves of sun leaf of tree species in tropical rain forest in Pasoh (Koyama, modified).

Generally speaking, pioneer and secondary species in category B, such as *Mallotus* spp., *Macaranga* spp. and *Glochidion* spp. are small tree species and they can live only for 5-20 years at most and soft wood which is not useful for general industrial purpose. While there are other type of species in the same category, they grow to tall and thick size, and they have relatively useful wood for pulp use or timber use. Popular tropical plantation species, so called "fast growing species" such as *Eucalyptus deglupta, Paraserianthes falcataria* and *Acacia mangium* belong to this category. Their maximum annual increment of tree height gets to 5-6m and tree height reaches 20m in 4-5 years after planting in fertile plantations, and their net production becomes 30-40 ton/ha/year (See table 2). There may be many unknown hopeful species in the natural forest. The species in A category are also the same pioneer spp. as in category B, while they live long time and become main trees in the middle term of regeneration and produce heavy useful wood.

industrial purposes because of the uneconomical harvesting. Ridges or streams sometimes disturb harvesting.

Plantation staff should always take harvesting into consideration from the first stage because plantations are established for harvesting. There is no problem on flat planting areas. However, SAFODA's plantation sites are usually hilly or rolling, so every establishing procedure must follow topography and accessibility.

2-4 Species choice

The most striking advantage of tropical plantations is rapid growth, fast growth is not only in relative volume but in relative value as well. Plantation forestry in the tropics can significantly aid economic development. So, species choice is an important decision in plantation establishment. Species suited for plantation must have the characteristic of reasonably fast growth so as to repay the investment.

Deciding the choice of species depends on these basic questions (Evans, 1982).

a. What is the purpose of the intended plantation?
b. Which species are potentially available for planting?
c. What will grow on the sites available?

(1) The purpose of the intended plantation

Purpose of plantation can be divided into four categories:

a. Industrial use --------- fuelwood, pulpwood, sawntimer, panel products.
b. Domestic use -------- firewood, poles etc.
c. Environmental protection use ------ soil and water conservation, windbreak etc.
d. Amenity use -------- shade, shelter, food fertilizer etc.

Chosen species must have suitable characteristics for the purpose of planting. Of course, these purposes are often related with each other. SAFODA's main purpose which affected species choice is wood production for industrial use, though it coexists with other purposes such as land rehabilitation and local employment promotion.

The species for industrial use must have the characteristics as shown in Table 5.

Table 5: Important factors in species choice for industrial end-uses (Evans, 1992)

	Fuelwood	Wood pulp	Sawn timber	Plywood/veneer
Growth and silviculture	Fast growth with early culmination of maximum growth rate. Large tree size unimportant or disadvantageous. Tree shape unimportant. Should be easy and cheap to grow; coppicing ability desirable.	As for fuelwood, but straight stems are important to aid rapid de-barking	Moderate to fast growth with ability to grow to large size. Good form important, ease of pruning and freedom from butt rots highly desirable	As for sawntimber, but growth to very large size important. Good natural pruning with rapid wound occlusion desirable
Wood properties	Quick drying. Low ash content. Burn steadily without smell, sparks, etc. Moderate to high density	Fibre length, colour, extractives content, density. Papermaking quality	Strength, dimensional stability, wood uniformity. Good seasoning, preservation, working and finishing properties.	Peeling or slicing quality. Figure. Knot-free. Good adhesive bonding for plywood. Good burning characteristics for matches.
Some examples of species Chosen for large-scale industrial plantations	*Casuarina spp* (India) Eucalypts (Brazil) *Gmelina arborea* (Malawi, W. Africa) *Leucaena leucocephala* (Philippines)	*Pinus patula* (Africa) *Pinus caribaea* (Fiji, S. America) *Gmelina arborea* (W. Africa, Brazil) *Paraserianthes falcataria* (Philippines) Eucalypts (Brazil, Congo) *Acacia mangium* (Sabah)	*Pinus patula* *Cupressus lusitanica* (Kenya) *Tectona grandis* (Indonesia, India) *Triplochiton* (W. Africa) *Pinus caribaea* (Queensland) *Cordia alliodora* (Central America)	*Swietenia macrophylla* *Alstonia scholaris* (matches) (Fiji) *Araucaria cunninghamii* (Papua New Guinea)

(2) Species potentially available

a. Tropical plantation species

There are two categories of widely planted species in the tropics as below:

- # Species occuring naturally within the tropics
- # Species planted widely and successfully in the tropics, often in the cooler highland regions, the natural distribution of which lies outside the tropics. Tree examples are *Eucalyptus grandis, Grevillea robusta* and *Pinus elliottii*.

b. Indigenous species and Exotic species

Once the purpose of plantation is known, the choice of species is narrowed: for example, in an industrial pulpwood plantation in the moist lowland tropics, there may be several suitable species, such as *Paraserianthes falcataria, Acacia mangium, Gmelina arborea* and *Eucalyptus deglupta*. These are all exotic species in Sabah. However, an exotic species should not be chosen if an indigenous species meets the need as it is important to emphasize that not all tree introductions are successful. Most of all exotic species may ended in failure caused by unpredictable factors. Well over 100 exotic species have been introduced into Papua New Guinea (PNG) but of the 42 tested in trial plots, only 6 have found wide use. Five (5) of these are widely planted elsewhere in the world (Evans, 1992).

Unfortunately most of all indigenous species in Sabah are unknown species for plantation and they have the same problems in seed supply, raising seedlings or growth in plantation conditions. Therefore at present, it is the second best policy that well-known exotic species should be chosen as the already-existing researches and experiences allow them to be used with some degree of certainty. In addition, a species whose seeds in large quantities can be easily obtained with reasonable low cost should be chosen for large scale plantation.

c. Genetic variation in one species

Most species grow naturally over a range of sites and location, and often isolation of stand may have led to genetically different population within one species. Different varieties and provenances often perform very differently when tested together in one site. These differences are shown in table 6, which compares local seed source of *Acacia mangium* and *Acacia auriculiformis* with new sources of these species from Papua New Guinea (PNG). Local seed source of *Acacia mangium* was introduces into Sabah from Queensland, Australia in 1967. Both species of new provenances from PNG are significantly taller than local seed sources. The poor showing of local source *A. mangium* probably arises from inbreeding depression since it is thought that all seeds in the original 1967 importation to Sabah came from one tree. Therefore the provenance is also important factor for species choice.

Based on preliminary data from 25 provenances, the most promising *A. mangium* for Sabah are Claudie River (Queensland), Oriomo River (PNG), Iokwa (PNG) and Western Province of PNG (Darus, 1992).

Table 6 Performance at 4 years of age of *A. auriculiformis* and *A. mangium* provenances on two sites in Sabah, E. Malaysia
(Sim Boon Liang, pers. comm.) (Evans, 1992)

Species	Provenance	Height (m)	
		Site 1	Site 2
A. auriculiformis	Sepilok (local)	9.87	11.51
A. auriculiformis	Balamuk, PNG	12.10	13.99
A. auriculiformis	Iokwa, PNG	14.91	13.07
A. auriculiformis	Bula, PNG	11.59	12.27
A. mangium	Tawau (local)	11.48	9.56
A. mangium	PNG	15.61	13.04

d. Genetic differences between rotations

In the moist tropics, yield are commonly three to seven times greater than either managed natural forest or most plantations in temperate regions. However almost all available growth data for example Table 7 come from the first rotation stand will later rotations yield as much wood as the first? And can ecosystems, relatively low yielding in wood such as the already degraded rain-forest sites or grassland, be turned permanently into highly productive forest plantations or is the very large initial gain only temporary?

Unfortunately, no certain answer can be given about yields of later rotations since few data are available. Most notably with *Pinus radiata* in South Australia, it cannot be assumed that the performance of the first rotation will be maintained in later crops.

One of the possible factors which could lead to change in productivity between rotations is genetic differences. A change of species will clearly influence productivity but so too will change in seed origin or seed quality. The use of genetically superior seed or selected clonal planting stock in the second rotation could disguise evidence of a general decline in site fertility.

Table 7: Growth rates of managed forest and plantations. (Modified from Wood 1975) (Evans, 1992)

	Yield ($m^3ha^{-1}a^{-1}$)	Rotation (years)
Canada average	1.0	-
Siberia (Russia)	1-1.4	-
Sweden average	3.3	60-100
US average	2.6	-
UK average (conifers)	11	40-65
New Zealand pines	18-30	20-40
South African pines	10-25	20-35
Subtropical eucalypts	5-30	8-25
Teak plantations	4-18	40-80
Tropical hardwood plantations	25-45	8-20
Tropical pines	15-45	8-30
Tropical eucalypts	up to 70	7-20
Tropical high forest (managed)	0.5-7	-
South-east Asia dipterocarp forest (managed)	up to 17	-

(3) Right tree on right site

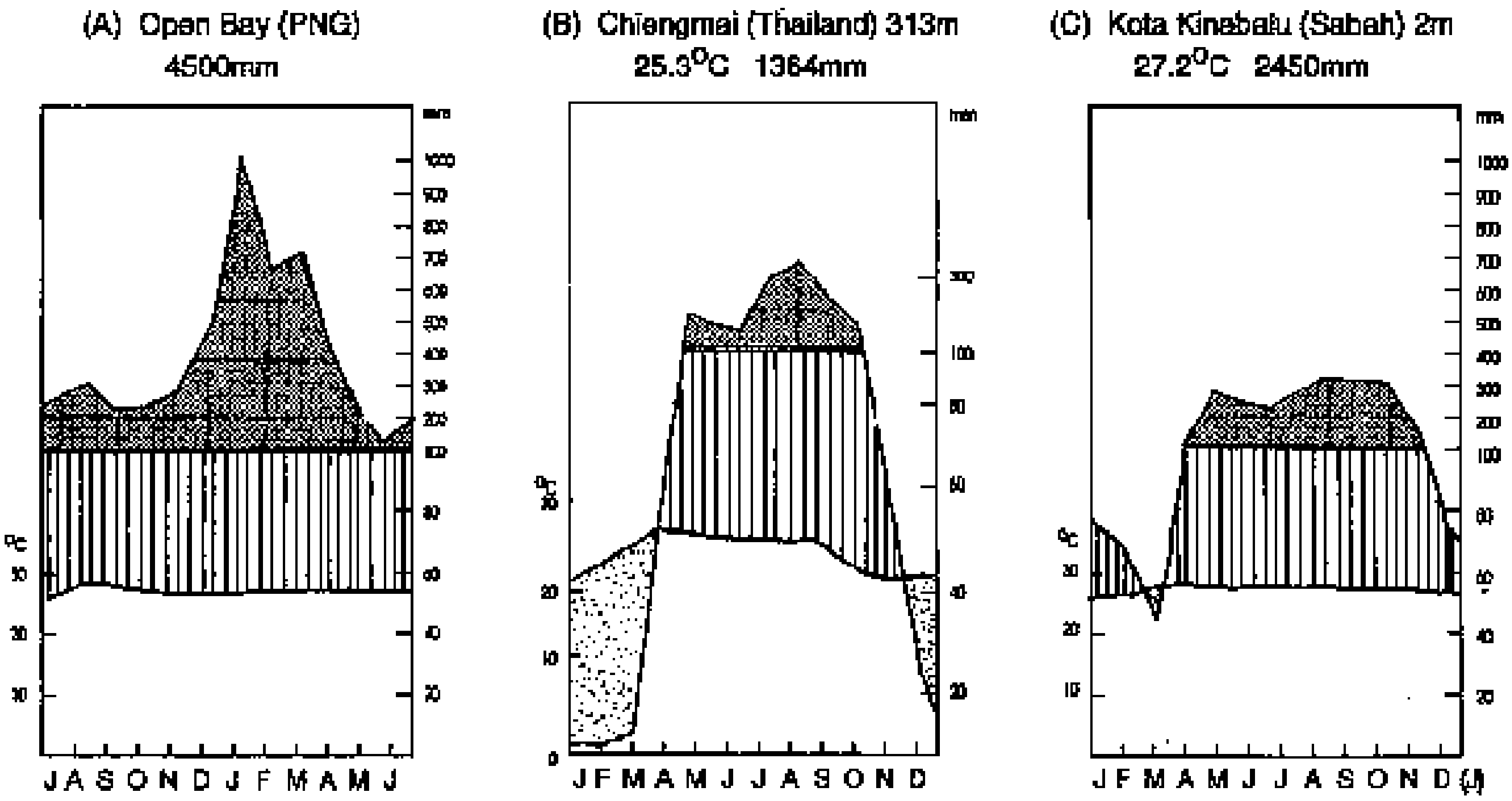
It is essential to achieve the best match between species (variety and provenance) and the planting site including creating environmental improvements such as adding fertilizer and cultivation. The problem of matching species with site is of little importance with indigenous species occuring naturally in or near the planting area, but it is of first importance when an exotic species is to be planted.

The site factors for tree growth are climate, height above sea level, azimuth, slope angle, terrain, geology, soil condition and so on. The climate and soil condition are the main important factors to consider the right species on its site.

a. Climate

Mean annual precipitation, Rainfall distribution, Mean temperature, Maximum and Minimum temperature etc, should be considered. The matching of plantation species in the tropics is rather influenced in the period of dry season than the amount of annual precipitation. Figure 6 shows the climatic diagram at natural occurence area of 2 species and Kota Kinabalu Airport. Open Bay (PNG) and Kota Kinabalu belong to tropical rain forest and Chiengmai (Thailand) belongs to tropical deciduous forest. However, it is important to stress that an exotic species may grow well in a climate not necessarily closely matching with its known habitat. The species may have potential to grow in much wider range of environments than its known habitat. Example include the very widely planted *Pinus caribaea* in the tropics.

Figure 6: Climatic diagram of natural occurrence area of *Eucalyptus deglupta* (A), *Gmelina arborea* (B) and Kota Kinabalu (C).



These are the classifications of climate according to height above sea level and the period of dry season with examples of suitable species as below:

I. Tropical lowland

(1) Dry season: less than 4 months — A type : less than 2 months; B type : 2-4 months.

Acacia mangium, Dyera costulata, Endosperum peltatum, Paraserianthes falcataria, Anthocephalus chinensis, Intsia bijuga, Intsia palembanica, Cedrela toona, Leucaena leucocephala, Cordia alliodora, Sesbania grandiflora, Pterocarpus indicus, Terminalia cattappa.

(A Type)

Agathis loranthifolia, Eucalyptus deglupta, Gonystylus bancanus, Casuarina equisetifolia, Mesua ferrea, Terminalia brasii.

(B Type)

Paraserianthes lebbeck, Gmelina arborea, Artocarpus integrifolia, Cedrela odorata, Pinus merkusii, Lagerstroemia speciosa, Ochroma lagopus, Pinus caribaea, Swietenia macrophylla

(2) Dry season : 4-6 months.

Adina cordifolia, Maesopsis eminii, Shorea robusta, Agathis palmerstonii, Azadirachta indica, Tectona grandis, Terminalia tomentosa, Toona calantas, Eucalyptus camaldulensis, Vitex parriflora, Eucalyptus urophylla, Vitex pinnata.

II. Tropical high-land

Acacia mollissima (1200m -). *Araucaria cunninghamii* (600 - 1500m). *Araucaria hunsteinii* (- 2500m). *Eucalyptus citriodora* (500 - 1200m). *Eucalyptus pilularis* (1200 - 1800m). *Eucalyptus saligna* (1000 - 1500m). *Pinus kesiya* (900 - 1500m).

b. Soil

Soil depth, physical structure, drainage, soil reaction, vegetation etc. should be considered.

The result of the soil survey in each area of SAFODA carried out by SAFODA/ARAB (1990) should be made good use as general consideration of each region. Moreover, when the planting site is large, there maybe various soil conditions in the site. For example, the soil condition varies due to the topographic position. In a slope, soil of the lower slope is wetter, thicker, and more fertile than soil of the upper slope, and, of course, tree growth is better on the lower slope. Table 8 shows the case of *Acacia mangium*.

Table 8: Growth of *Acacia mangium* (8.7 years old) on different soil catenas at Jalan Lee, Sabah (Jones, 1983).

Catena	Mean height (m)	Mean DBH (cm)
Skeletal	11.0	14.6
Hill creep	14.6	18.8
Sedentary	15.9	19.9
Hill wash	19.5	23.9
Alluvium	20.7	26.5

Tree height and DBH in table 8 are directly indicate the site quality on *Acacia mangium* based on the differences of micro-topography. However, if there is a plan to change to other species in the site but no data for its growth available, the site quality for certain species has to be indicated indirectly.

One of the relatively easy and effective method is by considering the vegetation as indicator. Taoda (1988) reported the indicator plants for *Acacia mangium* in Table 9 based on the assessment in SAFODA plantation area.

Table 9: Site index and vegetation type (Toada, 1988).

Index*	Dominant species
7 - 8	*Dicranopteris linearis, Gahmia tristis*
14	*Dicranopteris linearis, Scleria bancana*
14(?)	*Ischaemum sp.*
16	*Eupatorium odoratum, Dillenia suffruticosa*
17	*Scleria bancana*
18	*Scleria sumatrensis*
18(?)	*Imperata cylindrica*
18	*Panicum sp.*
18	*Eupatorium odoratum*
20	*Paspalum commersonii (?), Eupatorium, Lantana*

* Top height at age of six years.

c. Special protection needs

Tolerances of fire, flood and competition with other vegetations, sensitivity to pests and diseases should be considered.

(4) Present condition of suitable plantation species in Sabah.

a. 8 species recommended by the Forestry Department.

The Forestry Department has already selected and recommended 8 species that have the potential for plantation in Sabah. These are all exotic species as follows:

Hard wood	Soft wood
Paraserianthes falcataria	*Araucaria cunninghamii*
Acacia mangium	*Araucaria hunsteinii*
Eucalyptus deglupta	*Pinus caribaea*
Gmelina arborea	*Pinus oocarpa*

About 60% of the whole plantation areas planted in Sabah by the end of 1991 was *Acacia mangium* (See table 10) and the growth rates of common species in Sabah are shown in table 11.

Table 10: Approximate areas of plantation of Fast-growing Species in Sabah by The End Of 1991 (Lee and Anuar, 1992)

Species	Approximate area (ha)
Acacia mangium	38,000
Paraserianthes falcataria	8,560
Gmelina arborea	8,200
Eucalyptus deglupta	7,200
Pinus caribaea	1,050
Other *Eucalyptus* spp.	400
Other *Acacia* spp.	100
Others	90
Total	63,600

Table 11: Growth Rates of Common Fast-growing Species in Sabah (Adapted from Sim, 1987) (Lee and Anuar, 1992)

Species	Range of maximum mean annual increment (m^3/ha/yr)
Paraserianthes falcataria	25 - 70
Acacia mangium	15 - 45
Gmelina arborea	7 - 32
Eucalyptus deglupta	5 - 24
Pinus caribaea	4 - 48

Acacia mangium is well adopted to wide range of site include on degrade site such as *Imperata cylindrica* grassland. So, this is the main species planted in SAFODA plantations. On the other hand, *Paraserianthes falcataria* and *Gmelina arborea* are very site selective, they can grow only on fertile sites. Therefore, S.S.S.B. planted *Gmelina arborea* on deeper, more fertile soil, *Acacia mangium* on poorer, infertile sites and grassland, and use *Paraserianthes falcataria* for shading cocoa. However there are not species mixed in one stand (Evans, 1992).

Eucalyptus deglupta and *Pinus caribaea* are not adopted for planting in recent years because it was found that these species are not suitable in Sabah. From the experience in SSSB. *Eucalyptus deglupta* does not perform well as its growth slow down drastically after three years because of water stress and is highly susceptible to pests and diseases.

The growth rate of *Pinus caribaea* in Sabah has been very disappointing. This species is now considered not financially attractive for plantation establisment (Lee and Anuar, 1992).

Detailed description of these species is in Appendix 1 "Properties of plantation species".

b. Recent noticing species for plantation

Acacia mangium hybrid, *Acacia auriculiformis, Acacia crassicarpa, Acacia aulacocarpa,* and *Eucalyptus urophylla* are considered as a large scale plantation species.

Acacia mangium hybrid with *Acacia auriculiformis* is expected having the effectiveness of heterosis, thus better growth rate (See table 12), circularity, small number and thin branches, self-pruning and resistant from heart-rot disease compared with *Acacia mangium* and better straightness compared with *A. auriculiformis.*

Table 12: Growth rates of *A. mangium* and *hybrid Acacia*

(Lapongam, 1987) (Kijkar, 1992)

Station	Species	Age (yr)	Height (m)	Dbh (cm)
Ulu Kukut (Sabah)	A. hybrid	11	27.19	31.79
	A. mangium	11	25.54	28.55
Bengkoka (Sabah)	A. hybrid	7	19.71	24.44
	A. mangium	7	16.83	18.06

Acacia auriculiformis is observed as tall straight trees in its natural habitat in Australia and PNG suggested provenance selection could significantly improve stem form.

Two other phyllode *Acacias* of *A. crassicarpa* and *A. aulacocarpa*, form PNG, are growing at least as well as *A. auriculiformis* in some provenance trials in Sabah (Evans, 1992) and they produce large quantities of biomass comparable to or more than *A. mangium* on sandy soil in lowland (below 800m a.s.l) in SFI (Lee and Anuar, 1992).

Eucalyptus urophylla grows well on highland (above 800m a.s.l) in SFI.

c. Approach to indigenious species plantation

The exotic, especially in mono-culture, more susceptible to massive uncontrolled attack once a serious pathogen colonizes the species. And it is a serious question for long-term plantation by short cycle rotation such as pulp-log plantation wheather already degraded rain-forest site or grassland can be turned permanently into highly productive forest plantation or not.

SAFODA Research Division has started work on the propagation and establishment of dipterocarps species near Punteh in 1992 as indigenous species trial of high quality logs and longer rotation than pulp-log plantations. The *Parashorea* (*urat mata*) species is the main genus the research division is focussing on.

3. Silviculture operation.

Figure 7 shows plantation life-history. Most plantation establisments are managed according to this schedule.

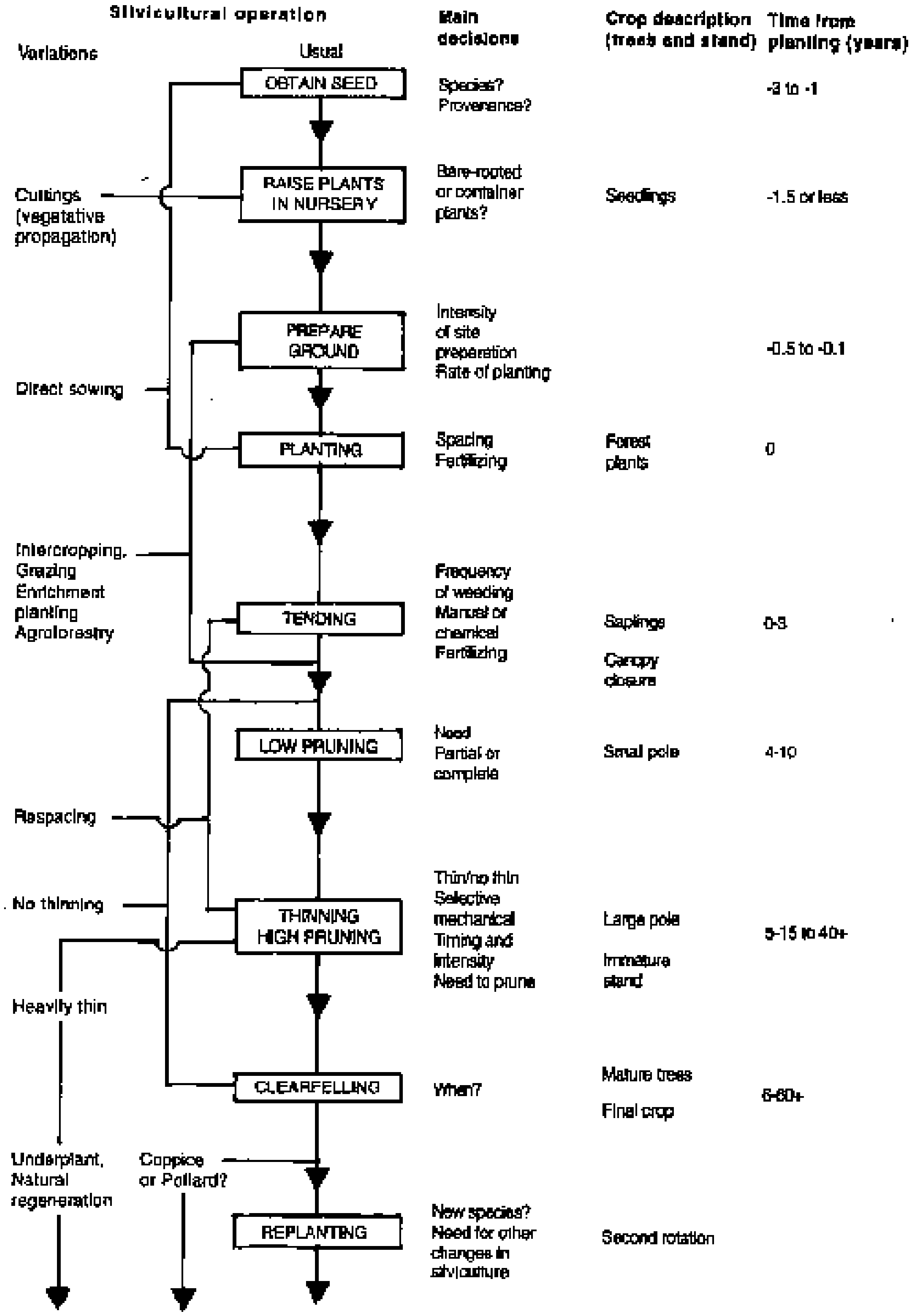


Fig. 7 Schematic representation of plantation life-history. (Evans, 1992)

Establishment practices such as ground preparation, planting and tending uniformly improve the quantity of growth of all planted trees (elementary operations). On the other hand, manipulation of initial spacing and the mostly selected practices of thinning and pruning are used to develop a certain kind of stand and a certain quality of tree growth (intentional operations).

3-1 Elementary operations

In a plantation, once the canopy is closed, many hazards are greatly diminish. Therefore, the overriding objectives of establishment are good survival and rapid early growth; they depends on satisfying all the requirements for tree growth. Correct choice of species (variety and provenance), adequate land preparation, control of weeds, addition of fertilizer if necessary, protection against grazing etc. must all be done properly. Omission of any one, perhaps because of cost, may greatly prolong establishment, and be a false economy. It is important that a standard of operation as minimum essential is made throught research.

Figure 8 shows how a silvicultural decision affects other operations.

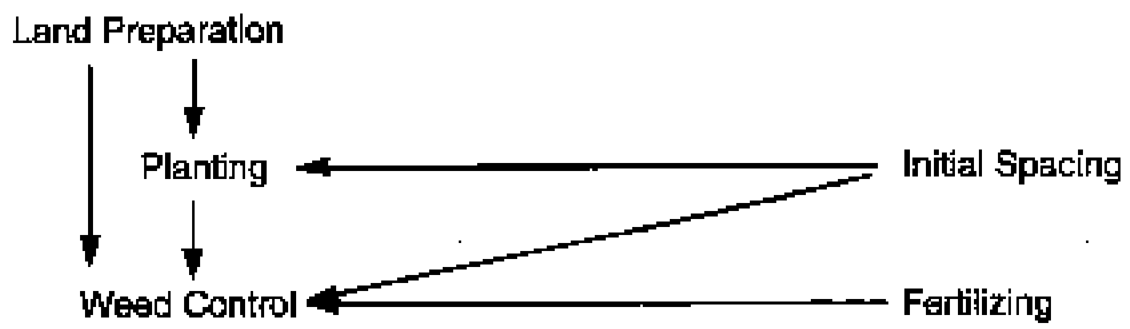


Figure 8: Relations between each elementary operation.

(1) Land preparation

All vegetation covers should be cleared to suppress competitive vegetation, to improve accessibility in the planting site and to facilitate lining, planting, weeding and manuring. All these operations are more effective where land clearance is carried out.

There are some methods of site preparation, such as manual, mechanical and chemical use. Chemical clearance must be considered only for site with grass vegetation. It can be cheap and effective in suppressing weed regrowth for a long period. In SAFODA's Bengkoka Project, herbicide is used on Lallang *(Imperata cylindrica)* grassland effectively.

For adoptation, the method of manual or mechanical site clearance, the advantages and disadvantages (See table 13) between these methods should be considered. Therefore, mechanical clearance should be used on large-scale plantation where the land is relatively flat. It improves subsequent growth of plants on compact soil conditions because of improved soil structure (See table 14).

Table 15 shows the comparison between manual and mechanical (Marden Roller) in Bengkoka Project.

Table 13: Comparison between manual and mechanical.

	Item	Manual	Mechanical
1.	Total cost	high	low
2.	Topography (steep slope rocky site)	possible	impossible (wet ground condition)
3.	Large scale	insufficient	sufficient
4.	Operation season	not limited	limited
5.	Operation skills	few new skills	much skills
6.	Capital cost	low	high
7.	Maintenance of equipment	small	large
8.	Plant growth in compact soil	low	high (soil damage)

Table 14 The Comparison of the Initial Growth between Mechanized Terracing and Manual Site Preparation on Yemane (*Gmelina arborea*) (Philippine - JICA project report, 1987)

Method of Site Preparation	Diameter in Root Collar	Height
	cm	m
Terracing	7.4	3.2
Manpower Site Preparation	5.5	1.6

Note: 1. Date planted : July, 1983
2. Date measured : December, 1985

Table 15: Provisional Figures of Marden Roller compare to Manual Slashing in Bengkoka (Nissanto and Francis, 1991).

Marden Roller:		
Area Rolled	=.	7 ha.
Machine hours	=	27 hours
Machines hrs/ha	=	3.8
Cost per hectare	=	3.8hrs x $60
	=	$250 (*)
Manual Slashing		
Average Mandays per ha	=	23.8
Average Wage rate	=	$15.20
Cost per ha.	=	$349.60
Therefore, saving cost per ha.	=	$99.60

(*) Cost of bulldozer + wages for operator.

Control burning after manual or mechanical clearance is an effective method of land clearance especially thick forest or shrub sites. It is widely used in tropical plantation. It has the advantages as below:

- o Further activities such as lining and planting operation are easy, thus the cost reduces significantly.
- o It can exterminate insects and animals harmful to workers such as snakes and to plants such as mice.

However, burning is not good for soil conservation. It causes loss of organic matters, nitrogen and even some bases from the soil. According to Lee and Anuar (1992), site preparation trial without burning increased the growth rate and reduced the weed infestation in the SFI *Acacia mangium* plantation. However, site preparation without burning has not been adopted in SFI from these points of view that the unburnt debris is an obstacle during weeding and other operations and it may harbour many pests and pathogens.

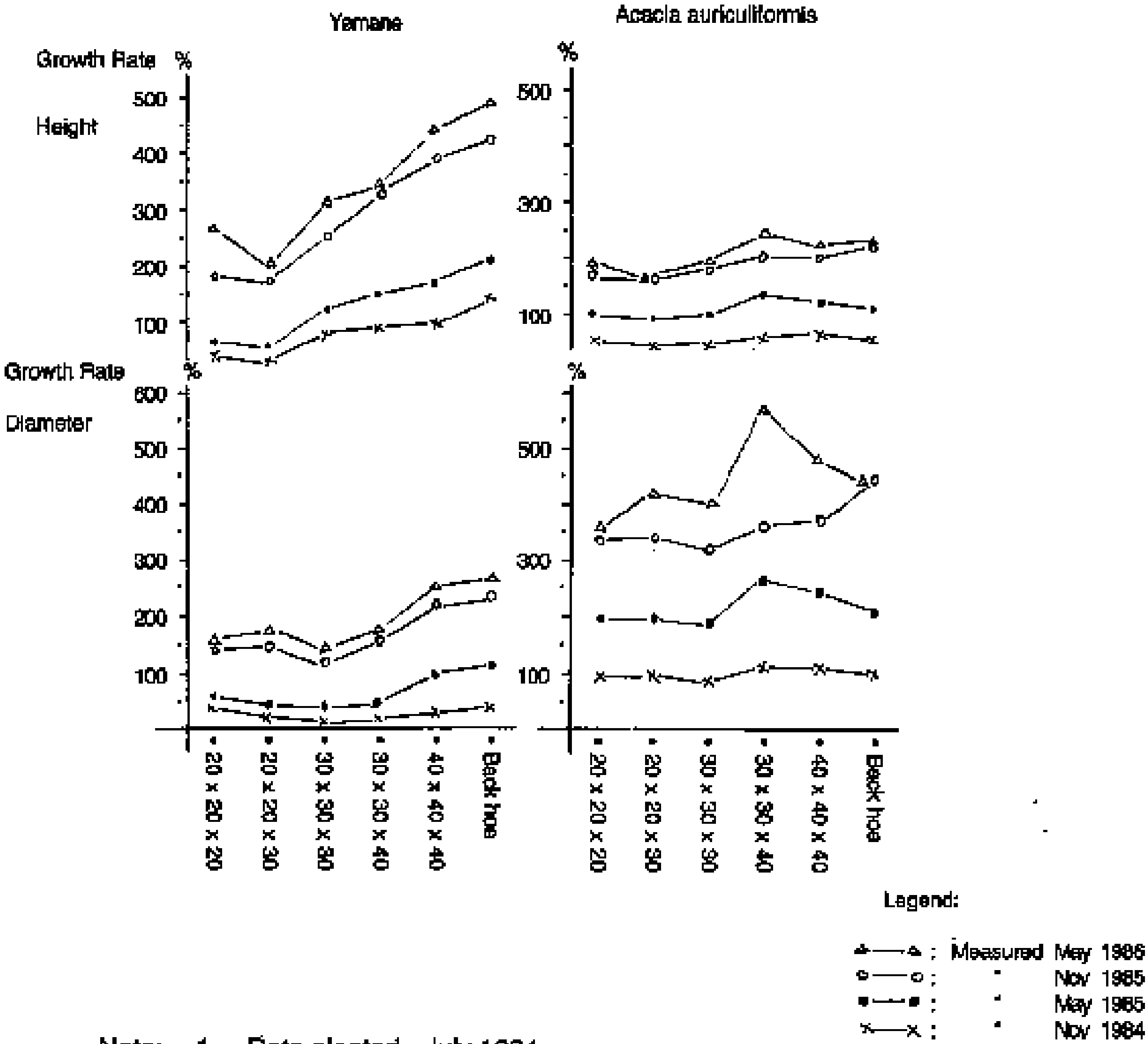
(2) Planting hole

A big planting hole is usually good for early growth because it improves physical properties of soil i.e. aeration and drainage around seedlings, especially on clayer and hard soil on the site with hardpan at shallow layer, deep holing which breaks the pan is very effective.

Figure 9 shows such condition of site in which dry season continues 5-6 months in the Philippines.

However, on sandy site like Kinarut, the physical condition of soil is not so bad that big holing is not so effective especially for *Acacia* species such as *A. mangium* and *A. auriculiformis* compared with its cost.

Figure 9: Influence of Hole Size on Growth Rate (Philippine-JICA project report, 1987).



Note: 1. Date planted - July 1984
2. Growth rate is a ratio to August 1984
3. Diameter is at root collar.

(3) Manuring

Historically, fertilizer use in forestry has been much less important than agriculture because slow growth and long rotations resulted in little not nutrient loss from the ecosystem. While with increasing emphasis on plantation forestry, this situation is now changing. In plantation, tree growth is rapid and therefore nutrient demands are high. With short rotation crops on poor soils nutrient depletion is a real possibility, especially in the moist tropics.

There are four stages in the life of a stand for fertilizer application as below, and fertilizing at planting time is the most important practice because it is the first stage in plantation (within a few months to a few years after planting) when deficiencies of nutrient mostly develop).

a. At establishment : within 3 months of planting
b. Post - establishment phase : up to canopy closure
c. Pole-stage : during early thinnings to boost thinning
d. Pre-felling : 3-10 years before felling.

Elements needed in large quantities, called macronutrient, are nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S). Elements needed in trace amount, micronutrients, are iron (Fe), copper (Cu), chlorine (Cl), manganese (Mn), etc.

For fast-growing broadleaved species, pines and generally in drier tropics, phosphorus is the element most often limiting growth. The levels of one nutrient can affect the requirement for others, notably with N and P, and P and K.

In Sabah, phosphate application at planting is a standard practice for *Acacia mangium* and *Gmelina arborea* plantations. These are some research results in SAFODA plantations as follows:

a. There was no significant difference in tree height and tree diameter among the Rock Phosphate Treatment (50, 100 and 150 gm/tree P_2O_5) and control (Rock Phosphate + NPK Blue) for *Acacia mangium* at Tanjung Piring, Bengkoka (Li, 1991).

b. o There is a very marked response to P and an additional response to N when applied along with the P.

   o Application of Triple Super Phosphate (TSP) may have an advantage over the rock phosphate for *Acacia mangium* at Kandang 7, Bengkoka (Nissanto and Francis, 1991).

c. There was no response of tree growth to rock phosphate (CIRP) and no significant differences with no treatment for *Acacia mangium* at Kinarut (Yamashita, 1994).

Mead and Miller recommended TSP fertilizing in place of rock phosphate, the response to which is small because of its placement and low solubility.

(4) Weeding

Control of competing weeds is an important activity of plantation establishment. All plantations require the same weeding during the first few years until the trees are growing well and approaching canopy closure and are adequate size to suppress competing weeds. Weed can damage young trees directly, compete for light, soil-moisture, and nutrients. For example, the survival rate of *Pinus kesiya* trees at age 8 months after planting at dense grassland without weeding, was 10-20%, while was 80-100% at no grass site with weeding (Evans, 1992).

There are three main alternatives: manual, mechanical and chemical weed control, and three levels of coverage on a site: complete, line, and circle weedings. Intensity of weed control such as frequency, period, timing and extent will be decided according to species initial spacing, site and climate. Complete slashing is essential for good early growth of most *Eucalyptus*. Spot weeding is less effective than strip weeding, with clean weeding the best of all for *Eucalyptus camaldulensis* (Evans, 1992). Many more weedings are needed in wet site than dry site. For slower growing *Araucaria* species are sometimes necessary for 6 to 8 years and for tropical pine, the period is typically 1-3 years. With pines, control of grass becomes essential only when it grows more than 50% taller than the tree.

Generally, weeding should begin when the grass grows more than 50-70% taller than the tree and ended when the trees are approaching canopy closure or growing 1.5 to 2.0 times taller than the weed.

(5) `Silviculture working scheme

Silviculture working scheme at early stage of plantation should be made based on the consideration of the right time of activities and allocation of the labour force. Table 16 shows the silviculture working scheme for *Acacia mangium* plantation in Kinarut project site. Planting on the right time is the most important part in this scheme. This should be made based on the consideration of climate (rainfall; see Figure 6-(c)).

Planting is possible in rainy season from May to December, but for better utilization of labourers for both nursery and silviculture works, the best planting times are mainly in early rainy season (May - June) and during monsoon season (September - November) where rainfall is abundant. This activity has to be completed until before 1 month the dry season starts (middle of December) for preventing dead of seedlings.

Table 15: Silviculture working scheme for *Acacia mangium* in Kinarut (Yamashita, S. 1992)

Month																							
12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11
LC	LC	FBC	FBC CB	RB, L	P	P			W (1)	W (1)	MLP					W (2)	W (2)						
										RP													
				LC	LC	LC	FBC	CB	RB, L P	P			W (1)	W (1)	MLP		RP			W (2)	W (2)		

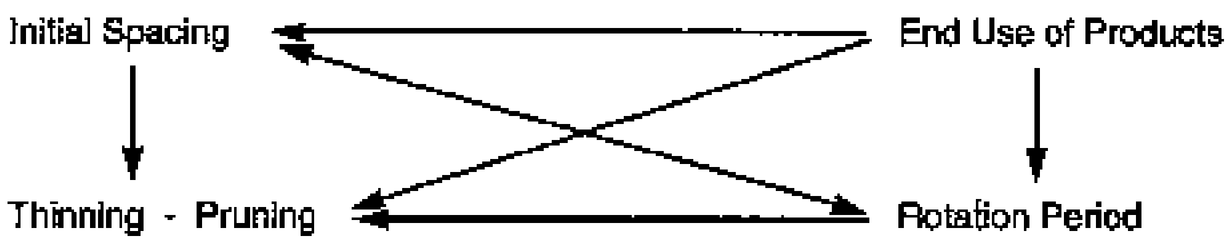
Note; LC - Land clearing
CB - Control burning
P - Planting
RP - Replanting
W(1) - Weeding (1)
W(2) - Weeding (2)
FBC - Fire break construction
RB, L - Reburning, lining
MLP - Multiple leader pruning

3-2 Intentional operation

(1) Initial spacing

Initial spacing is one of the most important silvicultural decision. It is closely related with the objective of plantation (see Figure 10).

Figure 10: Relation between initial spacing and other decisions.



Spacing affects plantation yield, tree sizes and growing costs and revenues (see Table 17). Very close spacings are extremely expensive and very wide ones grossly underuse a site.

Table 17: Effect of initial spacing on yield of *Acacia mangium* at 4.75 years old in Kinarut.

Initial spacing (m)	Stand density (stem/ha)	Survival rate (%)	Mean T.H (m)	Mean DBH (cm)	Volume V(total) m³/ha	Volume V10/V (%)
1.1 x 1.1	8,260	71	14.5	9.1	298.7	52
1.5 x 1.5	4,440	76	16.7	11.1	180.3	82
2.1 x 2.1	2,270	81	14.7	12.1	148.3	88
3.0 x 3.0	1,110	85	14.9	12.9	86.0	97
4.2 x 4.2	567	90	15.4	15.0	62.0	97

Note: V10 = Volume of more than 10cm (DBH): merchantable volume

Wider spacing can produce trees of larger diameter which are useful for saw log production. However, wider spacing has some disadvantages for timber production: tapered shape of the stem, short clear stem length, thick branches, large and many knots. Wider spacing requires pruning to improve these disadvantages. On the other hand, closer spacing has some advantages for timber production: completed shape of the stem, long clear stem length, slender branches, small and few knots. Closer spacing requires frequent thinning to stimulate diameter growth (see Table 18).

Table 18: General comparison between wide spacing and close spacing. (Taoda 1987, modified)

Item	Wide	Close
Planting cost	Low	High
Weeding cost	Low per one time but repeated, many times in a long period.	High per one time but required, only a few times in a period.
Thinning cost	Low	High
Stand volume		
1. Before closure	Small	Large
	(Volume increases as density increases)	
2. After commencement of closure	Small	Large
	(Volume does not increase in proportion to rise in stand density)	
3. Full closure	Same	Same
Mean DBH	Large	Small
Shape of the stem	Tapered	Nearly completed
Clear stem length	Short	Long
Branch	Thick	Slender
Size of knots in wood	Large	Small
Number of knots	Many knots, even away from the trunk centre	Knots decrease sharply away from the trunk centre
Knot-free wood production rate	Low	High

Evans (1982) recommends the approximate order of spacings for different kinds of crops below:

Firewood - maximize yield, short-rotations, no small size limit, but large timber difficult to handle --- 1m - 2m

Pulpwood - maximize yield, short-rotations (5-15 years), typical size limits 10-40cm diameter log --- 2m - 3m

Sawntimber and veneer - Large log size over 30cm in diameter, long rotations and regular thinning, loss in total volume compensate by high value of wood --- 2.5m - 4.5m

The decision of initial spacing must be based on research data and economic consideration. It is important that yield or economy per one unit (i.e. ha) is considered when profits and losses are estimated.

Acacia mangium was planted at the spacing of 3m x 3m (1,111 stems/ha) for pulplog production in Sabah. However main agencies in Sabah changed it based on their own research result as follows (Hongo, 1990; Lee and Anuar, 1992):

SSSB	2.44m x 2.44m	1,680 stems/ha
S.F.I	2.5m x 2.5m	1,600 stems/ha
SAFODA	2m x 4m	1,250 stems/ha

On the other hand, SAFODA-JICA project result in their final report (Yamashita, 1994) showed that the suitable initial spacing for pulplog production in Kinarut is 1,600-2,200 stems/ha which is more closer spacing than that of SAFODA adopting.

(2) Density Effect and Stand Density Control Diagram

See Appendix 2 "LAW OF DENSITY EFFECT AND STAND DENSITY CONTROL DIAGRAM".

(3) Thinning

High quality timber like sawn timber cannot be produced without proper maintenance such as thinning to improve the final crop. Suitable tree form for sawn timber production is as follows:

(a) Long clear stem and small and scarce knot.

(b) Small difference in stem diameter between upper point and lower point.

(c) Large diameter stem.

(d) Straight and round stem.

(a) and (b) can be achieved by closure of canopy with quite high stand density, while (c) should be achieved by low density. Therefore to meet (a), (b) and (c), it is necessary that thinning should be done for close spacing stands after canopy closure, (d) is achieved by tree improvement only.

The aim of thinning is not only to stimulate the growth in diameter by reducing the stand density (see Fig. 11) but also to reduce the number of dead, dying, diseased and poor form trees. The size of timber is standardized for a certain use and the price of a log is decided on the size of timber which can be gotten from the log. Figure 12 shows the effect of thinning in critical sense.

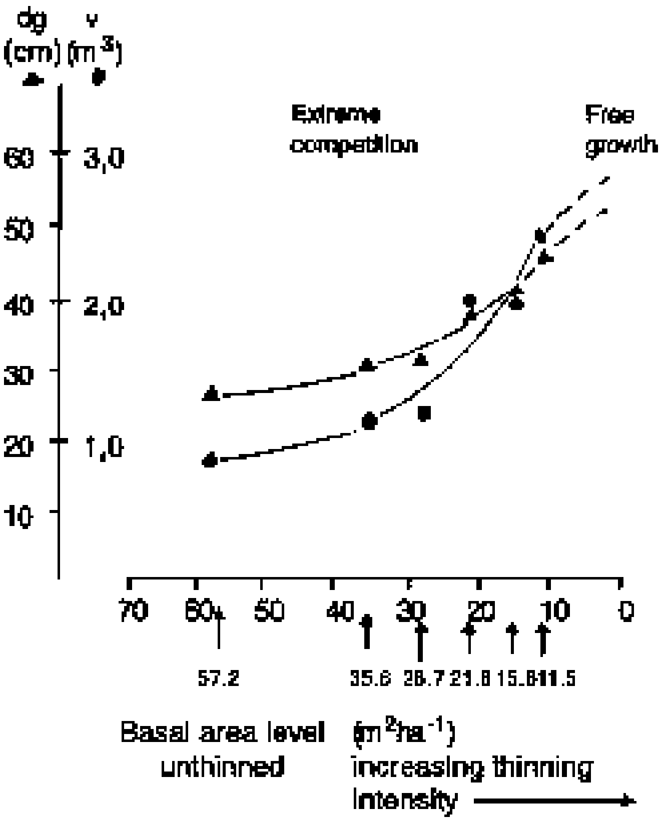


Fig. 11: The relationship between average tree size (mean diameter, dg; mean volume, V) and intensity of thinning in *Araucaria cunninghamii* (Evans, 1982)

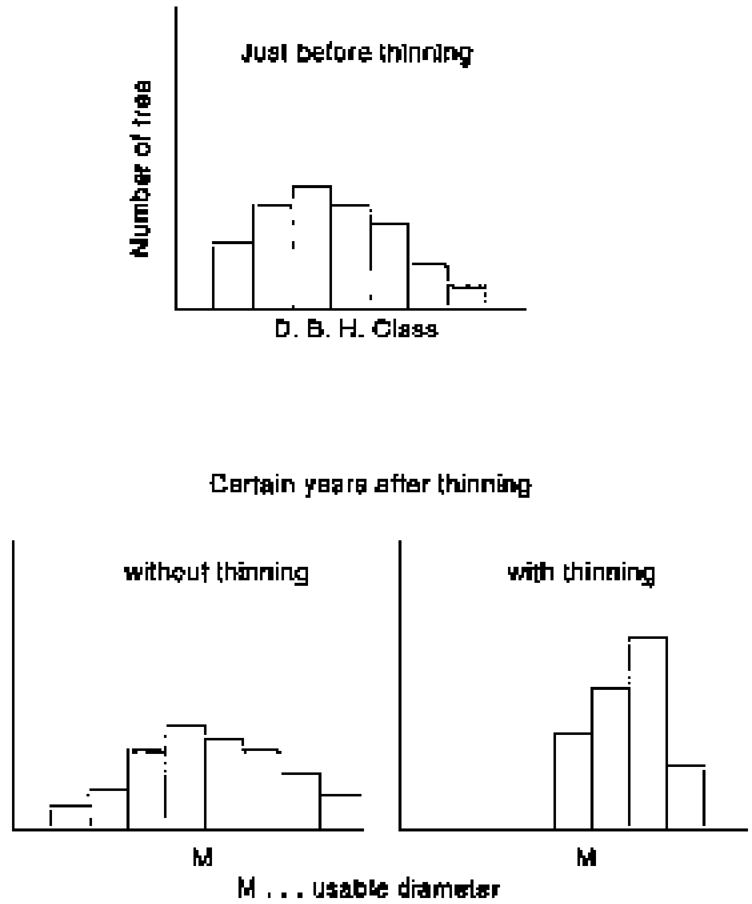
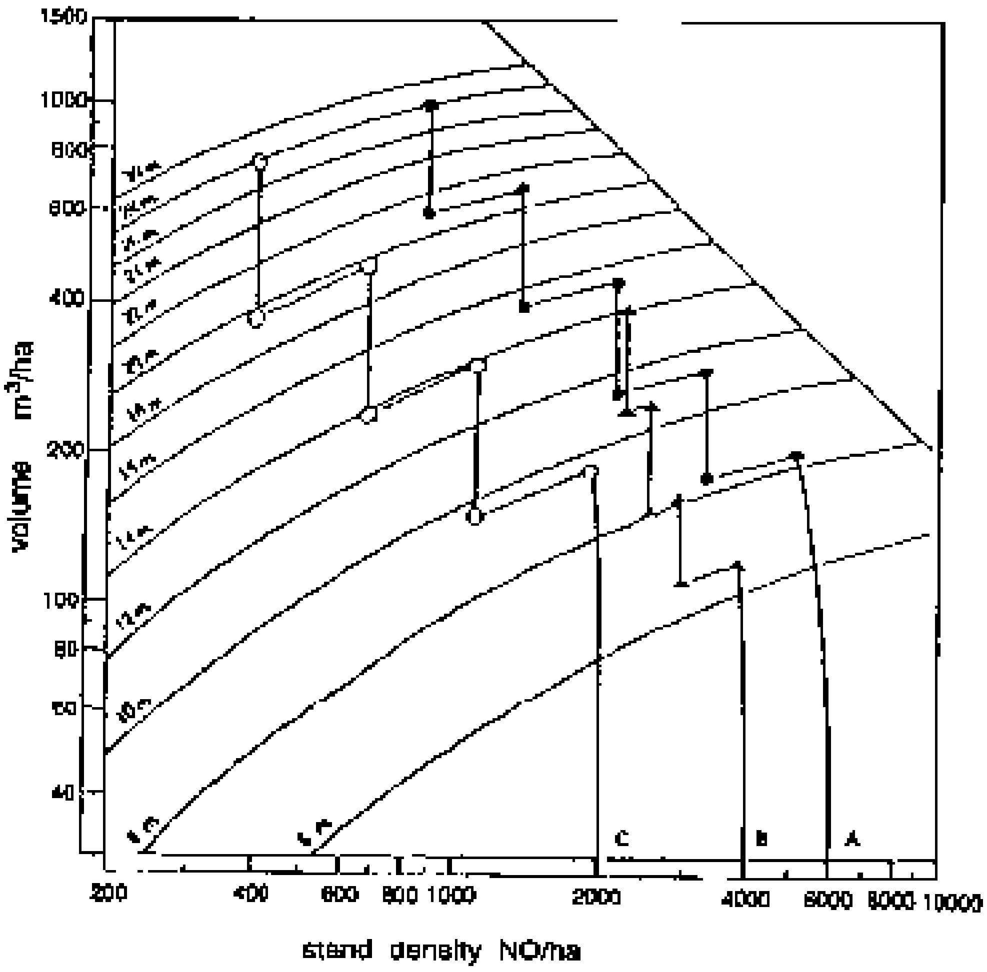


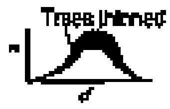
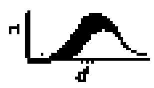
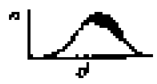
Figure 12. Diagram showing the effect of thinning.

Figure 13. Thinning model by using density control diagram.



There are several ways of doing a thinning, but two main categories are recognized. One is mechanical or line thinning. Removal of every third row of trees is an example. This method may be applied to mechanized afforestation. Another is selective thinning. Trees are thinned or left depending on the subjective judgement of the person making the thinning. Above-mentioned thinning regime belongs to this category. There are two main methods in this category; Low thinning and Crown thinning. Table 19 shows immediate effects of these thinning method.

Table 19 Immediate effects of thinning method on stand parameters (Evans, 1992)

Method	Description	Mean stand height (h)	Diameter Mean (dg)	Distribution	V_t/V_r
Systematic	Systematic removal of trees favouring no kinds	Unchanged	Unchanged		1.0
Selective low	Mostly removal of smaller trees	Increased	Increased		0.6 - 1.0
crown	Selected trees favoured by removing competing dominants + co-dominants	Decreased	Decreased		1.0-1.2 (1.2 is an extreme tending to a 'selection' thinning)

V_t = average volume of trees thinned out; V_r = average volume of trees remaining after thinning; n = number of trees; d = diameter.

Thinning may have some negative effect.

a. **Increase in taper**
This tends to reduce slightly the percentage utilization of log.

b. Increase in coarseness of branches and knot size
However these two are avoidable by good association with pruning.

c. More rapid diameter growth
This may lead to slightly less dense wood and the amount of juvenile wood may increase. The important aim in growing timber is steadiness in growth. This is produced by regular, moderate thinnings. Infrequent, very heavy thinnings lead to greater variation in wood properties.

Thinning regime is decided on initial spacing, final spacing and frequency (affected by labour cost) as shown in figure 13 (page 30). The final spacing must be estimated by estimating tree growth. The timing of thinning should be decided on stand density (Yield Index) or basal area (limiting basal area), live crown ration, volume, height etc., not on age. The intensity of thinning should be indicated on stand density, basal area, volume, etc. These factors become available after research activities. However, at present time, research is not enough to decide thinning regime.

There are two temporary regimes recommended by SAFODA-JICA project to be applied to sawn timber production for *Acacia mangium* as below:

a) Tentative schedule in a productive site like Lumat (Hongo, 1990).

1. First thinning .... Stand basal area is more than 18m²/ha. (Stand volume is more (one out of three) than 100 m³/ha, around 4 years old).

2. Second thinning ..... Stand basal area is more than 27m²/ha. (Stand volume 200 m³/ (one out of two) ha, around 8 - 9 years old).

3. The results of final crop

i) DBH : 30cm
ii) Harvest year : 15 years old
iii) Stand Density : 460 trees/ha
iv) Total Stem Volume : 280m³/ha

b) Large size sawn timber production procedure in the place of high land productivity (Yamashita, 1994).

i)	Mean DBH	:	40 + cm (2.7 - 3.1cm of MAI)
ii)	Harvest year	:	13 - 15 years old
iii)	Stand Density at harvesting time	:	about 280 stem/ha
iv)	Volume	:	250 + m³/ha

The procedure is shown in Table 20.

Table 20: Thinning and Pruning schedules for sawlog production.

Age month (year)	Mean Tree height (m)	Mean DBH (cm)	Stand Density (stems/ha)	OPERATION	
				Activities	REMARKS
0	-	-	980	Planting spacing 3.2m x 3.2m.	
12 (1)	5	5	900	Improvement cutting	bad form tree during pruning activity.
				Pruning (1st)	density: 35 - 40% of tree height.
24 (2)	10	9.5	450	Thinning	waste.
				Pruning (2nd)	density: 40-50% of tree height.
36 (3)	14	13.5	-	Pruning (3rd)	density: 40-50% or up to 6m.
48 (4)	17	17.5	300	Thinning	commercial.
				Pruning (4th)	up to 6m if not completed at 3rd pruning.
(13 - 15)	28	40 over	(280)	Clear harvesting	

(4) **Pruning**

The main aim of pruning is to produce high quality logs for sawntimber and veneer with knot-free wood (Fig. 14). No pruning is required for the production of fuel wood or pulpwood. When the timber is of high enough quality to bring in a reasonable income, pruning is profitable.

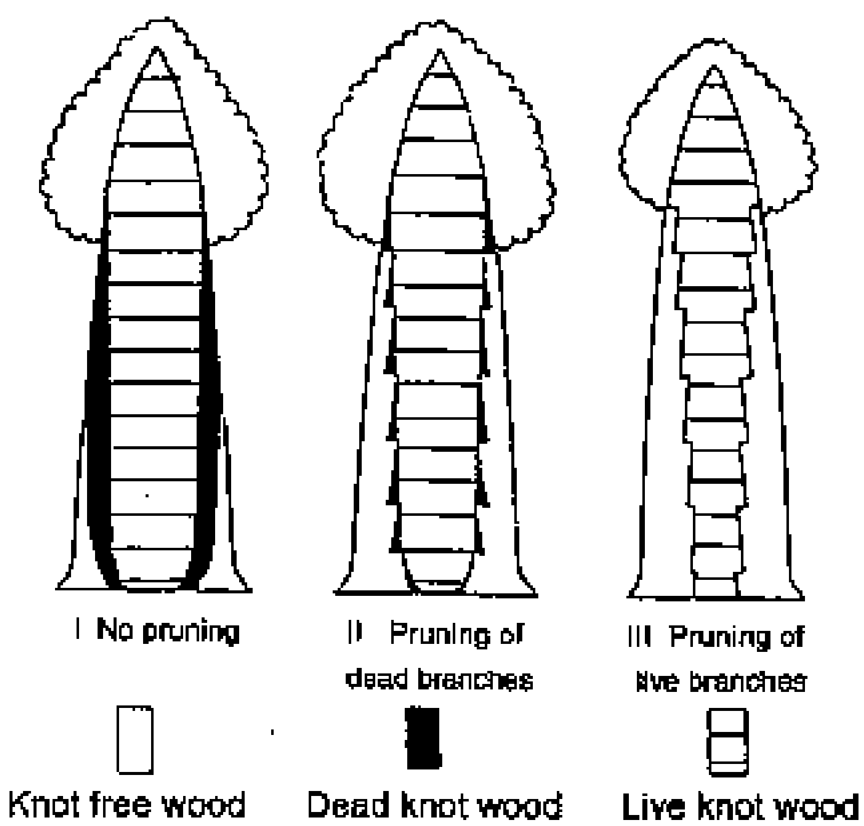


Fig. 14 Model figures of the distribution of knots in a stem on the basis of several data (Fujimori 1975, modified)

Pruning practice brings mainly two results. One is to improve the trunk form as shown in Fig. 15. Another is to hide dead knots in the wood, and to produce knot-free timber as shown in Fig. 16. Diameter growth of 10 - 20mm is normally required to hide the pruning scars. In addition, pruning prevents wood from insect damage by removing dead branches, and increases sunlight in the forest, introducing undergrowth on the forest floor.

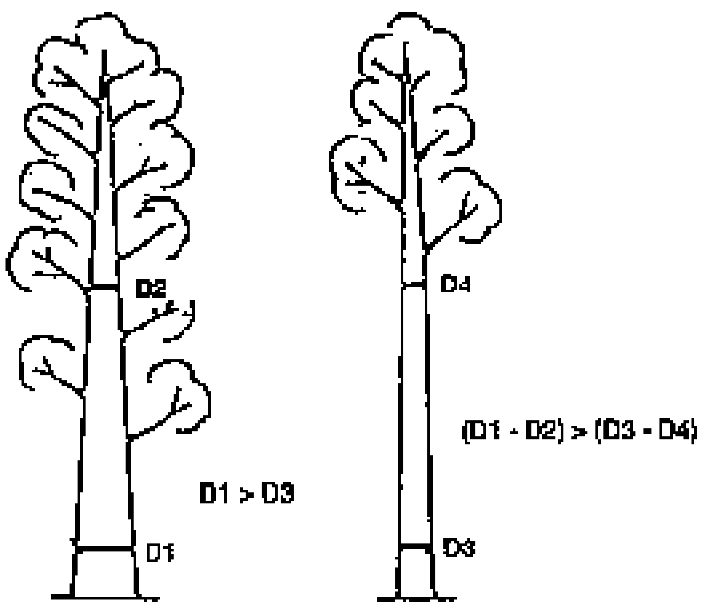


Fig. 15 Effect of pruning on the form of the stem.
(Taoda 1987)

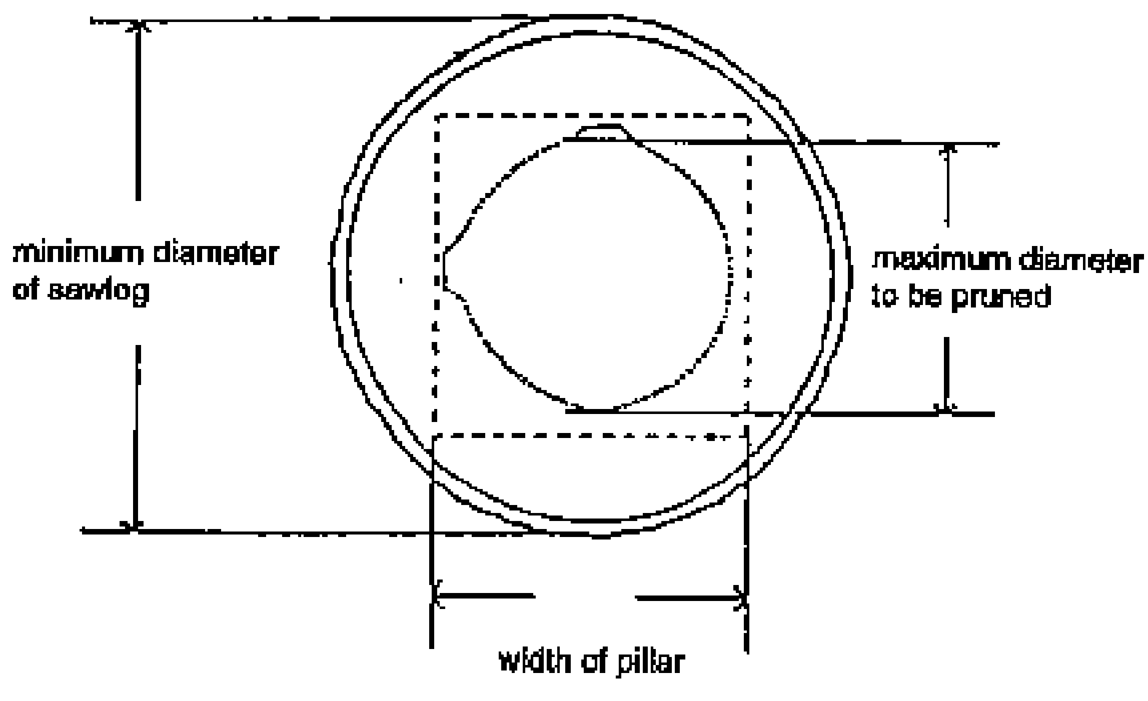


Fig. 16 Diagram showing the maximum size of the stem to be pruned to obtain a knot-free pillar
(Taoda 1987)

The timing of pruning is dependent on diameter which is closely related to the size of sawntimber. Fig. 16 sets out the principle for deciding the timing of pruning to hide knots in the sawn timber (pillor).

It is important to decide pruning intensity, because intensive pruning suppresses tree growth. Pruning intensity can be expressed as the ratio of pruned stem length to crown length (Fig. 17). The leaves of the lower part of the crown do not have much productivity when the canopy is closed. If only the lower branches are pruned, it does not slow tree growth very much. The limit of pruning intensity that does not slow tree growth should be made clear by research. Fig. 18 shows an example of pruning in a Japanese red wood (Japanese cedar) and a Japanese cypress plantation. In general, the diameter growth is suppressed more than height growth.

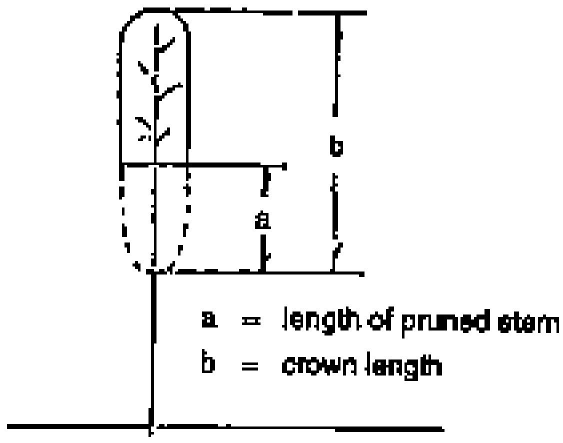


Fig. 17 Length of pruned stem and crown length

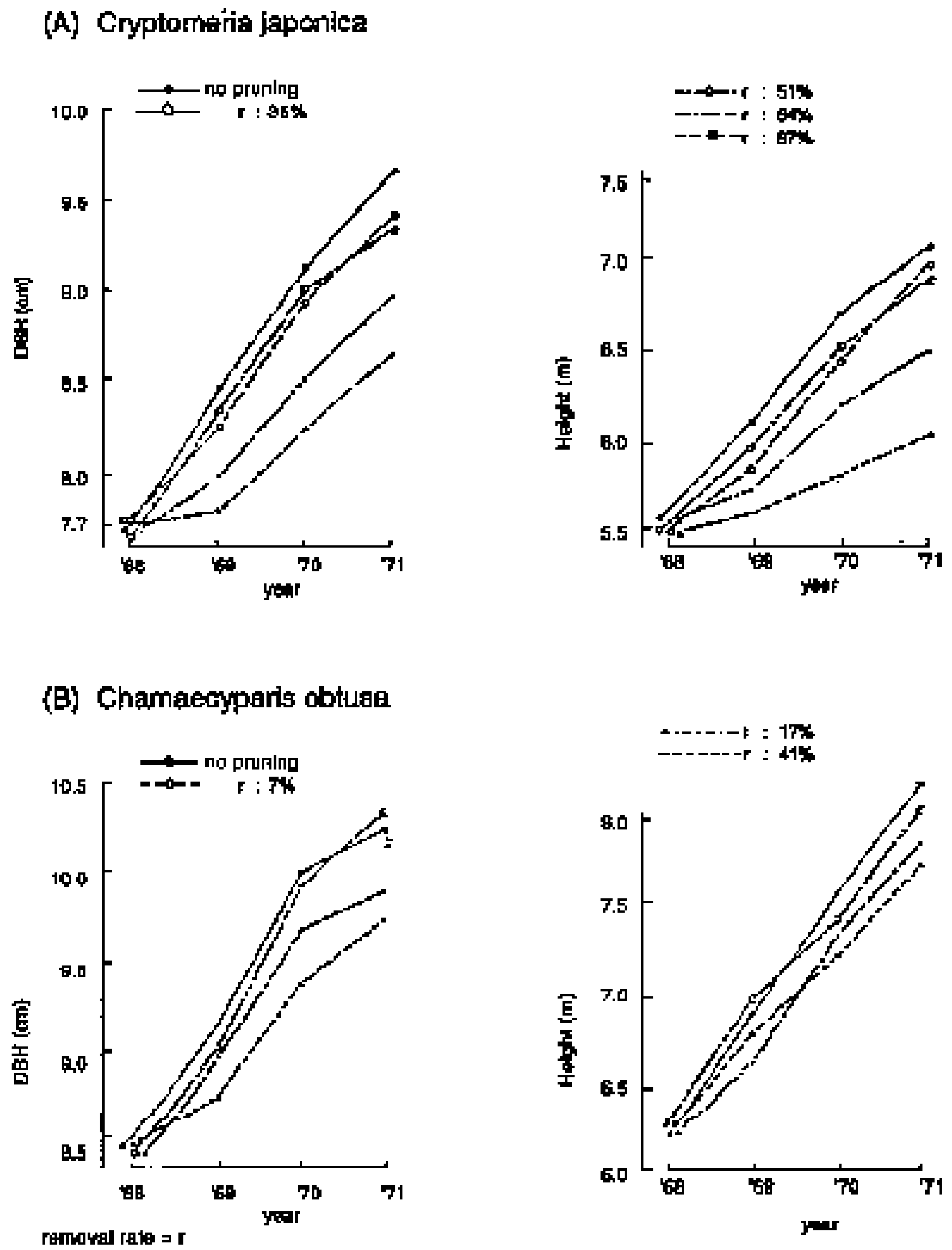


Fig. 18 Tree growth after different pruning intensities (removal rate of leaf) (Fujimori 1984, modified)

In practice, it is difficult to instruct pruning workers in pruning intensity. In addition, difference of growth between individual trees will become greater and greater if all trees are pruned at the same intensity. Therefore, pruning length should be controlled by stem diameter. For example, if all branches growing from the section of the stem measuring 6cm in diameter and more are pruned, then the length of the remaining crowns will be the same.

The following pruning regime may be applied to the above-mentioned thinning regime.

1. Dead and suppressed branch pruning should be done in young plantations (1-2 years old or more) if necessary.

2. Live branch pruning (green pruning) should not start until maximum DBH reaches 7cm (Mean DBH is probably about 5 - 6 cm).

3. All branches where the stem diameter is more than 6cm must be pruned.

4. Next pruning should be done when the biggest diameter of the stem at the lowest branches reaches 9cm.

5. Pruning should be continued until the branch-free trunk is 6m long.

For plywood production, pruning must be done on smaller trees to enclose knots within the area less than about 3cm from the stem center.

The effect of depressing growth temporarily by green pruning becomes extremely important if only selected trees are pruned. If these trees are not free from competition with unpruned tree, the slowing in growth due to green pruning may result in they being overtopped and losing their dominance. Therefore, selective pruning must be done in association with thinning so that the pruned trees are favoured. Table 20 (Page 33) shows the example of it.

3-3 Harvesting and Regeneration

(1) Rotation Length

For how long is the crop to grow? The rotation is the planned number of years between planting and felling (Evans, 1992). Rotation length is an important tool for controlling tree size. The foresters identify several different kinds of rotation and the main of these are as follows:

a) Technical rotation

This is the rotation planned to yield the most outturn of a specified size and type to satisfy a particular end-use. Some examples are, *Araucaria* plantation in P.N.G. is adopted 40 years rotation to produce 60cm or more DBH final crop, high quality teak in India for typically 70 years, the highly prized pole product from *Eucalyptus* plantations are cut from densely stocked plantations/copplces on 3-6 years rotations of specified upper limits of size, and *Eucalyptus tereticornis* must be adopted a rotation at least 9 years to maintain satisfactory pulp quality.

b) Rotation of maximum volume production

This is the rotation that yields the greatest average annual outturn of timber. This rotation is completed when the annual growth increment of the stand falls to level of the overall mean annual increment (see Figure 19). Once the current annual increment (CAI) falls below mean annual increment (MAI) the MAI itself will begin to fall gradually. Therefore, the point of intersection between the CAI and MAI curves must also be the peak MAI will reach; this is the rotation of maximum volume production if the stand is felled at this point (R1).

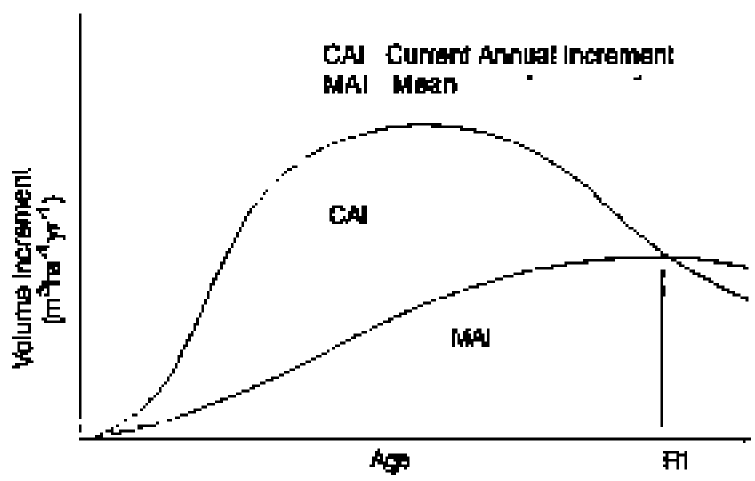


Fig. 19 Generalized relationship between current annual volume increment and mean annual volume increment with age. Rotation of maximum volume production is indicated (R1) (Evans 1992, modified)

However, in the tropics the maximum MAI is achieved on 10-15 year rotations or sometimes even less (see Table 21). Consequently many tropical plantations are grown for longer than the rotation of maximum MAI usually for technical reasons to achieve the size of material required. For *Acacia mangium* as a pulplog production in Sabah, this rotation of maximum MAI production is mainly adopted.

Table 21: Rotations of maximum volume production for plantations (Evans, 1992)

Species	Where grown	Rotation (years)	Notes
Pinus caribaea var. *hondurensis*	Queensland, Australia	26 - 33	Thinned to limiting basal area of $30m^2 ha^{-1}$
Pinus patula	Swaziland	14 - 17	Unthinned, planted at 2.74m spacing
Araucaria cunninghamii	Papua New Guinea	18 - 22	From plot data used for Figs 15.5 and 15.6
Eucalyptus deglupta	Papua New Guinea	2 - 8	Determined by initial spacing
Paraserianthes falcataria	Philippines	2 - 3	Revilla (1974)
Eucalyptus tereticornis	India	6 - 11	Sharma (1979), Kondes (1982). Culminates earlier for first coppice crop
Tectona grandis	Central America	10 - 22	Keogh (1980b)
Eucalyptus globulus	Peru	18 - 19	Rivadeneyra and Cabrejo (1980)
Gmelina arborea	Nigeria	7 - 8	Akachuku (1981)
Acacia mangium	SAFODA	7 - 11	Inose (1991)

(2) Harvesting

Harvesting is the end operation of plantation establishment. However, after harvesting the first rotation crop, establishment of the next crop must be carried out. Harvesting methods effect the regeneration operation. So harvesting must be carried out so as not to obstruct the regeneration of the plantation.

Harvesting should be done in a way which minimizes damage to the site and does not prolong the period the soil is exposed. Damage to the site may arise from:-

a. soil compaction
b. waterlogging
c. oil spillage
d. stream/drain blockage
e. scouring of soil surface and erosion.

The method of extraction is the most important factor effecting damage. Skidding or dragging logs by rubber-tyred or tracked vehicles causes the severest damage.

Rough harvesting methods must be avoided even though they reduce extraction costs, since they increase the cost of establishing the second rotation.

Harvesting is normally done by outsiders, and not by plantation workers. As outsiders never consider the future task of regeneration, plantation staff must supervise them strictly and, if necessary, an agreement on the extraction method must be made with the extraction company.

(3) Replanting

Site conditions for the second rotation will be radically different from those that existed when afforestation began.

a. The replanting site will be relatively weed free.
b. The site will be covered with stumps.
c. There may be prodigious natural regeneration of the former species or viable seeds on the ground awaiting the opportunity to germinate.
d. On infertile soil-less sites or man-made ground, one rotation of trees will have initiated the development of a soil structure and rendered it more amendable to tree growth.

These factors may lead to different silvicultural practices or different species choice from the first rotation. Certain species cannot grow after their first rotation (allelopathy).

Vegetation clearance is usually not needed. Burning must be avoided so as to maintain good soil condition for replanting. Weed control may be easier, but there are two problems. One is unwanted natural regeneration and the other is vigorous coppice regrowth of the first crop species. If the same species (variety or provenance) is replanted, these regenerated trees should be tended as long as they do not cause trouble. Otherwise, they should be removed.

(4) Natural Regeneration

Natural regeneration by seeding or coppice is profitable, because no nursery and no planting operations are needed.

In the case of *Acacia mangium*, we (SAFODA-JICA project) are optimistic that natural seeding regeneration is viable. Fire stimulates the germination of viable *Acacia mangium* seeds under the ground. Some natural regeneration stands can be seed on sites destructed by fire or shifting cultivation. Natural seeding regeneration can establish dense forest which produces *Acacia mangium* trees with good form, straight and complete stems, and small branches. Intensive research on this subject must be done for the next rotation, concerning seed distribution, conditions of germination, necessary operations, density control, etc.

The procedure for natural regeneration establishment was recommended by SAFODA-JICA project (Yamashita, 1994) as follows:

Work procedure for natural regeneration establishment.

a) First Improvement Cutting (I.C.) : 1.5 m upper story seedlings height.
: 6 - 11 months after control burning.

i) Decide the stand density (S.D.) of 2nd I.C. : 1000 - 2500 trees/ha

Example (A)	Example (B)
1600 trees/ha -> 2.5 x 2.5m square spacing	1200 trees/ha -> 2.9 x 2.9m spacing

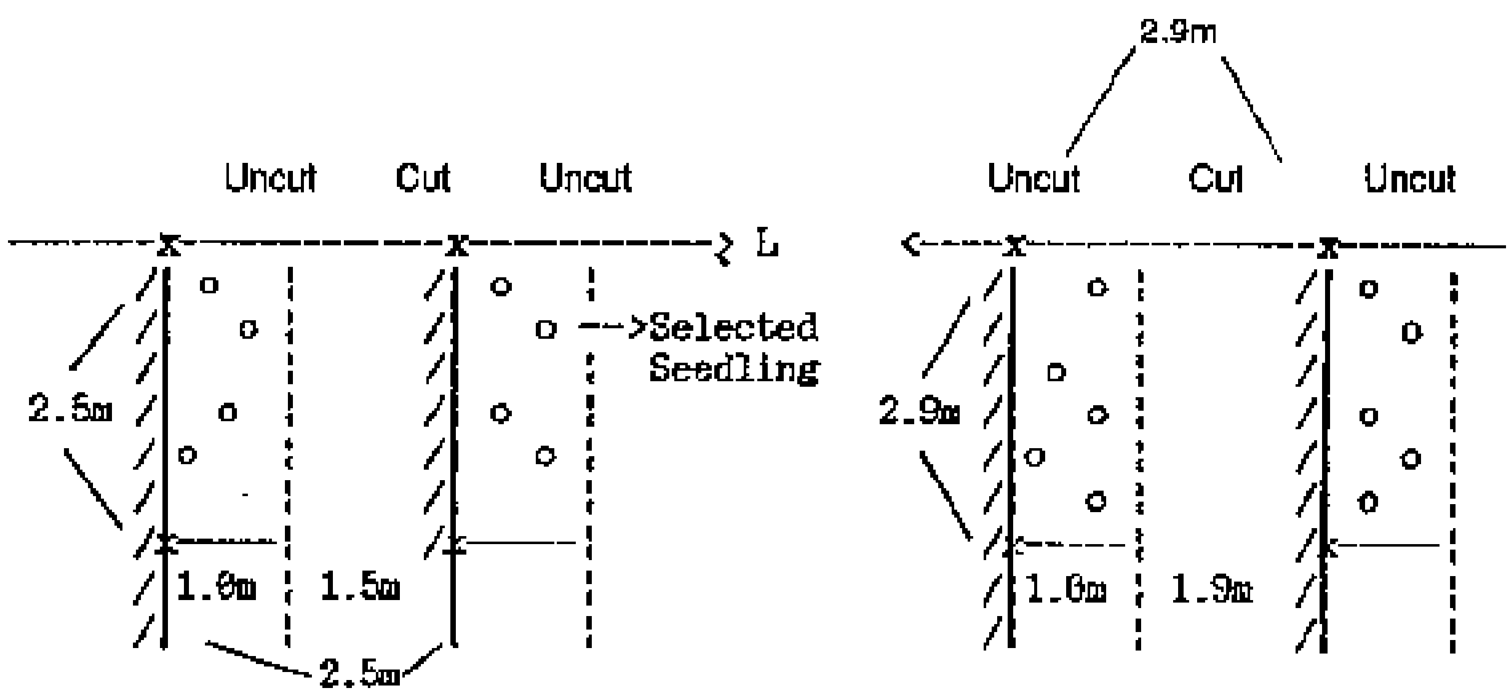
ii) Strip cutting

2.5m spacing -> { Uncut 1.0m { Cut 1.5	2.9m spacing { Uncut 1.0m { Cut 1.9

iii) Decide the S.D. of 1st I.C. : 5000-8000 trees/ha

1600 x 4 times = 6400 trees/ha   1200 x 5 times = 6000 trees/ha

iv) Lining and 1st I.C.



- Set up certain line (L) and mark certain spacing distance (e.g. 2.5m or 2.9m).

- Right-angled line (solid line on the art) should be set parallelly and mark spacing distance like normal lining in planting method. At that time ▨ part will be cut along the uncut band.

- The other side of uncut band should be cut to keep one meter uncut band by eye measurement.

- Certain number of seedlings to be left, should be selected from the certain square in the uncut band.

  e.g. (A) 4 trees in the 1.0 x 2.5m square,
  (B) 5 trees in the 1.0 x 2.9m square.

- These trees should be taller and vigorous.

- Full slashing should be done in all areas except selected seedlings.

b) Second I.C. : Tree height of seedlings 3.0 - 4.0m
7 - 12 months after 1st I.C.

i) Select trees to be left : One out of certain number
(e.g.: (A) 1 out of 4
(B) 1 out of 5)

ii) Selected tree should be
- largest and vigorous in the group
- direct bole and no forking.

iii) Slashing is needed at the same time inorder to cut sprouted and new regenerated trees.

c) Activities after 2nd I.C.

Basically the activities are no differences with normal planting method after 2nd I.C.

i) For pulplog production -

No activity is needed until harvesting except when it is necessary.

ii) For large bole production like sawn timber -

Improvement thinning should be needed in few years.

Expectation for coppice regeneration are optimistic in many tropical broadleaved species in some genera such as *Acacia, Albizzia, Cassia, Leucaena, Eugenia, Eucalyptus, Gmelina* and *Tectona.* However, even in these genera not all species coppice well, for example, *Acacia mangium* and *Eucalyptus deglupta* have poor coppicing ability. Weeding costs of coppice stands can be reduced because the initial growth of coppice is usually rapid, though the overall performance of coppice stands are not usually very different from planted stands. However, there is a problem concerning the quality of their wood. Wood-rot sometimes occurs in a stem near the ground, because wood-rot fungi can easily enter wood from an old stump. In addition, stem form is also unfavourable. The trunks are apt to be bent because two or three coppice shoots are usually still left after thinning. Coppice regeneration is useful for fuelwood or pulpwood production. The yield from the first coppice crop is higher or not very different from the seedling crop, but thereafter declines with each coppicing after the first.

Direct sowing is also an economical establishment method. It might be possible in the case of an *Acacia mangium* plantation on a vegetation-free site. However this method has a few difficulties. It needs much more seeds than the planting method. Seedlings established by direct sowing have to compete with vegetation at a very young stage. Therefore, weed control is costly except for completely vegetation-free sites. Furthermore, there is a danger of soil erosion because it requires the removal of litter layer on the ground surface for rootage.

4. Conclusion.

It is most important in establishment of plantation that silvicultural decisions and operations should be done suitably for the purpose of plantation and end use of products. Simultaneously foresters must take their effort to reduce the establishment cost.

5. Note.

Many expressions are copied from "PLANTATION FORESTRY IN THE TROPICS" (EVANS 1982 and 1992) in this textbook.

This text book was first manuscripted by Mr. Koji Hongo (Silviculture expert of this project) in 1988. And this time, revised edition was published by Takachika Yamashita (Present silviculture expert). The whole sentences written by Yamashita, were grammatically checked and some were revised to suitable ones by Ephraim E. Laujang (Counterpart).

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Properties of Plantation species in Sabah

(1) *Acacia mangium*

a. Natural occurence

*Mollucus - New Guinea - Queensland

*Latitude 1°S - 18°S (mainly 8°S - 18°S)

*Altitude 0m - 800m (mainly 0m - 300m)

b. Climate at natural occurence area

*Mean maximum temperature of the hottest month : 31°C - 34°C

*Mean minimum temperature of the coolest month : 15°C - 22°C

*Forest-free

*Mean annual rainfall : 1500mm - 3000mm

*Mean rainfall of the driest month: above 40mm

c. Soil at natural occurence area

*Acid and infertile soil

*Volcanic formations and sandy or loamy alluvium soil

*Shallow sandy loam overlying a heavy clay

*Moderate - well drained (sometimes imperfectly drained) soil

d. Other matters at natural occurence

*This species grows on the margins of closed-forest, in open-forest, in woodland disturbed by fire and on the bank of a river.

*This species dominates in small stands on disturbed site.

e. Silvicultural feature

*Height: 30m DBH: usually below 60cm

*Straight trunk (but not cylindrical trunk near ground)

*Flowering and seeding start at 2-3 years old at plantation and this species seeds very much every year.

*It takes 3-4 months to produce a seedling for planting.

*It grows on acidic soil, especially can grow with pH.4, but cannot grow on alkaline soil.

*It can grow on infertile soil. It is nitrogen-fixing species.

*It is tolerent of competition with grass.

*It can grow on poor drained site.

*Adopted initial spacing: 3m x 3m, 2.5m x 2.5m, 4m x 2m.

*Good natural regeneration ability: fire stimulates the germination of buried seeds.

*Direct sowing is possible.

*Vegetative propagation by grafting and cutting is possible.

*Moderate coppice power, but bad growth.

*It is apt to have double leaders.

f. Increment

Locality	Age	H	DBH	BA	N	V10	MAI10
Brumas	64m	25.0	18.8	23.8	860	164	23.4
"	"	24.5	17.6	22.3	920	151	21.5
"	30m	13.9	13.3	11.1	800	42	16.6
"	"	15.0	10.4	10.2	1200	42	16.6
"	48m	10.7	9.1	4.6	700	13	3.2
"	"	16.0	11.3	8.9	880	39	9.7
Kinarut	4.8y	16.1	13.3	13.2	911	-	-
"	6 y	11.3	10.3	9.6	1017	43	7.2
"	6 y	13.9	14.4	16.9	922	99	16.5
"	6 y	5.5	6.6	4.0	937	2	0.3
Mandahan	5.6y	14.2	17.0	27.2	1153	156	27.9
Timbang							
Menggaris	4.5y	13.3	13.0	16.5	1161	87	19.3
Langkon G	6.0y	14.8	16.2	13.1	594	75	12.5
Langkon A	8.0y	20.8	20.4	27.1	792	217	27.1
Mantanau	3.5y	12.2	14.2	16.9	1036	81	23.1
Karamatoi	7.8y	13.8	9.3	29.3	3913	132	16.9
Bunang	3.8y	5.5	6.1	3.3	1038	1	0.3
"	3.8y	11.3	11.8	13.1	1139	61	16.1

g. Suitable site

*The lower slope or costal plain with acidic soil which contains clay over 35%

h. Pest and disease

*Heart rot : This is main serious disease of this species in Sabah. *Acacia mangium* is very susceptible to heart rot disease. The incidence of attack in 6-9-year-old stand is 35.5%, but the volume of merchantable wood affected is usually less than 1.5% (Mahmud et al, Lee and Anuar 1992), Disease index in 4-5 year-old stand is 10 - 40% and 6-7-year-old stand is 50%, there was a growing tendency for more than six-year old stand. Heart rot fungus in *Acacia mangium* mainly invades from dead branches (Ito, 1991).

*Termites (*Coptotermes* sp.)

*Carpenter ants (*Camporatus* sp.)

*Mealy bug

*Cerambycid wood borer (*Xystocera* sp.)

*Die-back disease on poor soil (*Tremetes sacrosa* and *T. corrugata*)

*Pink disease (*Corticium salmonicolor*)

i. Utilization

*Density: 420kg/m³, Air-dry density: 690kg/m³

*Easily sawn and processed

*Very durable when exposed to weather but not in contact with the ground.

*Pulpwood, particle board, furniture, cabinet, veneer etc.

(2) *Gmelina arborea*

a. Natural occurence

*Pakistan, India, Nepal, Bangradesh, Sri Lanka, Burma, Thailand, Vietnum, Cambodia, Southern China

*Altitude: mainly 0m - 1200m

b. Climate at natural occurence area

*Maximum temperature: 37°C - 38°C

*Minimum temperature: 1°C - 16°C

*Annual rainfall: 760mm - 4600mm

c. Soil at natural occurence area

*Moderately moist, base-rich, well-drained alluvium.

d. Other matters at natural occurence area

*Deciduous tree in area with a long dry season (6-7 month)

e. Silvicultural feature

*Height: 30m, DBH: 1.3m

*Big branch and bad tree form

*Semi-decidious tree

*Flowering and seeding start at 3-4 years old in plantation and this species seeds much every year.

*It takes 4 months - 1 year (average 6 months) to produce a seedling for planting

*Coppice regeneration is possible

*Vegetative propagation by cutting and grafting is done successfully

*Direct sowing is possible

*Stump planting is done successfully

*This species is intolerent of competition with grass

*Adopted initial spacing: 2.4m x 2.4m, 3.6m x 3.6m for pulpwood or sawntimber production

*Natural regeneration is possible on the site with suitable light condition

*Semi-sun tree

*This species is tolerent of fire

*This species is intolerent of frost

f. Increment

Locality	Age	H	DBH	BA	N	V10	MAI10
Brumas	96m	23.9	24.5	28.2	600	185	24.3
"	73m	21.6	19.0	25.5	900	146	24.2
"	96m	25.9	23.6	24.4	560	175	21.9
"	85m	18.3	18.7	19.3	700	96	13.6
"	85m	20.2	20.7	23.5	700	135	19.2
"	47m	19.4	17.3	19.9	840	98	24.9
"	25m	12.5	13.4	10.9	780	26	12.5
"	84m	22.2	21.5	25.4	700	158	22.5
"	73m	20.0	19.3	28.2	960	157	26.0
"	60m	15.9	14.7	16.7	980	59	11.7
"	60m	20.8	15.1	18.5	1040	84	16.7
Bt Hijan	9 y	24.4	21.0	31.4	914		
	11y	25.6	27.4	33.2	558		

g. Suitable site

*It requires 1800mm - 2300mm of annual rainfall with one dry season in a year for optimum growth.

*Rate of stone to soil should be below 30%.

*Alkaline - slightly acid soil with abundant nutrient for good growth

*Flat or gentle slope

h. Pest and disease

*In general, the damage of pest and disease is not serious, but, in Thailand, the damage by defoliator is very serious; *Calopera leayana, Podogrica delicta, Macrosoma candens*, and *Prioptera punctipennis*.

*The most important disease reported is root rot (*Poria rhizomorpha*).

i. Utilization

*Air-dry density: 0.5kg/m^3

*Easily sawn and processed

*Moderately durable

*Pulpwood, fiberboad, general carpenter use, furniture, curving material etc.

(3) *Paraserianthes falcataria*

a. Natural occurence
*Mollucus - - New Guinea - - Solomon
*Latitude: 3°N - 10°S
*Altitude: 0m - 1500m

b. Climate at natural occurence area
*Annual rainfall of 2000 - 2700mm with uniform distribution

c. Soil at natural occurence area

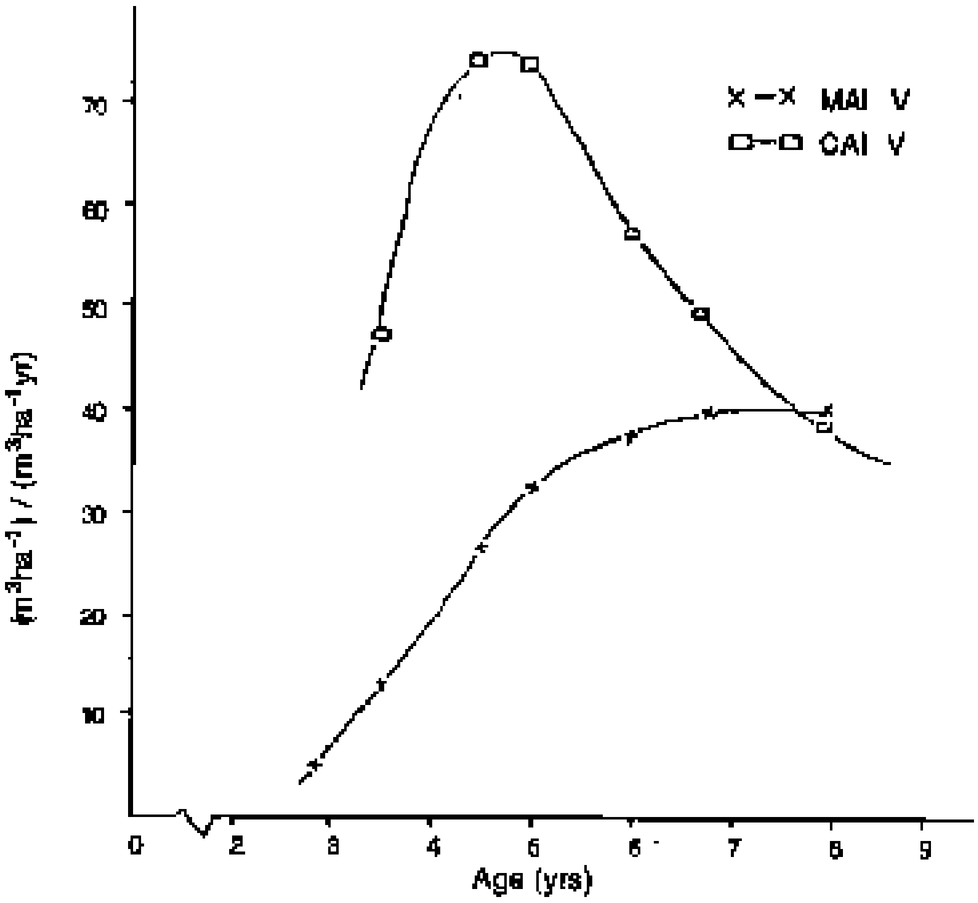
d. Other matters at natural occurence area
*This species is early secondary forest species

e. Silvicultural feature
*Height: 45m, DBH: 1m
*Straight trunk and extended flat crown
*Flowering and seeding start at 3 - 4 years in plantation and this species seeds very much every year.
*It takes 1.5 - 4 months to produce seedling for planting
*Adopted initial spacing: 2m x 2m - - 4m x 4m
*Very good coppice regeneration
*Cutting is possible
*Suitable for agroforestry species
*This species can grow on infertile site.
*Very fast growth at suitable site
*It can grow on the soil of below pH. 4.5 though it grows better on alkaline soil than acid soil.
*This species is intolerent of strong wind

f. Increment

Locality	Age	H	DBH	BA	N	V10	MAI10
Brumas	96m	34.4	26.5	28.7	520	453	56.7
"	"	32.6	23.5	26.9	620	397	50.7
"	"	30.4	21.1	21.7	620	294	36.6
"	"	32.6	21.7	22.1	600	320	39.8
"	85m	34.1	22.6	24.1	600	367	52.0
"	"	32.2	25.4	27.4	540	404	57.3
"	72m	29.2	22.4	31.4	800	415	63.9
"	"	33.2	21.3	28.5	800	418	69.4
"	"	26.4	22.5	19.1	480	247	46.4
Sg. Buloh	9.8/12 y	22.9	19.3	14.7	497		

SSSB -- see figure --



g. Suitable site

*Uniformly distributed precipitation over 2000mm

*Fertile, thick, wet and well drained soil for optimum growth

*Widely suitable for from heavy clay soil to soil formed in volcanic ash material for moderate growth

*Gentle slope

h. Pest and disease

*Pink disease caused by *Corticium salmonicolor* is serious disease at unsuitable site.

*Yellow leaf disease (*Camptomeris albizziae*)

i. Utilization

*Air-dry density: 0.24 - 0.48kg/m³ (mainly 0.30 - 0.35)

*Undurable and not strong

*Easily sawn and processed

*Pulpwood, venner, interior trim, panelling etc.

(4) *Eucalyptus deglupta*

a. Natural occurence

*Mindanao - Sulawesi - Seram - New Guinea - Manus- New Ireland - New Britain

*Latitude 9°N - 11°S

*Altitude 0m - 600m

b. Climate at natural occurence area (New Guinea)

*Mean annual rainfall 2500mm - 5000mm with uniform distribution.

*Mean temperature 27°C - 31°C

c. Soil at natural occurence area. (New Britain)

*Costal plain - hill slope - plateau

*Soil formed in basic volcanic ash and pumice stone with abundant organic matter

*Well drained soil

*Thick alluvium soil along the river

d. Other matters at natural occurence

*This species dominates or forms pure stand as secondary forest species on site disturbed by fire, volcano eruption and shifting cultivation.

e. Silvicultural feature

*Height: 75m, DBH: Over 2m

*Straight and cylindrical trunk

*Flowering and seeding start at about 2 - 4 years and this species seeds very much every year.

*It takes 3 months to produce a seedling for planting.

*It is intolerent of competition with grass and scrub because of extreme sun tree.

*It grows well at altitude of 1500 - 2000m in P.N.G.

*It cannot grow well at place with intensive dry season

*It cannot grow well on a poorly drained site

*Adopted initial spacing:

4.5m x 4.5m -- 5m x 5m for sawntimber production

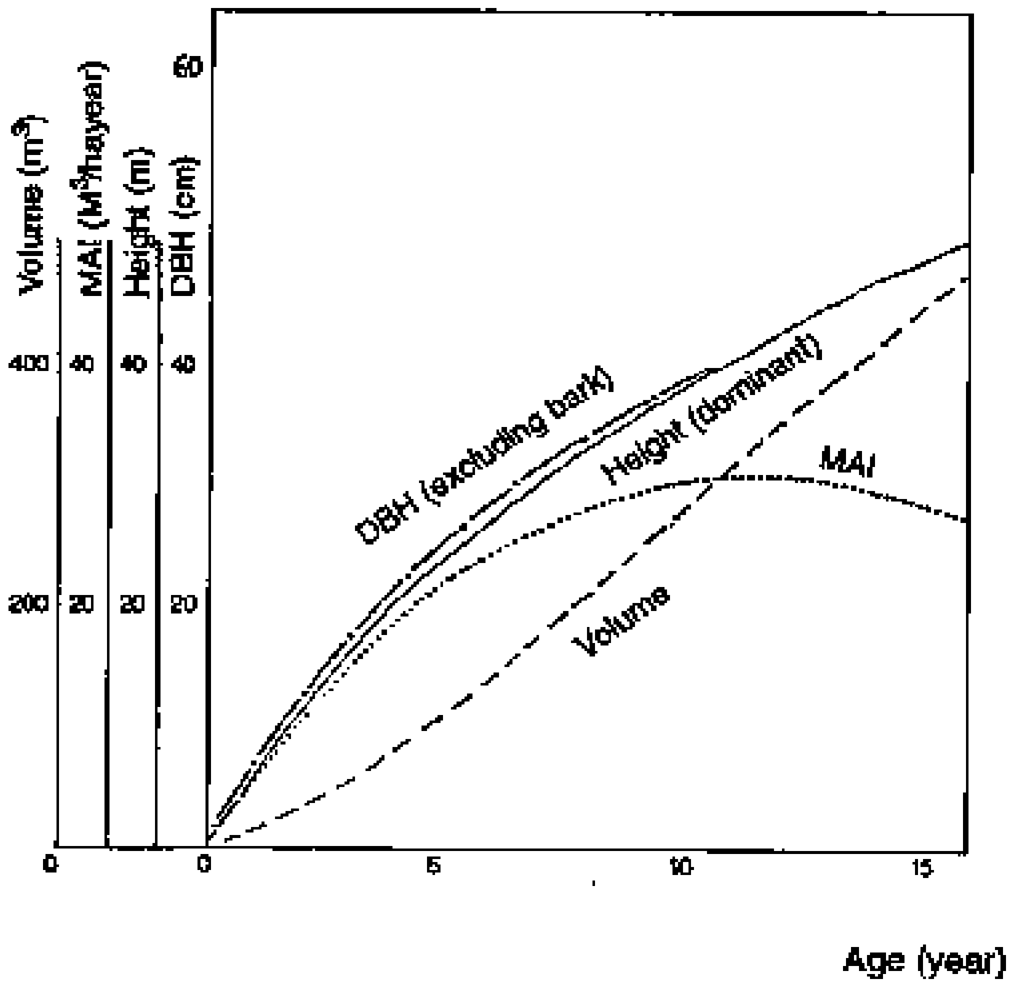
3.5m x 3.5m -- 4m x 4m for pulpwood production

*Good self-pruning

*Vegetative propagation by grafting is possible

f. Increment

Locality	Age	H	DBH	BA	N	V10	MAI10
Karabat	-- see the figure --						
Brumas	97m	31.9	23.5	12.1	280	143	19.2
"	"	22.7	19.8	8.0	260	68	8.5
"	"	24.1	20.6	10.6	320	96	12.6
"	"	26.2	21.2	10.6	300	103	13.3
Sg. Buloh	28y	39.1	43.5	29.0	316		
Ulu Sedili	9 y	19.2	20.9	15.5	480		



Spacing : 4.5 m x 4.5 m

g. Suitable site

*Flat or gentle slope along the river with thick, fertile and well drained soil

*It needs at least 2500 - 3000mm of rainfall for good growth

h. Pest and disease

*Stem and bark borer (*Agrilus* sp.)

This causes serious damage io PNG provenancé in Mindanao

*Ring bark borer (*Hepialidae* sp., *Endoclita hosei*)

*Heart rot - - observed at poorly drained site

*Die-back - - (deficiency of Boron)

*Termite (*Neotermes* sp.)

*Carpenter borer (*Cossidae* sp., *Zeuzera coffeae*)

i. Utilization

*Air-dry density: 0.4 - 0.84kg/m³

*Durable when exposed to weather but not in contact with the ground

*Moderately strong

*Easily sawn and processed

*Pulpwood, furniture, cabinet, floring, plywood, etc.

(5) *Pinus caribaea* var. *hondurensis*

a. Natural occurence

*Central America (Hondurus, Belize, Guatemara, Nicaragua)
*Latitude: 12° 13'N - 18° 00'N
*Altitude: 0m - 1000m

b. Climate at natural occurence area

*Inland area
Maximum temperature: 27°C
Minimum temperature: 5°C
Annual rainfall: 1200mm - 1690mm
*Costal area
Maximum temperature: 32°C
Minimum temperature: 15.6°C
Annual rainfall: 2300mm - 3900mm
*There is a long dry season.

c. Soil at natural occurence area

*Well aerated soil at costal plain, and hill slope

d. Other matters at natural occurence area

*It dominates on the site disturbed by fire.

e. Silvicultural feature

*Height: 45m, DBH: 1.35m
*Straight trunk
*Flowering and seeding needs high temperature through the year and a dry season.
*Female flower's flowering starts at 3 - 4 years old, but good quality seeds are available after 10 years old.
*It takes 6 - 8 months to produce a seedling for planting.
*This species forms mycorrhiza.
*Adopted initial spacing: 2.4m x 2.4m, 3m x 3m, etc.
*This species can grow on infertile soil.
*It is tolerent of drought and fire.
*It is not less tolerent of competition with other vegetations than other pine species.
*The leaf is very flammable.

e. Increment

Locality	Age	H	DBH	BA	N	V10	MAI10
Brumas	84m	15.2	15.6	14.9	780	57	8.1
"	"	15.0	15.4	19.1	1020	72	10.2
"	96m	14.6	11.7	9.7	900	28	3.5
"	61m	12.1	11.1	9.3	960	21	4.2
"	97m	19.2	18.2	29.8	1140	148	18.4
"	73m	11.6	14.4	10.4	640	30	4.9
"	60m	11.1	15.6	3.1	160	9	1.8
"	72m	11.9	14.8	8.9	520	27	4.5
"	72m	12.2	14.9	21.3	1220	66	10.9

f. Suitable site

*Acid, deep, well-drained and well aerated soil

*Loam or sandy loam soil with pH 4.5 - 5.5

*Lower position on gentle slope

g. Pest and disease

*Many pests and diseases are reported.

*Disease on the plantation site

Cercospora needle bright (*Cercospora pini-densiflora*)

Dothistroma needle bright (*Dothistroma pini*)

Needle cast (*Lophodermium pinastri*)

Stem rust (*Cronatium fasiforme*)

Armillaria mellea

Phytophthora cinnamomi

*There are many defoliators, shoot borers, wood borers etc.

h. Utilization

*Air-dry density: 0.75kg/m^3

*Strong and moderately durable

*Ship, general building use, pulpwood, etc.

(6) *Araucaria cunninghamii*

a. Natural occurence
*P.N.G. - Queensland. New South Wales
*Latitude 1°S - 31°S
*Altitude lowland - 2400m (mainly 600m - 1500m) in P.N.G.
0m - 900m in Australia

b. Climate at natural occurence area
*Annual rainfall 1,270mm - 1,780mm
*There is no dry season and more rainfall in summer than in winter.
*Mean temperature 21.1°C - 26.6°C
*Minimum temperature 9.4°C - 17.7°C

c. Soil at natural occurence area
*Thick and fertile clay loam soil for optimum growth

d. Other matters
This species occurs shifting area between rain forest and Eucalyptus forest in Australia.

e. Silvicultural feature
*Height: 46m, DBH: 1.6m
*Straight trunk
*Clear trunk length: two-thirds of tree height
*Flowering and seeding starts above 15 years, but it takes 20 years to produce good quality seeds.
*This species seeds every year.
*It takes 15 months in nursery stage.
*Adopted initial spacing: 2.7m x 2.7m - 2.4m x 2.4m
*It can grow on rather steep slope and a little dry site.

f. Increment

Locality	Age	H	DBH	BA	N	V10	MAI10
Beaury	16 y	17.1		27.0	939	132	8.2
Bo Bo	18.5y	14.6		22.7	889	71	3.9
Beaury Mt.	19y	19.8		41.7	1099	271	14.3
Pikapene	17y	19.5		28.2	1186	150	8.8

g. Suitable site
*Well drained and fertile, clay-loamy soil with abundant moisture through the year
*The site with a short dry season (2 - 3 months) is better

h. Pest and Disease

Pest

**Vanape aberthurii* (wood)

**Setomorpha rutella* (seed)

**Hylurdrectonus araucariae* (leaf and trunk)

**Aesiotes notabilis* (trunk)

**Miliona Isodoxa* (leaf)

**Coptotermes elisae* (wood); this termite causes serious damage.

Disease

**Fomes noxius* (wood rot)

*Damping off

*Collar rot (*Selerotium rolfsii*)

*Die-back (*Botryodiplodia theobromae*)

i. Utilization

*Air-dry density: 0.52kg/m^3

*Easily sawn and processed

*undurable and sensitive to insect and fungi (especially for supwood)

*Indoor use, furniture, plywood, veneer, boat, pulpwood, etc.

(7) *Araucaria hunsteinii*

a. Natural occurence
*P.N.G.
*Latitude 5°11'S - 10°11'S
*Altitude mainly 520m - 2100m

b. Climate at natural occurence area
*Annual rainfall: 1600mm - 1800mm
*no dry season
*Maximum temperature 26.6°C - 32.2°C
*Minimum temperature 17.7°C - 18.8°C
*Annual mean temperature 20°C - 27°C
*Humidity 60 - 70%

c. Soil at natural occurence area
*Slope in the Valley
*Alluvium site is better

d. Other matters at natural occurence area
*Natural occurence is smaller than that of *A. cunninghamii*

e. Silvicultural feature
*H: 46 - 85m, DBH: 2m
*Straight and cylinderic trunks
*Clear trunk length: half of tree height
*Flowering starts12 - 15 years old(male)
*Seeding starts at after 20 years old
*Good quality seeds are available at the interval of 1 - 4 years
*Adopted initial spacing: 2.8m x 2.8m - 2.5m x 2.5m
*It can grow or rather steep slope or a little dry site.

f. Increment

Area	Age	H (best 49)	DBH	BA	N
PNG	8.5	12.5	14.2	10.5	578
"	8.5	13.7	13.7	13.8	820
"	12.5	20.4	23.3	24.7	509
"	13.5	23.5	22.0	32.3	781
"	16.5	28.4	34.5	29.0	336
"	16.5	27.4	25.1	38.0	716

g. Suitable site

*The soil formed in volcano ash material
*Well drained hill slope
*The site with a short dry season (2 - 3 months) is better

h. Pest and Disease

Pest
*Termite (*Coptotermes* sp.): serious damage
**Milliona isodoxa* (leaf)
Disease
**Fomes noxius, Armillaria* sp. (wood rot)
*Rhizoctoria crocorum

i. Utilization

*Air-dry density: 0.45kg/m^3
*Easily sawn and processed
*Undurable and sensitive to termites and ambrosia beetles
*Building structure use, furniture, cabinet, match, pulpwood, plywood, etc.

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