

HEART ROT ON *ACACIA MANGIUM* IN SAFODA PLANTATIONS

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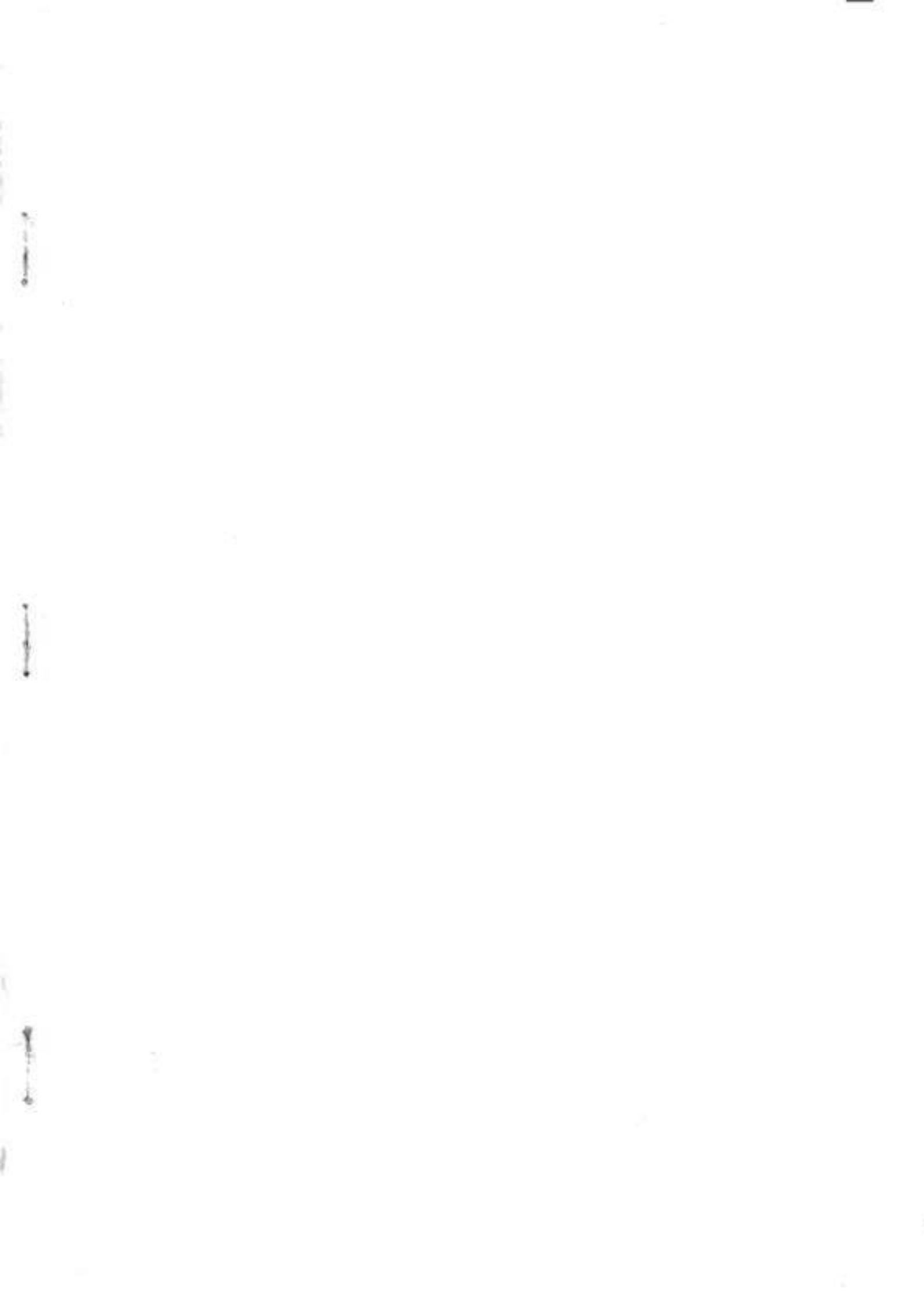


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**Sabah Re-Afforestation Technical Development
And Training Project**

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1. Introduction

Acacia mangium Willd is a leguminous tree species in the subfamily Mimosoideae. The natural distribution of *A. mangium* stretches from Aru Island in the Moluccas and Irian Jaya (the eastern most part of Indonesia), to the River Ordome in the Western Division of Papua New Guinea and down to the northern part of Queensland. In Queensland, *A. mangium* is found where rainfall exceeds 1400mm and is most frequent where rainfall exceeds 2,000mm. It is reputed to tolerate a wide range of soil types, usually on the acid side of pH 5, preferring heavy soils with high clay and silt fractions, often with low available phosphorous.

A. mangium appears to be one of the most promising species for tree planting programs in the humid tropics, where it has recently been introduced. The success of *A. mangium* is primarily due to its rapid growth rate, robustness and wide range of uses. When planted as an exotic, it has often shown an unexpectedly good performance, and has now been widely planted throughout tropical Asia, the Pacific Islands, West Africa, and the Americas. Being a relatively new plantation species, it has not yet, however, been thoroughly studied, and little information and experience on it has so far been gathered. There are many aspects which need to be studied and developed before the true potential of this species can be assessed.

A. mangium was introduced to plantation forestry in Sabah in 1966 by D. I. Nicholson. In 1967, plants raised were planted as a firebreak in Ulu Kukut (now known as Jalan Madu, Plate 1-A) and in a research plots at the Gum Gum and Sibuga Experiment Stations. Plants from seed collections at Jalan Madu were planted at Ulu Kukut and Sook plantations and seeds from Gum Gum stand were used to establish trial plots at Lungmanis.

Since the early 1980's *A. mangium* was planted widely in Malaysia. SAFODA (Sabah Forestry Development Authority), formed in 1976 to establish forest plantations on land degraded by shifting cultivation and logging, planted *A. mangium* as a forest plantation species. It was noticed that *A. mangium* had better form than *A. auriculiformis*. SAFODA now has 20,000 ha. of *A. mangium* plantation.

A. mangium has been remarkably free from disease problems until recently. In 1981, heart rot in *A. mangium* was reported in Sabah by Gibson (1981) from thinning of a 44 months old seed stand where 12% of the thinning had heart rot. A similar observation was made in four years old thinnings from Kemasul plantation in Peninsular Malaysia (Lee 1985). Lee (1988) also conducted an extensive study of heart rot in four, five and six years old stands in same plantation. From her study, she found that discolouration and heart rot in *A. mangium* were caused by fungal invasion of poorly healed wounds, especially those left by branch stubs.

Generally, monoculture plantations are known to be very susceptible to diseases and pests. Heart rot causes loss in quantity and reduction in quality in forest production. Gibson (1981) identified heart rot as a major potential problem in future plantation forestry with *A. mangium* in Sabah. Furthermore, it was recommended that a survey of the problem be conducted at the earliest opportunity. However to date, no detailed research of heart rot in *A. mangium* (Plate 1-B) has been conducted.

2. Materials and methods

(Same preliminary survey of heart rot in *Acacia mangium*)

Acacia mangium trees possessing signs of possible decay, such as a dead or broken branches, decayed branch stubs or cankers were marked. The selected trees were felled and cut into 1.2m lengths with a chainsaw. Vertical extent of heart rot in each tree was observed by splitting the logs into halves and the infection courts were examined in each tree affected by the rot. A total of 22 *A. mangium* trees were collected from six SAFODA project sites.

(A survey of heart rot on *A. mangium* in SAFODA plantations)

The survey of heart rot was carried out at 14 *A. mangium* plantations in four SAFODA project sites, i.e. Bongkol, Lumat, Ulu Kukat and Kinarut. They were from two to seven years old and nine years old plantations. In the selected *A. mangium* plantations, 10 tree x 10 tree study plots (plot A-G) were laid out and then ten trees were selected by the manner shown in Figure 1. Detailed description of each plot is shown in Table 1.

The selected trees were felled and total height (TH), each branch height (DH, LBH) and diameter at breast height (DBH) as expressed in Figure 2 were measured. After measuring, each tree was cut with chainsaw into logs approximately 1.0m in length and the logs were taken back to Kinarut for evaluation of discolouration and decay. The logs were sawn axially with chainsaw and the absence or presence, length and width of discolouration and decay were recorded (Figure 3). From these results, disease severity of each tree was evaluated as shown in Table 2.

Chips 5 x 5mm were cut from discoloured and decayed portions of heart wood. They were sterilized by procedure shown in Figure 4 and incubated on culture medium at room temperature. PDA (Potato Dextrose Agar) was used as culture medium in this study.

(A survey of heart rot in plots with different growth rates)

The survey of heart rot was carried out at 5 years old plantations in Lumat. Two plots i.e. H-1 and H-2 were established in compartment 22 and 23. Growth of *A. mangium* in each compartment was as follows:-

| Compartment | 22 | 23 |
|----------------|---------|---------|
| Mean DBH | 18.3 cm | 13.0 cm |
| Maximum DBH | 24.6 | 24.6 |
| Minimum DBH | 6.5 | 6.5 |
| Mean Height | 18.8 m | 14.6 m |
| Maximum Height | 23.0 | 20.5 |
| Minimum Height | 11.6 | 8.3 |

In plot H-1 and H-2, 20 trees that had diameters of about 20cm and 15cm respectively, were selected. The selected trees were felled and total height (TH), each branch height (DH, LBH) and diameter at breast height (DBH) were measured on November 14 and 16, 1991. Measuring methods were the same as mentioned above.

(A survey of heart rot in spacing trial plots)

The survey was conducted at three spacing trial plots at SAFODA-JICA project site at

Kinarut, i.e. J-1 (spacing 1.0 x 1.0m), J-2 (2.1 x 2.1m) and J-3 (4.2 x 4.2m) in August 1989. Five trees were selected from each plot. Measuring methods were the same as mentioned above.

(A survey of heart rot in provenance trial plots)

The survey was conducted at five provenance trial plots at SAFODA-JICA project site at Kinarut, i.e. J-1 (Whyanbell, Australia), J-2 (Balamuk, Papua New Guinea), J-3 (Barum, PNG), J-4 (Sabah - Ulu Kukut, Malaysia) and J-5 (Sabah - SSSB, Malaysia) in August 1989. Five trees were selected from each plot. Measuring methods were the same as mentioned above.

(A survey of heart rot in pruning trial plots)

Plots from pruning trials were established in 2 years old plantation (planted in October 1988) at Kinarut. Ninety trees were pruned between 1.0m and 2.5m in height on January 5, 1991 and thirty trees were not pruned (K-4). Pruned trees were divided into three treatments. Pruning scars (wounds) of two treatments were treated with Topzin (K-3) that contained fungicides and callus promoting substance and paint (K-2) that contained fungicides only. One treatment or control (K-1) was treated with nothing. Diameters of five fixed pruning scars were measured on each sample tree. Assessment were conducted on January 5, May 21, September 21, 1991 and January 5, 1992.

On December 8, 1991 (11 months after pruning), three trees were felled from each plot and no pruning plot. The discoloration and decay of knots (pruning parts) were examined after splitting the logs through the pruning parts.

On August 10, 1993 (19 months after pruning), ten trees were selected and felled from each plot and discoloration and decay in knots and heart wood were examined after splitting the logs through the pruning parts.

(A survey of heart rot in *A. auriculiformis* and *Acacia* hybrid)

Survey was conducted at the arboretum established at Kinarut where 5 years old *A. mangium*, *A. auriculiformis* and hybrid of *A. auriculiformis* and *A. mangium* were planted. Ten trees were selected from each plot i.e. L-1 (*A. mangium*), L-2 (*A. auriculiformis*), L-3 (hybrid) on July 28, 1993. Measuring methods were the same as mentioned above.

(Diseases found in forest nurseries and plantations)

The survey of other diseases on *A. mangium* was conducted at six SAFODA project sites shown below from November to December 1989.

| | | | |
|-----|-----------|---|------------------|
| (1) | Bongkol | Forest nursery and plantations | December 8, 1989 |
| (2) | Bunang | Plantations | November 28 |
| (3) | Karamatol | Forest nursery and plantations | November 28 |
| (4) | Kinarut | Forest nursery, arboretum and plantations | |
| (5) | Lumat | Forest nursery and plantations | December 12 |
| (6) | Punteh | Forest nurseries and plantations | December 12 |
| (7) | Ulu Kukut | Forest nursery and plantations | November 27 |

Most of the diseased materials were examined microscopically and slide specimens were prepared. For the isolation of microorganisms from the diseased materials, diseased parts were sterilized and cultured on Potato Dextrose Agar (PDA) medium.

(Die-back in plantations)

For a survey of die-back, two trees (M-A and M-B) that showed die-back symptom were felled in ten years old plantation at Kinarut on November 11, 1991. The outer bark of felled trees were removed and dead parts of inner bark were examined at the project site at Kinarut. Root condition was also examined.

(Tree mortality in plantations)

For a survey of tree mortality, two plots that had 10 x 10 trees, were established in 12 years old plantation at Hobut on November 21, 1991. All trees in the two plots were checked and divided into sound, abnormal and dead, and a distribution map of mortality was made. To investigate the causal agents, two trees were felled and stems and roots were carried to project site at Kinarut. Dead parts of inner bark in stems and roots were examined after removing the outer bark. Fungi were isolated from the living inner bark near the dead one.

3. Results and Discussion

3.1. Some preliminary survey of heart rot in *A. mangium*.

In *A. mangium* trees, it was observed that sound sapwood was pale yellow to straw colour while sound heartwood was pale olive brown to grey brown. In comparison, discoloured heartwood was purple to black in colour (Plate 2-A) and decayed heartwood had a light yellow to bleached straw colour (Plate 2-B). Incipient decay was more difficult to detect, but was intermediate in color between normal heartwood and advanced decay. In some specimens, the zone of incipient decay was found to be surrounded by a circle of dark brown stain. This zone is significantly darker than normal heartwood.

Incipient decay exhibited physical properties intermediate between those of decayed wood and healthy wood. In general, the wood got softer and easier to cut as the heart rot became more advanced. Care should be taken not to confuse the physical properties of incipient decays with those of juvenile heartwood in *A. mangium*, as both had similar properties. Juvenile wood was most likely to be found near the pith and in younger stem sections.

Results of survey are shown in Table 3. It was found that decayed branch stubs, dead branch and wound were good indicators of heart rot in *A. mangium* of various ages. Table 3 indicates that man-made and other injuries (including fire scars) act as favorable entry points for the infection to younger *A. mangium* trees. On the other hand, in the case of older trees the most common point of entry appeared to be branch stubs and dead branch.

It is therefore highly desirable that artificial pruning of *A. mangium* be conducted at an early stage while the branches are still of small diameter so that the resulting wound is small and can heal over rapidly. Selection of trees which produce fewer branches or those that self-prune efficiently is probably important in reducing the incidence of heart rot in *A. mangium*.

It is not sure what percentage of *A. mangium* wood are affected by heart rot in SAFODA plantations. But it would appear that good quality timber and chips could not be obtained from

rotted trees, because cellulose and lignin would be decomposed and utilized by heart rot fungi. More detailed research is indispensable.

3.2 A survey of heart rot on *A. mangium* in SAFODA plantations.

The main objectives of this survey are as follows:

- (1) To determine the percentage of incidence of heart rot in plantations of *A. mangium*.
- (2) To determine the relationship between the incidence of heart rot and tree age.
- (3) To find out the infection court of decay fungi.

From this year's observation of heart rot in *A. mangium*, it was reconfirmed that the type of wood decay was white rot caused by white rot fungus that produced enzymes for digestion of both cellulose, the main structural component of wood and lignin, the second most abundant component of wood. As the disease progressed, the heartwood of *A. mangium* became white yellow (Plate 2-B, disease index R₃) and soft. Decayed portions appeared stringy (Plate 2-C, disease index R₄) and were removed easily with fingernail. Finally, the heart wood became hollow (Plate 2-E).

As already shown in Table 2, five disease index were decided according to progress of discoloration and decay in heartwood of *A. mangium*, and five degrees of disease severity judging from severity of wood decay were evaluated and were given to each disease index. So each disease severity was corresponded to each disease index in this study. Of the five disease indexes, R₃ and R₄ (disease severity 3 and 4) were defined as heart rot because these logs would have degraded commercial value for sawlog and/or pulplog.

Detailed results of heart rot survey in *Acacia mangium* are shown in Table 4. From Table 4, percentage of incidence of heart rot and disease severity in each plot are summarized and shown in Table 5.

It was evident that incidence of heart rot and disease severity depended on tree ages. Heart rot could occur at four years old trees and incidence of heart rot increased with age of trees. Percentage of incidence in this survey ranged between 10 and 50%. Disease severity also increased with age.

Disease severity of trees under three years old was 0 to 1. It means that they still did not have decay in their heartwood. Four and five years old trees have 10 to 40% heart rot, but average disease severity was between 1 and 2.

There was a tendency for more than six years old trees to have disease severity 3 and 4. This indicated that all trees on the average had decay and discoloration. It also indicated that disease severity of trees over seven years old were more severe and about 50% of trees were suffering from heart rot. Furthermore, enough attention should be paid that 20% of trees in seven and nine years old plantations were disease index R₄ (disease severity 4).

Infection courts in trees of disease index R₃ and R₄ were examined in detail. Results are summarized in Table 6. Infection courts of heart rot in *A. mangium* were as follows:- dead branch stub (Plate 3-A), dead branch (Plate 3-B), unhealed pruning wound (Plate 3-C), unhealed branch stub (Plate 3-D), forked injury (Plate 3-E) and squirrel damage (Plate 3-F).

Table 6 indicated that about 50% of infection courts were dead branch stubs and dead branches. So it is evident that heart rot fungus of *A. mangium* mainly invades from dead branches.

Heart rot fungus also invaded from wounds caused by many reasons. In this study, it was indicated that wounds produced by irregular pruning were important infection court. However plantations burned before were not included in this study, it was generally known that fire scars (Plate 3-G) were important entry points of some heart rot fungi.

It is known that *A. mangium* has many thick branches that do not drop easily. From results mentioned above, it seems that dead branches are indispensable to disease cycle of heart rot in *A. mangium*. Results of the relationship between tree age and dead branch height are shown in Figure 5. Figure 5 indicated that as *A. mangium* grew older LBH (height to the lowest living branch) increased rapidly. In contrast, DH (height to the lowest dead branch) increased gradually. For example, DH of 3 and 9 years old tree were 1.7m and 2.9m and LBH of same aged tree were 6.7m and 11.8m respectively. It is clear that difference of the former two is very small, but there is great difference between the latter two. It means that dead branches of *A. mangium* remained on the stem for long years. Figure 5 also indicated that *A. mangium* trees had many branches when they were about three years old.

To find out the fruiting body of heart rot fungi, the *A. mangium* stands at Gum Gum and Jalan Madu, the oldest *A. mangium* stands in Sabah, were visited. In those areas, several kind of fruiting bodies were collected, but common fruiting bodies that seem to cause heart rot in *A. mangium* were not found.

From the isolation study, mainly six species of fungi were isolated in discolored and decayed portions of heartwood. Among those species, *Phialophora* spp., *Macrophoma* spp. and an unknown one were isolated from discolored heartwood. *Phialophora* spp. was isolated most frequently. This fungus is well known for causing discoloration of woods in many living trees.

From decayed heartwood, three white sterile fungi were isolated and distinguished from one another by their colour and colony type on culture medium. A more extensive study is needed to identify these fungi clearly.

It is inferred from the results mentioned above that heart rot will occur and progress in *Acacia mangium* as shown in Figure 6.

One and two years old *A. mangium* trees have little dead branches, but three years old ones will have increasingly many dead ones. It is generally known that chemical changes take place in the wood when trees are wounded by some reasons (Rayner and Boddy 1988). Dead branches are thought to be one sort of wound. In these wood, some micro organisms, for example bacteria and non-decay fungi called the pioneer wound invading fungi, become active and discoloration occurs. After the wood discolors, decay fungi infect and decay begins.

In the case of *A. mangium*, pioneer fungi will invade from dead branches of about 3 or 4 years old trees, and cause the discoloration of wood. After that, heart rot fungi invade from the same dead branches and cause the decay of heartwood in about 5 or 6 years old trees. In more than 7 years old trees, the decay advances and heartwood become soft.

From this study, it is concluded that *Acacia mangium* trees are very susceptible to heart rot. So it will appear that losses in wood quantity and quality of *A. mangium* from heart rot is very high. If it is proposed to produce good sawlogs, it is highly desirable that artificial pruning of *A.*

mangium be conducted at an early stage while the branches are still of small diameter so that the resulting wound is small and can heal over rapidly.

3.3 Factors affecting on the incidence of heart rot

3.3.1 A survey of heart rot in plots with different growth rates.

To clarify the relationship between growth rate of *A. mangium* and the incidence of heart rot, a survey was conducted at two plots at Lumat.

As shown in Table 7, significant differences in the height and diameter at breast height were detected between plot H-1 and H-2. Average height in plot H-1 and H-2 were 20.3m and 15.7m and average DBH of them were 21.0cm and 14.9cm respectively. Judging from the average height and DBH of sampled trees, plot H-1 is regarded as good site, while plot H-2 seems to be poor site.

It is evident that there are significant differences in the incidence of heart rot between two plots (Table 8). In plot H-1, 75% of trees were already suffered from heart rot (R3 or R4), while only 25% of trees were R3 in plot H-2. Compared with results reported in Table 4 (plot D-1 and D-2), growth rate and percentage of heart rot in trees of plot H-1 were extremely high. On the other hand, percentage of diseased trees results in plot H-2 were similar to that in plot D-1 and D-2.

The results of the study showed that the incidence of heart rot was higher in bigger diameter class trees. This imply that the faster the growth rate of the *A. mangium* tree, the higher is its suscepibility to heart rot infection. It is however difficult to confirm that good growth trees or trees grown on good sites are susceptible to heart rot disease from these results because the percentage of diseased trees in plot H-1 was abnormal and almost all trees in this plot were attacked by ambrosia beetles several times.

There may be other biotic or abiotic factors that effect the occurrence of heart rot in *A. mangium*, but it is probable that good growth trees tend to have many thick branches that will remain on the stem for a few years after die-back. From them, heart rot fungi will be able to invade the heart wood of *A. mangium*.

The rough volume of discoloured and decayed wood in each log was determined from the wood at the upper end shown in Table 8. The amount of discoloured wood in the trees of plot H-1 and H-2 ranged 7% - 19% and 0% - 27% respectively. And the amount of heart rot ranged 1% - 8% and 0% - 11%. The maximum volume of wood affected by discoloration and decay in a tree was 36% in the 5 years old plantation. Even though the percentage of volume loss due to heart rot was small, but it's occurrence would affect the quality of sawlogs to be produced from these plantations.

3.3.2 A survey of heart rot in spacing trial plots.

The survey was conducted in three spacing trial plots, 1.0 x 1.0m, 2.1 x 2.1m and 4.2 x 4.2m on August 16, 1993 (Table 9). Collected trees were 5 years old. Results of survey are shown in Table 10.

The size of branches was larger at wider spacing (I-3) than those at closer spacing (I-1). It

is expected that heart rot fungi invade large sized branches easier and wider spacing is expected to have more severe damage. However both the percentage of heart rot and disease severity at closer spacing (I-1) were the highest among the three plots because they had many dead branches and many wounds on their stems probably produced by trees rubbing against each other. It is probable that fungi easily invade from their branches and/or wounds and cause heart rot.

3.3.3 A survey of heart rot in provenance trial plots.

Tree form differs between provenances. To determine any correlation between provenance and incidence of heart rot, a survey was conducted in provenance trial plots on August 10, 1993. Five trees were selected from five provenance plots (Table 9), i.e. Whyanbell, Australia (J-1), Balamuk, Papua New Guinea (J-2), Barum, PNG (J-3), Sabah - Ulu Kukut, Malaysia (J-4) and Sabah - SSSB, Malaysia (J-5). Results of survey are shown in Table 11.

The disease severity of two provenances from Papua New Guinea was higher than other provenances and heart rot (disease index is R_3 or R_4) occurred only in them. On the contrary, disease severity of two provenances from Malaysia was low. The reason why disease severity is different among provenances is unknown but it is expected that tree shape and size of branches affect incidence of heart rot.

A more detailed survey should be carried out in spacing and provenance trial plots, if possible, in 7 or 8 year-old plantations, to verify the relationship between spacing or seed provenance and the incidence of heart rot because only five trees were examined in this survey.

3.3.4 A survey of heart rot in pruning trial plots.

To attempt to determine the effect of pruning on the incidence of heart rot, surveys were conducted in pruning trial plots.

As mentioned in 3.2., it was found that heart rot fungi invaded mainly from dead branches. It is also known that *A. mangium* has a poor self-pruning ability. So the stands should be artificially pruned to improve the quality of the timber and to prevent the invasion of heart rot fungi. To survey the effect of pruning on the incidence of heart rot in *A. mangium*, plots were established in 2 years old pruning trials. Trees were pruned on January 5, 1991, and pruning scars were treated with chemicals. The diameter of five fixed pruning scars were measured. Results are shown in Table 12.

In all plots, size of pruning scars decreased with time. In pruning plot (K-1), average diameter of pruned scars diminished till 16% and about 50% of branches were covered completely in 12 months after pruning. In plot K-3 where pruned scars were treated with Topzin, recovering rate of branch was very fast and over 60% of branches were covered completely after 12 months. There were no differences between paint treatment and no treatment. From Table 12, it was clear that plot K-3 treated with Topzin, had good ability to heal the scars of pruning.

Discoloration and decay of knots in pruning trial plots were examined in 11 months and 19 months after pruning. Results are shown in Table 13 and 14. It is clear that percentage of discolored or decayed knots were very high in the *A. mangium* trees with no pruning (K-4). At five years old, trees in that plot had 70% of discolored or decayed knots.

Table 15 shows the occurrence of discoloration or heart rot on *A. mangium* in pruning trial plots. Disease severity was low in plot K-3 and K-1 but percentage of heart rot was no difference among plots except Topzin treated plot. The reason for this result was probably that trees in this study plot were pruned at about 2 year-old when they already had dead branches.

From the results of Table 12-15, it is evident that pruning is effective in hindering heart rot fungi from invading in *A. mangium* and preventing heart rot. According to tree age, trees in the no pruning plot had many dead branches and disease severity is more severe. It is to be desired that first pruning should be done at about one year old when branches are still living.

3.4. A survey of heart rot on *A. auriculiformis* and *Acacia* hybrid.

It is said that *A. auriculiformis* seems to have less heart rot because it is known that it has thin branches compared to *A. mangium*. But no survey of heart rot was conducted in *A. auriculiformis* and *Acacia* hybrid. To determine the incidence of discoloration and heart rot on them, a survey was carried out at the arboretum where 5 years old *A. mangium*, *A. auriculiformis* and hybrid of *A. auriculiformis* and *A. mangium* were planted, in July 1983.

The incidence of heart rot and disease severity in *A. mangium* plot (L-1) were 50% and 2.2 respectively (Table 16). These results were same as previous surveys. On the other hand, disease severity in plot L-2 (*A. auriculiformis*) and L-3 (hybrid) were 0.8 and 1.0 respectively and they did not have heart rot. They were remarkably different in degree from plot L-1 (*A. mangium*). This survey showed that 5 years old *A. auriculiformis* and the hybrid of *A. auriculiformis* and *A. mangium* had no heart rot. It is supposed that *A. auriculiformis* is resistant to heart rot. To determine the susceptibility of *A. auriculiformis* to heart rot, inoculation test was conducted by using several fungi isolated from decayed heart wood on *A. mangium*. After one or two years, result of the inoculation experiment will be examined.

3.5. A survey of other diseases of *A. mangium* in SAFODA plantations.

3.5.1. Diseases found in forest nurseries and plantations.

Several diseases have been reported on *A. mangium* till now (Khamis 1982) but there have been no occurrence of serious damage by those diseases. In SAFODA nurseries and plantations, a survey of diseases was conducted in November and December 1989.

Three kind of diseases were collected on *A. mangium* in nurseries and plantations during the survey apart from heart rot. These were damping-off (*Fusarium* sp), Sooty mold (unknown) and Spotting (*Pestalotiopsis* sp. was mainly isolated). Sooty mold on leaf (Plate 4-A) was observed frequently in both nurseries and plantations but severe damage by this sooty mold and other two diseases were not found.

3.5.2. Die-back in plantations

It was found that die back in *A. mangium* occurred in plantations at Kinarut (Plate 4-C) and other SAFODA areas. To examine the causal agents of die back, two *A. mangium* trees, M-A and M-B, were collected from ten years old plantation (plot M) in Kinarut where die back had been observed several years before.

Height of M-A was 4.0m and inner bark of it was dead between 1.2m and 1.6m in height (Figure 7), and almost all heart wood was decayed. In M-B, height was 7.0m and inner bark was also dead between 4.0m and 4.8m height (Figure 7) but decay was not observed. Fruiting bodies were not found on the dead part of trees, but *Macrophoma* sp. was isolated frequently from living inner bark near the dead part (Plate 4-C). *Macrophoma* sp. was also isolated from canker parts of stem that was sometime observed on relatively upper part of *A. mangium* trees. Death and abnormality were not observed in the root tissues and no fungi were isolated from them. Khamis (1982) reported that die back on *A. mangium* occurred in the areas where soils were poor in nutrients and mainly podzolic with a hard pan at about 40cm depth, which had profound effect on root penetration as well as water infiltration. Soil condition in surveyed area was the same as that Khamis mentioned. It seems that soil condition effected occurrence of die back but the pathogenicity of *Macrophoma* sp isolated has not been confirmed. It is, however, closely correlated to occurrence of die back on *A. mangium*.

3.5.3. Tree mortality in Plantations

Recently it was observed that tree mortality in *A. mangium* plantation occurred in several areas in SAFODA. Field survey was carried out in a 12 years old plantation (plot N) at Hobut (Plate 4-D). To examine the causal agent, newly dead (N-A) and abnormal trees (N-B) were collected.

In plot N-1, 86% of the trees were already dead and 2% of the trees were abnormal (Figure 8). On the other hand, 71% of trees were dead and 4% were abnormal in plot N-2 (Figure 9). It is not clear in plot N-1, but distribution of sound, abnormal and newly dead trees were concentrated in plot N-2. It was also observed that abnormal trees were distributed near newly dead trees.

Collected trees were examined to determine whether the inner bark at each 1m height of stem was dead or alive. Newly dead tree (N-A), still with dead leaves, was 21m height and had living inner bark till 14m height. Only the upper 4m was dead. Abnormal tree (N-B), had yellow or scattered leaf, was 20m in height and the inner bark was still alive till the top.

Roots of both trees were also examined. And it was found that 30% of inner bark were already dead on the lower side of the roots in both trees (Plate 4-E). Judging from the symptom of the root, it seems that tree mortality are caused by red root disease. It is known that causal agent is *Ganoderma pseudoferreum*, causing death of pines, rubber and oil palm. It is also observed that the root of diseased trees bear a dark red rhizomorphic skin which blackens with age. The red colour becomes more distinct after infected roots have been wetted (plate 4-F). The attacked wood is discoloured reddish brown or brown mottled with white patches. In advanced stages of decay, the wood becomes light, dry and friable and honey combed, and a brown network of lines appears on the surface of the wood under the bark.

In both plots, it was observed that shrub trees near the dead *A. mangium* were also killed by this disease. It seems that the disease spreads by root contact with dead tree. As information of this disease on *A. mangium* is still lacking, it is desirable that a detailed survey be carried out.

4. Conclusion

- (1) Heart rot is the most important disease in *A. mangium* in SAFODA plantations. The incidence of heart rot is considered serious in SAFODA plantations.
- (2) Heart rot in *A. mangium* was top rot caused by white rot fungi (Causal fungus could not be identified).
- (3) Incidence of heart rot originated from dead branches. It was evident that heart rot fungi in *A. mangium* would invade mainly from dead branches. They also invaded from wounds caused by squirrel, fire and physical damage.
- (4) The incidence of heart rot at *A. mangium* plantations in SAFODA aged two to nine years old ranged from 0 to 50%. At five or six years old plantations, more than 40% of the samples already had heart rot. Incidence of heart rot was found to be positively correlated to age.
- (5) It is supposed that the incidence of heart rot in *A. mangium* would have correlation with silviculture activities for example pruning or spacing trial.
- (6) It also had correlation with site condition and seed-sources, especially the degree of the discoloration and heart rot which were different between the provenances.
- (7) It is concluded that pruning is effective in preventing *A. mangium* heart rot.
- (8) It was evident that 5 years old *A. auriculiformis* and the hybrid of *A. auriculiformis* and *A. mangium* had no heart rot. From this fact, there is a possibility that heart rot in *A. mangium* can be controlled by a disease-resistant breeding.

5. Recommendation

- (1) It is very difficult to protect *Acacia mangium* trees from heart rot disease immediately. It is strongly recommended from the stand point of forest pathology that *A. mangium* should be planted for pulpwood on a seven or eight years rotation until a protective system and technique is perfected.
- (2) It is clear that heart rot fungus in *A. mangium* mainly invades from dead branches. So it is important to establish a method to control branch formation/production in the near future. It is recommended that the active detailed survey should be continued at SAFODA areas to determine the relationship between silvicultural activities and the incidence of heart rot in *A. mangium*, for example the effect of pruning and chemical treatment, spacing, site condition and so on.
- (3) It is also recommended that *A. mangium* with no-forked and thin branch be selected as CPT (candidate-plus-tree) as early as possible and survey of heart rot in *A. auriculiformis* and hybrid of *A. mangium* and *A. auriculiformis* should be carried out.
- (4) The forest plantations of large scale monoculture are known to be very susceptible to pests and diseases. It is recommended that while *A. mangium* planting should continue, other promising species should also be tried.
- (5) The importance of heart rot in *A. mangium* can scarcely be underrated. Heart rot disease has a high potential for loss to forest production in quantity in addition to reduction in quality. It is recommended that lecture about heart rot disease in *A. mangium* be given to the related staff in training.
- (6) It is probable that diseases (and pests) problems in *A. mangium* plantations will be serious in the near future. But our knowledge about them in tropical areas is still lacking. It is recommended that the specialists of diseases (and pests) should be trained in SAFODA.
- (7) Careful watching of *A. mangium* plantations is necessary to find diseases (and pests) occurrence and to prevent spread of the diseases (and pests). And it will be necessary to exchange the diseases and pests information of each project. It is recommended that forest diseases (and pests) damage report system should be established in SAFODA.
- (8) To protect *A. mangium* from heart rot, it will be essential to collect the information about heart rot and other diseases in *A. mangium*. It is recommended that a close relationship should be established with the forest pathologist at Forest Research Institute in Kepong, the University Agriculture of Malaysia in Serdang, Selangor and Plant Pathologists at State Agriculture Research Center in Tuaran.

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B. Figures and Tables

Figure 1. Arrangement of the selected ten trees in a plot.

O : Each selected tree

Figure 2. Diagrammatic representation of each measurement.

T H : Total tree height (m)

D H : Height to the lowest dead branch (m)

LBH : Height to the lowest living branch (m)

DBH : diameter at breast height (cm)

Figure 3. Diagrammatic procedure of cutting and sawing.

A : The felled tree is cut into logs 1m in length.

B : The logs are sawed longitudinally.

Figure 4. Schematic diagram of method how to isolate fungi from discolored and decayed wood.

A : Pieces of wood 5 x 5m are cut from discolored or decayed wood.

B : (1) Pieces are placed in 70% ET-OH for several seconds, (2) and placed in antiformin for two minutes, (3) and washed in sterilized water twice.

C : Sterilized pieces are incubated in PDA.

Figure 5. Relationship between tree age and height to the lowest dead and living branch.

Figure 6. Diagram illustrating progress of discoloration and decay in heartwood of *Acacia mangium*.

A : One and two years old *Acacia mangium* trees have only little dead branch.

B : Three years old ones have increasingly many dead branches.

C : Heart rot fungus begins to invade from dead branches and/or dead branch stubs of three or four years old trees.

D : Discoloration is produced in heartwood of four or five years old trees. Fungus occasionally invades from other branches.

E : Some parts of discoloration progress toward decay between five and seven years old.

F : In more than seven or eight years old trees, decayed heart wood becomes soft gradually.

Figure 7. Rough sketch of die back tree.

■ : Dead part

Figure 8. Distribution map of mortality trees (plot N-1).

Living tree

○ : Sound tree

⊙ : Abnormal tree

Dead tree

● : Newly dead tree

• : Dead tree

★ : Felled tree

Figure 9. Distribution map of mortality trees (plot N-2).

Table 1. Description of study plots.

Table 2. Evaluation of discoloration and decay of heart wood in *A. mangium*.

Table 3. The incidence of heart rot and infection courts in *A. mangium* plantations.

Table 4. Detailed results of heart rot survey in *A. mangium*.

Table 5. Disease severity and incidence of heart rot in each plot.

Table 6. Infection courts in heart rot of *A. mangium*.

Table 7. Description of sampled trees.

Table 8. Evaluation of disease severity and volumes of wood affected in discoloration and decay in sampled trees.

Table 9. Description of study plots.

Table 10. The incidence of heart rot in spacing trial plots.

Table 11. The incidence of heart rot in provenance trial plots.

Table 12. Effect of chemical treatments on the healing of wounds by pruning.

Table 13. Effect of pruning and chemical treatments on the occurrence of discoloration or decay in knots.

Table 14. Percentage of discolored or decayed knots.

Table 15. Detailed results of heart rot survey in pruning trial plots.

Table 16. The incidence of heart rot in *A. mangium*, *A. auriculiformis*, and *Acacia* hybrids.

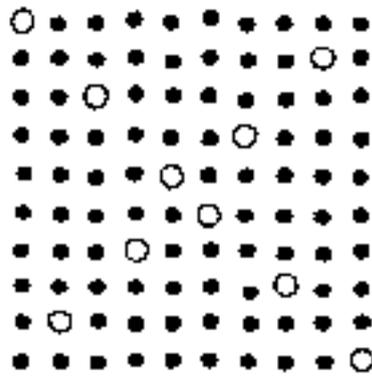


Figure 1. Arrangement of the selected ten trees in a plot.

○ : Each selected tree.

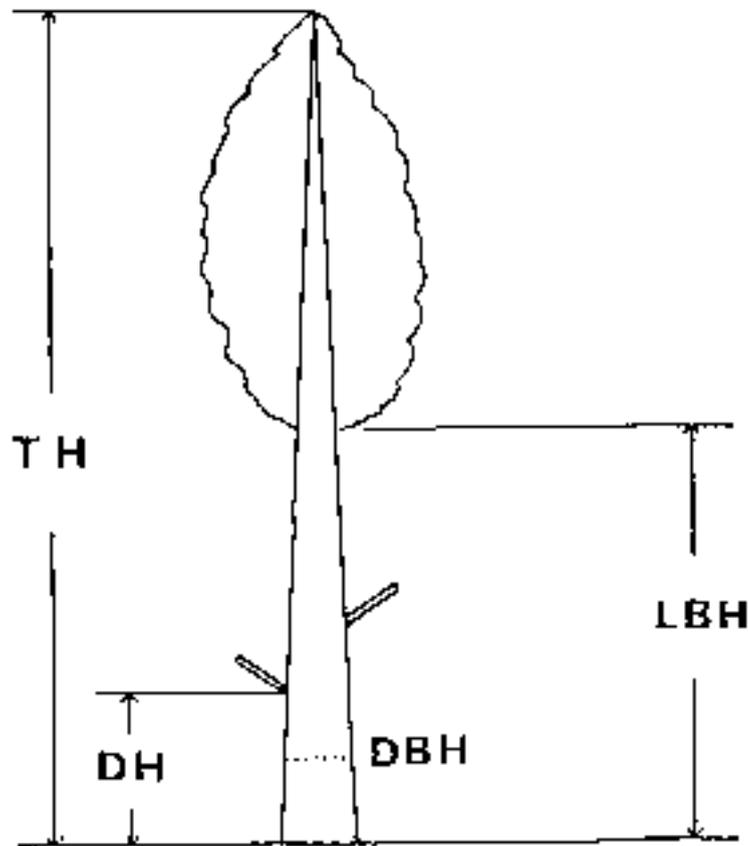


Figure 2. Diagrammatic representation of each measurement.

- TH** : Total tree height (m)
- DH** : Height to the lowest dead branch (m)
- LBH** : Height to the lowest living branch (m)
- DBH** : Diameter at breast height (cm)

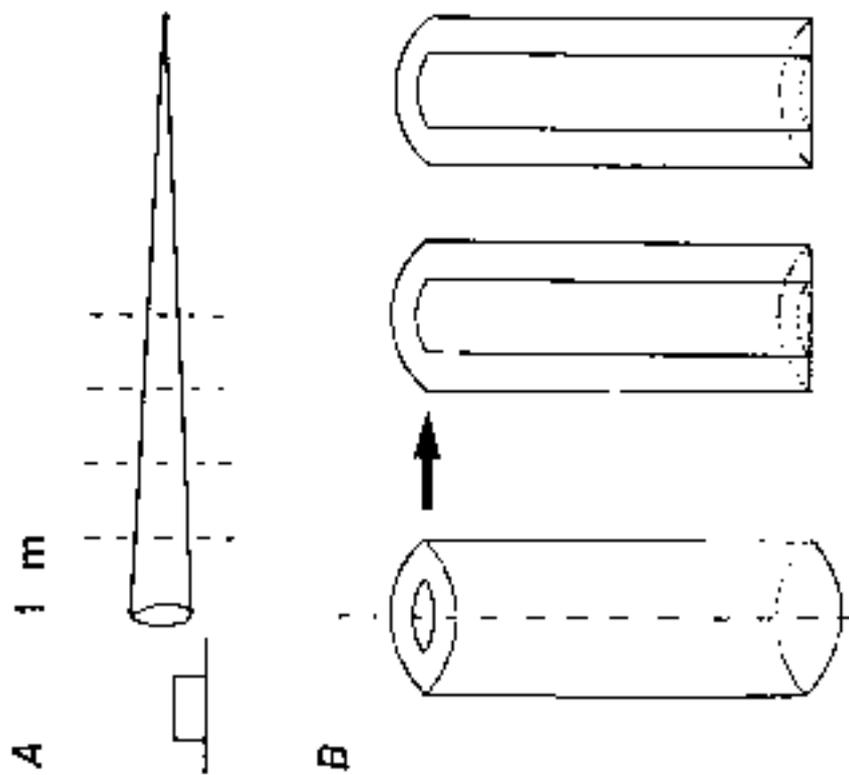


Figure 3. Diagrammatic procedure of cutting and sawing.

- A : The felled tree is cut into logs 1 m in length.
- B : The logs are sawed longitudinally.

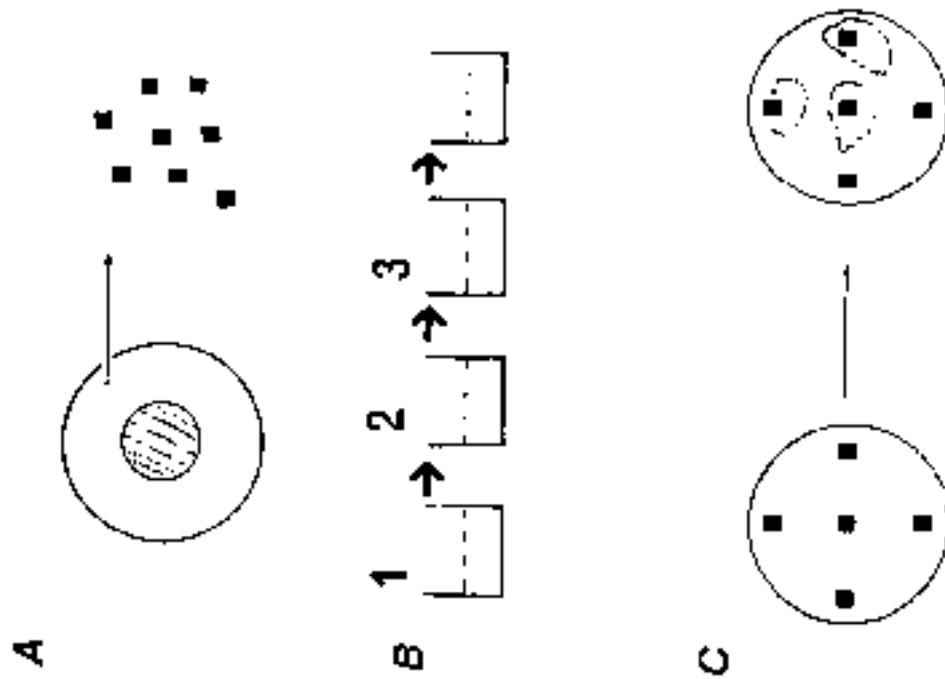


Figure 4. Schematic diagram of method how to isolate fungi from discolored and decayed wood.

- A : Pieces of wood 6 x 5 cm are cut from discolored decayed wood.
- B : (1) Pieces are placed in 70% ET-OH for several seconds, (2) and placed in antiformalin for two minutes, (3) and washed in sterilized water twice.
- C : Sterilized pieces are incubated in PDA.

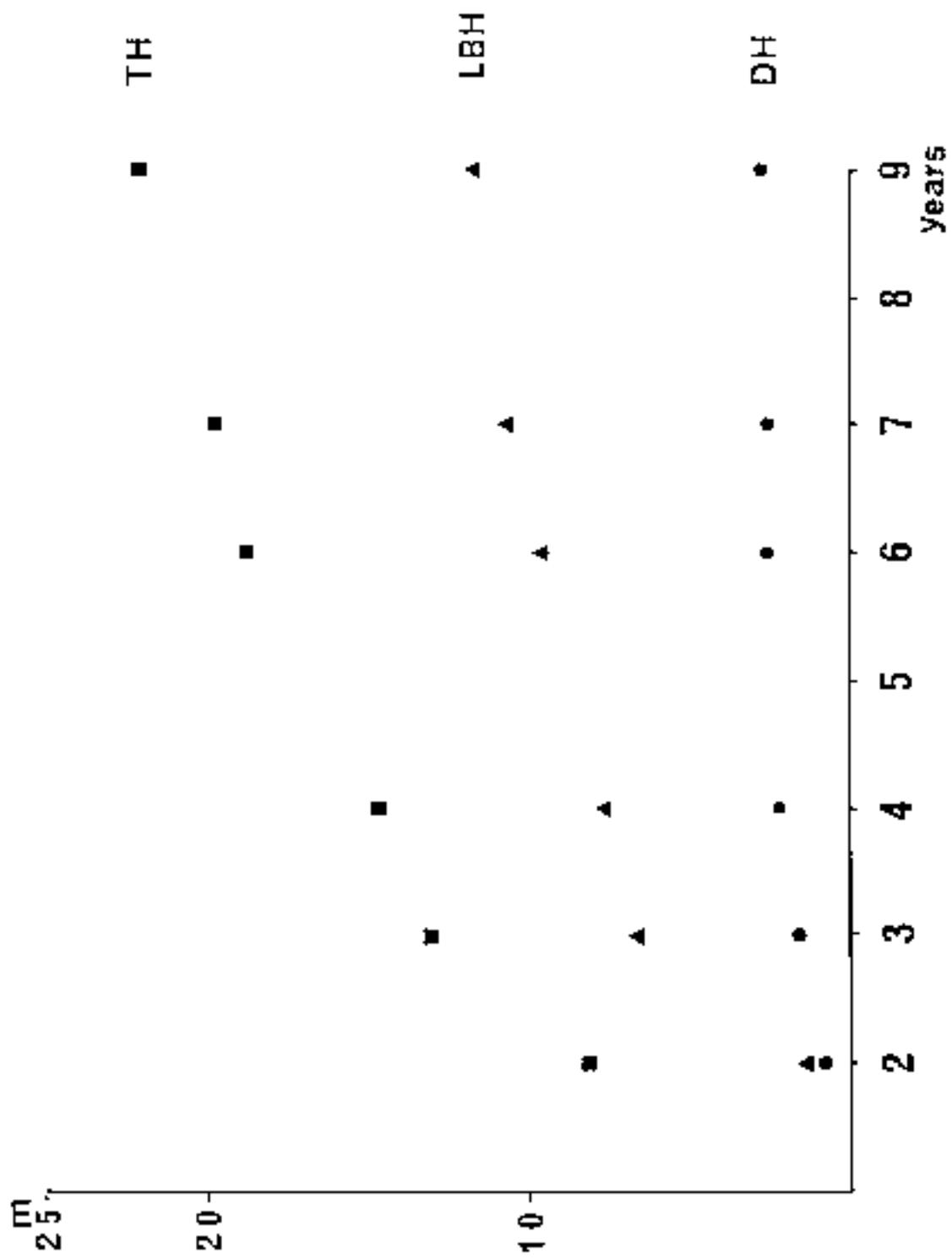
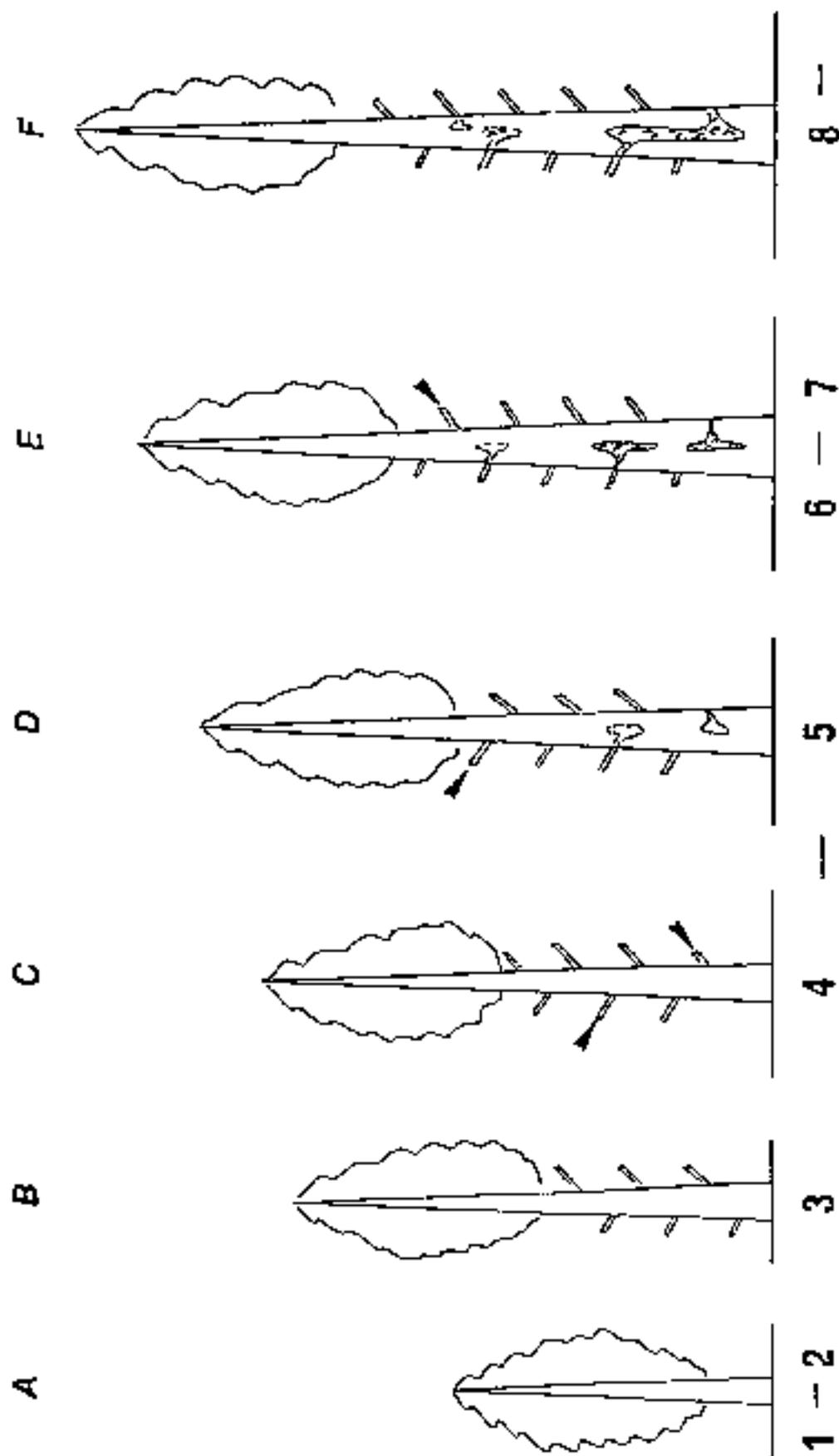


Figure 5. Relationship between tree age and height to the lowest dead and living branch.



Years

Figure 6. Diagram illustrating progress of discoloration and decay in heartwood of *Acacia mangium*.

- A : One and two years old *Acacia mangium* trees have only little dead branch.
- B : Three years old ones have increasingly many dead branches.
- C : Heart rot fungus begins to invade from dead branches and/or dead branch stubs of three or four years old trees.
- D : Discoloration is produced in heartwood of four or five years old trees. Fungus occasionally invades from other branches.
- E : Some parts of discoloration progress toward decay between five and seven years old.
- F : In more than seven or eight years old trees, decayed heart wood becomes soft gradually.

8 m

6

4

2

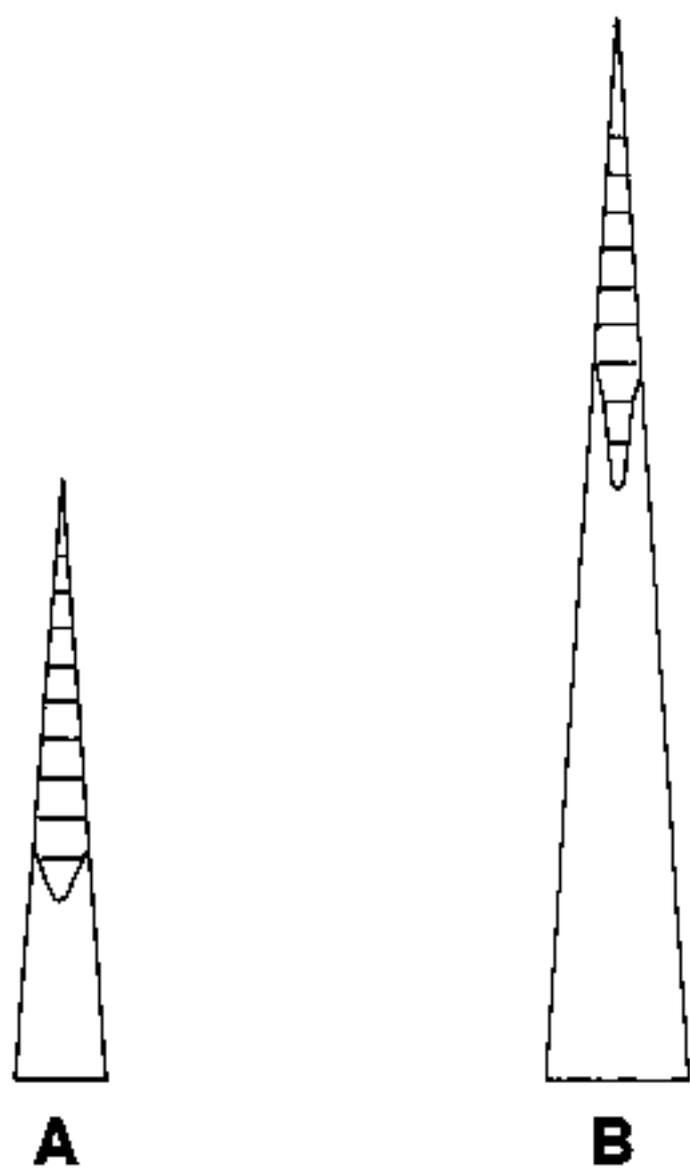


Figure 7. Rough sketch of die back tree.

— : Dead part

N - 1

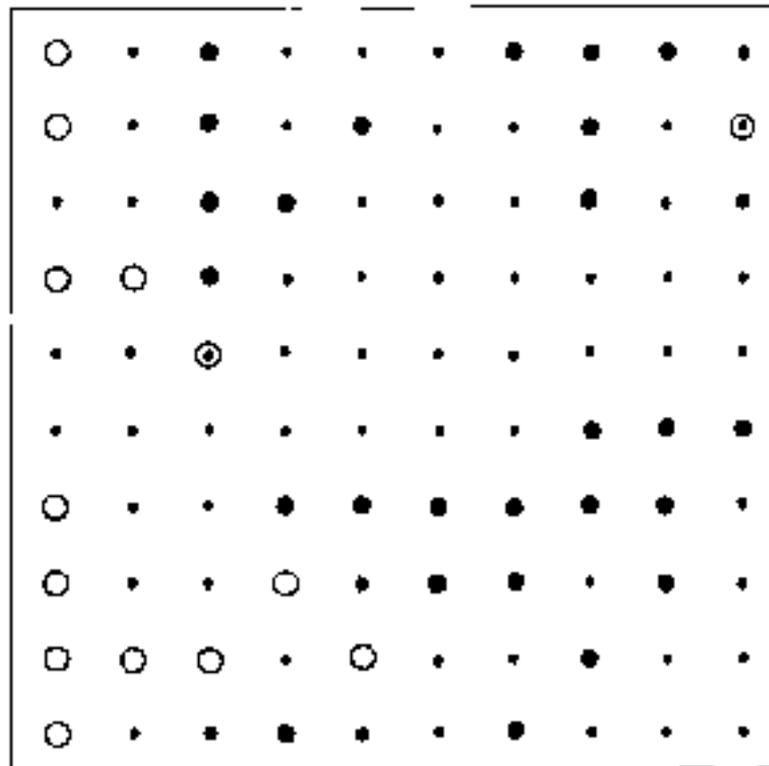


Figure 8. Distribution map of mortality trees (plot N - 1).

Living tree

- : Sound tree
- ⊙ : Abnormal tree

Dead tree

- : Newly dead tree
- : Dead tree
- * : Felled tree

N - 2

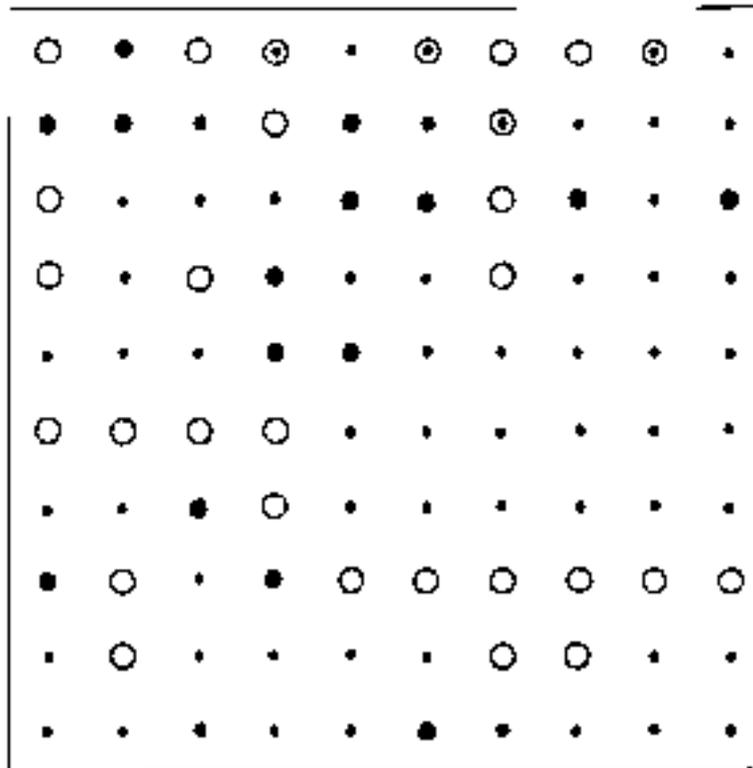


Figure 9. Distribution map of mortality trees (plot N - 2).

Table 1. Description of study plots.

| Plot | Locality | Tree Age (years) | Date of planting | Spacing (cm) | Date of sampling | Remarks |
|-------|-------------------|------------------|------------------|--------------|------------------|-----------------------|
| A - 1 | Bongkol | 2 | Nov. 1988 | 5.0 x 2.0 | Dec. 4 1990 | |
| - 2 | Kinarut | 2 | Dec. 1988 | 2.1 x 2.1 | Dec. 21 1990 | |
| B - 1 | Bongkol | 3 | Mar. 1987 | 3.0 x 3.0 | Dec. 5 1990 | |
| - 2 | Bongkol | 3 | Apr. 1987 | 3.0 x 3.0 | Dec. 5 1990 | |
| C - 1 | Bongkol | 4 | Dec. 1985 | 3.0 x 3.0 | Dec. 5 1990 | |
| - 2 | Lumat | 4 | Dec. 1985 | 2.5 x 2.5 | Dec. 14 1990 | |
| D - 1 | Bongkol | 5 | 1985 | 3.0 x 3.0 | Dec. 5 1990 | |
| - 2 | Ulu Kukut | 5 | Apr. 1985 | 3.0 x 3.0 | Dec. 19 1990 | |
| E - 1 | Timbang Menggaris | 6 | 1984 | | Dec. 20 1990 | Natural re-generation |
| F - 1 | Bongkol | 7 | 1983 | 3.0 x 3.0 | Dec. 4 1990 | |
| - 2 | Bongkol | 7 | 1983 | 3.0 x 3.0 | Dec. 4 1990 | |
| G - 1 | Kinarut | 9 | 1981 | 3.0 x 3.0 | Nov. 28 1990 | |
| - 2 | Kinarut | 9 | 1981 | 3.0 x 3.0 | Nov. 29 1990 | |
| - 3 | Bongkol | 9 | 1981 | 3.0 x 3.0 | Dec. 4 1990 | |

Table 2. Evaluation of discoloration and decay of heart wood in *A. mangium*.

| Disease Index | Description of discoloration and decay in heart wood | Disease severity |
|---------------|---|------------------|
| R0 | Sound wood or less than 1 m of discolored part is observed. | 0 |
| R1 | Length of discolored part extends more than 1 m. | 1 |
| R2 | Some part of wood, less than 1 m, are decayed. | 2 |
| R3 | Length of decayed part extends more than 1 m. | 3 |
| R4 | Decayed part is softened and easily removed. | 4 |

Table 3. The incidence of heart rot and infection courts in *A. mangium* plantations.

| Tree No. | Tree age (years) | Height (m) | DBH (cm) | Point of invasion (a) | Locality (b) | Note (c) |
|----------|------------------|------------|----------|-----------------------|--------------|----------|
| 1 | 1 | 2.7 | 4.2 | BS | PU | |
| 2 | 2 | 11.0 | 10.5 | WO | BU | |
| 3 | | 12.5 | 14.3 | WO | BO | |
| 4 | 3 | 10.0 | 15.8 | BS | BO | Pr |
| 5 | | 13.6 | 10.5 | — | KA | |
| 6 | | 11.8 | 11.0 | -- | BO | In |
| 7 | | 9.5 | 10.9 | — | BO | |
| 8 | | 9.3 | 8.4 | WO | BO | |
| 9 | 4 | 13.0 | 17.0 | BS | BO | Pr, In |
| 10 | | 16.4 | 12.5 | -- | UL | In |
| 11 | | 17.6 | 15.8 | WO | BO | |
| 12 | 5 | 19.3 | 13.4 | -- | BU | Pr |
| 13 | | 17.3 | 12.5 | BS | BU | In |
| 14 | 6 | | 18.0 | WO | KI | |
| | | | | DB | | |
| 15 | | 15.6 | 14.8 | BS | BO | In |
| 16 | 7 | 15.2 | -- | BS | KI | Pr, In |
| 17 | | 14.5 | | WO | KI | Pr, In |
| | | | | BS | | |
| | | | | DB | | |
| 18 | | 17.1 | 10.6 | BS | PU | Pr |
| 19 | | 19.7 | 13.7 | DB | PU | In |
| 20 | 8 | 15.9 | 15.5 | DB | BO | |
| 21 | 9 | | 22.2 | BS | KA | Pr, In |
| | | | | DB | | |
| 22 | | 19.1 | 15.1 | WO | KA | In |
| | | | | DB | | |
| | | | | BS | | |

(a) BS : Branch Stub
 DB : Dead Branch
 WO : Wound
 — : No Heart Rot

(b) PU : Punteh
 BU : Bunang
 BO : Bongkol
 KA : Karamatol
 UL : Ulu Kukuf
 KI : Kinarut

(c) Pr : Pruning
 In : Insect (Pin holes)

Table 4. Detailed results of heart rot survey in *A. mangium*.

| Plot | Tree No. | TH (m) | DH (m) | LBH (m) | FH (m) | DBH (cm) | Disease severity | Point of invasion | Remarks |
|-------|----------|-----------|-----------|------------|-----------|-------------|---------------------|----------------------|---------|
| A - 1 | 1 | 10.1 | - | 0.9 | | 10.5 | 0 | | |
| | 2 | 8.3 | 0.5 | 1.2 | | 14.0 | 0 | | |
| | 3 | 7.8 | 0.7 | 1.9 | | 8.1 | 0 | | |
| | 4 | 8.3 | 1.2 | 1.7 | | 8.8 | 0 | | |
| | 5 | 7.2 | 0.7 | 0.9 | | 9.0 | 0 | | |
| | 6 | 7.0 | 0.3 | 0.8 | | 7.8 | 0 | | |
| | 7 | 8.1 | 0.7 | 1.5 | | 9.1 | 0 | | |
| | 8 | 8.0 | 0.8 | 1.4 | | 9.7 | 0 | | |
| | 9 | 8.0 | 1.1 | 1.7 | | 8.1 | 1 | | |
| | 10 | 7.9 | 1.0 | 1.3 | | 9.4 | 0 | | |
| | Ave. | 8.1 | 0.8 | 1.3 | | 9.6 | 0.1 | | |
| A - 2 | 1 | 7.0 | 0.4 | 1.0 | 4.3 | 4.3 | 0 | | |
| | 2 | 6.4 | 0.7 | 1.7 | | 4.7 | 0 | | |
| | 3 | 6.7 | 1.1 | 2.1 | | 6.0 | 0 | | |
| | 4 | 7.3 | 0.5 | 1.4 | 3.7 | 6.0 | 0 | | |
| | 5 | 9.4 | 0.5 | 1.9 | | 6.6 | 0 | | |
| | 6 | 8.7 | 0.5 | 1.1 | | 6.2 | 0 | | |
| | 7 | 6.6 | 0.4 | 0.7 | | 7.6 | 0 | | |
| | 8 | 10.1 | 0.3 | 0.8 | | 6.3 | 0 | | |
| | 9 | 8.2 | 0.2 | 0.6 | | 6.2 | 0 | | |
| | 10 | 8.5 | 0.5 | 1.0 | | 9.0 | 0 | | |
| | Ave. | 8.3 | 0.5 | 1.2 | 4.0 | 7.1 | 0 | | |
| B - 1 | 1 | 12.4 | 1.5 | 8.1 | 4.5 | 11.6 | 1 | | |
| | 2 | 13.5 | 1.8 | 7.2 | | 8.9 | 1 | | |
| | 3 | 13.7 | 1.7 | 7.7 | | 9.1 | 1 | | |
| | 4 | 14.3 | 2.0 | 7.3 | 6.7 | 16.0 | 1 | | |
| | 5 | 12.0 | 1.5 | 6.5 | 5.0 | 10.6 | 1 | | |
| | 6 | 13.8 | 1.5 | 6.8 | | 11.3 | 0 | | |
| | 7 | 13.0 | 1.7 | 5.8 | | 9.9 | 0 | | |
| | 8 | 14.2 | 1.9 | 8.2 | 6.4 | 13.9 | 0 | | |
| | 9 | 11.9 | 1.5 | 6.6 | | 7.5 | 0 | | |
| | 10 | 12.2 | 1.4 | 6.4 | | 11.8 | 0 | | |
| | Ave. | 13.1 | 1.7 | 6.7 | 5.7 | 11.1 | 0.5 | | |
| B - 2 | 1 | 8.8 | 1.5 | 2.1 | | 8.0 | 0 | | |
| | 2 | 11.9 | 1.6 | 4.1 | 4.8 | 17.4 | 0 | | |
| | 3 | 12.3 | 1.5 | 4.1 | 4.6 | 16.4 | 0 | | |
| | 4 | 11.7 | 1.0 | 2.7 | | 11.1 | 0 | | |
| | 5 | 12.3 | 1.3 | 3.4 | 7.1 | 13.7 | 1 | | |
| | 6 | 10.1 | 1.7 | 3.0 | | 6.8 | 0 | | |
| | 7 | 10.5 | 1.6 | 2.7 | | 10.3 | 0 | | |
| | 8 | 11.8 | 1.5 | 2.5 | | 10.8 | 1 | | |
| | 9 | 13.3 | 1.5 | 2.7 | 3.5 | 18.3 | 0 | | |
| | 10 | 11.9 | 1.4 | 4.0 | 4.7 | 13.5 | 1 | | |
| | Ave. | 11.5 | 1.5 | 3.1 | 4.9 | 12.9 | 0.3 | | |

Table 4. (continued)

| Plot | Tree No. | TH (m) | DH (m) | LBH (m) | FH (m) | DBH (cm) | Disease severity | Point of invasion | Remarks |
|-------|----------|-----------|-----------|------------|-----------|-------------|---------------------|----------------------|---------|
| C - 1 | 1 | 14.6 | 1.7 | 6.4 | | 12.5 | 0 | | |
| | 2 | 15.1 | 3.4 | 7.9 | | 12.0 | 3 | BR | |
| | 3 | 15.7 | 1.9 | 8.2 | 3.3 | 17.6 | 2 | | |
| | 4 | 15.0 | 2.0 | 8.7 | | 11.1 | 0 | | |
| | 5 | 15.8 | 2.9 | 9.1 | | 12.4 | 0 | | |
| | 6 | 15.0 | 2.7 | 8.1 | 10.1 | 12.4 | 1 | | |
| | 7 | 14.8 | 2.0 | 7.2 | | 13.4 | 0 | | |
| | 8 | 13.4 | 2.1 | 7.8 | | 9.1 | 0 | | |
| | 9 | 14.2 | 2.5 | 7.9 | 3.9 | 15.3 | 0 | | |
| | 10 | 13.7 | 1.6 | 6.1 | 4.8 | 13.8 | 0 | | |
| | Ave. | 14.7 | 2.2 | 7.7 | 5.5 | 13.0 | 0.6 | | |
| C - 2 | 1 | 12.5 | 1.0 | 4.9 | | 8.6 | 4 | BR | |
| | 2 | 13.0 | 0.8 | 8.6 | | 8.3 | 0 | | |
| | 3 | 15.6 | 0.9 | 9.7 | 3.8 | 13.6 | 3 | BR | |
| | 4 | 15.9 | 1.1 | 8.2 | | 13.5 | 2 | | |
| | 5 | 15.4 | 0.8 | 10.0 | | 12.4 | 0 | | |
| | 6 | 14.6 | 1.1 | 8.3 | | 15.5 | 2 | | |
| | 7 | 13.4 | 0.8 | 9.8 | | 10.0 | 3 | BR | |
| | 8 | 13.3 | 1.4 | 7.7 | | 9.2 | 3 | BR, WO | |
| | 9 | 14.0 | 0.2 | 7.9 | 1.0 | 10.4 | 0 | | |
| | 10 | 14.0 | 0.4 | 7.8 | | 10.5 | 0 | | |
| | Ave. | 14.2 | 0.8 | 8.3 | 2.4 | 11.2 | 1.7 | | |
| D - 1 | 1 | 7.2 | 2.1 | 6.5 | | 10.9 | 0 | | |
| | 2 | 13.0 | 2.3 | 5.1 | | 12.2 | 1 | | |
| | 3 | 13.5 | 1.7 | 5.9 | 7.6 | 11.0 | 0 | | |
| | 4 | 12.2 | 1.7 | 3.2 | 5.8 | 17.0 | 3 | WO | SQ |
| | 5 | 12.7 | 2.4 | 3.6 | | 15.9 | 2 | | |
| | 6 | 12.0 | 1.5 | 5.3 | | 9.4 | 1 | | |
| | 7 | 13.4 | 1.7 | 3.6 | | 16.5 | 0 | | |
| | 8 | 12.9 | 2.1 | 3.1 | 7.3 | 14.7 | 4 | WO | SQ |
| | 9 | 10.7 | 1.7 | 3.5 | 6.9 | 10.8 | 0 | | |
| | 10 | 7.9 | 1.2 | 3.0 | | 6.8 | 0 | | |
| | Ave. | 11.6 | 1.8 | 4.2 | 6.7 | 12.4 | 1.1 | | |
| D - 2 | 1 | 13.8 | 2.0 | 4.7 | 10.0 | 16.3 | 1 | | |
| | 2 | 14.4 | 1.1 | 3.7 | | 16.6 | 3 | BR | IN |
| | 3 | 14.0 | 1.3 | 6.8 | 4.5 | 15.0 | 3 | BR | |
| | 4 | 14.1 | 1.6 | 7.9 | 7.9 | 12.3 | 1 | | |
| | 5 | 13.3 | 1.0 | 3.7 | 7.5 | 19.0 | 3 | BR, WO | SD |
| | 6 | 14.1 | 1.5 | 5.3 | 6.5 | 16.7 | 1 | | |
| | 7 | 14.0 | 1.4 | 4.3 | 3.0 | 14.4 | 2 | | IN |
| | 8 | 11.3 | 1.1 | 4.9 | 5.2 | 10.0 | 1 | | |
| | 9 | 14.0 | 1.1 | 5.2 | 7.9 | 17.7 | 3 | BR | IN |
| | 10 | 13.9 | 1.1 | 6.3 | 3.5 | 18.0 | 2 | | |
| | Ave. | 13.7 | 1.3 | 5.3 | 6.3 | 15.6 | 2.0 | | |

Table 4. (continued)

| Plot | Tree No. | TH (m) | DH (m) | LBH (m) | FH (m) | DBH (cm) | Disease severity | Point of invasion | Remarks |
|-------|----------|--------|--------|---------|--------|----------|------------------|-------------------|---------|
| E - 1 | 1 | 16.1 | 1.9 | 3.1 | 10.6 | 9.2 | 1 | | |
| | 2 | 20.6 | 2.1 | 9.4 | 9.5 | 17.5 | 1 | | |
| | 3 | 16.6 | 4.2 | 12.4 | | 13.2 | 4 | BR, WO | CA |
| | 4 | 19.2 | 3.1 | 12.4 | 7.7 | 12.1 | 2 | | |
| | 5 | 19.9 | 2.2 | 6.8 | | 15.9 | 0 | | |
| | 6 | 18.2 | 2.9 | 11.5 | 9.8 | 11.5 | 0 | BR, WO | CA, IN |
| | 7 | 19.6 | 3.3 | 6.3 | | 14.7 | 1 | | |
| | 8 | 17.4 | 2.2 | 12.7 | 6.2 | 10.9 | 3 | BR, WO | |
| | 9 | 19.6 | 2.7 | 12.6 | 7.6 | 12.8 | 2 | | |
| | 10 | 19.4 | 2.6 | 8.5 | 8.6 | 17.4 | 3 | BR, WO | |
| | Ave. | 18.9 | 2.7 | 9.6 | | 13.5 | 2.0 | | |
| F - 1 | 1 | 19.5 | 1.7 | 11.1 | 4.6 | 17.1 | 2 | | |
| | 2 | 20.6 | 3.6 | 12.4 | 7.3 | 14.5 | 4 | BR | |
| | 3 | 18.0 | 2.2 | 9.8 | | 12.5 | 2 | | |
| | 4 | 20.1 | 3.0 | 9.0 | | 16.4 | 3 | BR | |
| | 5 | 20.4 | 1.5 | 9.6 | 7.4 | 21.2 | 3 | BR, WO | IN |
| | 6 | 18.1 | 3.0 | 11.3 | 7.6 | 14.2 | 3 | BR, WO | IN |
| | 7 | 20.5 | 3.2 | 12.1 | 10.2 | 20.4 | 2 | | |
| | 8 | 20.0 | 1.9 | 12.7 | 5.1 | 18.4 | 0 | | |
| | 9 | 19.5 | 1.5 | 12.5 | | 13.4 | 1 | | |
| | 10 | 18.9 | 1.3 | 7.0 | | 17.4 | 4 | BR | IN |
| | Ave. | 19.6 | 2.3 | 10.8 | 7.0 | 16.6 | 2.4 | | |
| F - 2 | 1 | 19.2 | 2.2 | 6.0 | 5.6 | 19.1 | 2 | | IN |
| | 2 | 19.5 | 2.5 | 10.4 | 6.4 | 16.4 | 2 | | |
| | 3 | 20.7 | 2.1 | 12.3 | 6.7 | 17.6 | 3 | BR | IN |
| | 4 | 20.6 | 2.1 | 10.7 | | 19.7 | 0 | | |
| | 5 | 19.8 | 2.5 | 10.7 | | 15.5 | 2 | | IN |
| | 6 | 20.0 | 1.7 | 10.0 | | 18.3 | 1 | | |
| | 7 | 19.5 | 3.2 | 12.4 | | 16.0 | 4 | BR | IN |
| | 8 | 18.1 | 2.6 | 6.4 | | 16.3 | 3 | BR | IN |
| | 9 | 19.7 | 2.9 | 11.0 | 3.8 | 16.7 | 0 | | |
| | 10 | 18.9 | 2.0 | 10.0 | | 16.0 | 3 | BR | IN |
| | Ave. | 19.6 | 2.4 | 10.2 | 5.4 | 17.1 | 2.0 | | |
| G - 1 | 1 | 17.5 | 3.0 | 8.3 | | 13.8 | 2 | | SQ |
| | 2 | 17.3 | 3.0 | 8.7 | | 18.0 | 2 | | SQ |
| | 3 | 18.0 | 3.3 | 8.6 | | 15.6 | 4 | WO | |
| | 4 | 13.8 | 3.3 | 3.9 | | 12.0 | 0 | | |
| | 5 | 15.0 | 4.0 | 4.2 | | 18.1 | 3 | WO | |
| | 6 | 19.9 | 3.6 | 8.2 | | 16.5 | 3 | WO | SQ |
| | 7 | 16.8 | 3.4 | 3.9 | | 14.5 | 4 | WO | SQ |
| | 8 | 15.0 | 2.3 | 8.9 | | 12.5 | 2 | | SQ |
| | 9 | 16.3 | 3.8 | 5.9 | 3.4 | 18.5 | 4 | WO | SQ |
| | 10 | 9.9 | 2.5 | 4.3 | | 8.5 | 1 | | |
| | Ave. | 16.0 | 3.2 | 6.3 | 3.4 | 14.6 | 2.5 | | |

Table 4. (continued)

| Plot | Tree No. | TH (m) | DH (m) | LBH (m) | FH (m) | DBH (cm) | Disease severity | Point of invasion | Remarks |
|-------|----------|-----------|-----------|------------|-----------|-------------|---------------------|----------------------|---------|
| G - 2 | 1 | 8.5 | 1.8 | 2.0 | | 8.8 | 4 | WO | DI |
| | 2 | 8.4 | 2.4 | 3.2 | 4.3 | 9.6 | 1 | | DI |
| | 3 | 10.5 | 2.9 | 2.7 | 4.4 | 14.5 | 0 | | SQ, DI |
| | 4 | 13.0 | 3.6 | 3.7 | 6.2 | 15.7 | 4 | WO | SQ, DI |
| | 5 | 9.6 | 2.8 | 2.9 | | 8.4 | 0 | | DI |
| | 6 | 10.1 | 2.9 | 4.4 | 3.0 | 13.7 | 3 | WO | SQ, DI |
| | 7 | 11.7 | 2.8 | 2.8 | | 12.9 | 1 | | SQ, DI |
| | 8 | 11.9 | 3.6 | 5.9 | 3.0 | 13.4 | 3 | WO | SQ |
| | 9 | 13.2 | 3.0 | 4.0 | | 15.5 | 3 | WO | |
| | 10 | 10.1 | 2.6 | 3.1 | | 11.1 | 0 | | DI |
| | Ave. | 10.5 | 2.8 | 3.5 | 4.2 | 12.4 | 1.9 | | |
| G - 3 | 1 | 22.4 | 3.0 | 15.6 | 9.0 | 18.5 | 4 | BR | |
| | 2 | 23.6 | 2.6 | 15.7 | 19.0 | 22.6 | 3 | BR | |
| | 3 | 21.6 | 3.8 | 13.4 | | 13.6 | 1 | | |
| | 4 | 22.9 | 2.7 | 12.9 | | 21.8 | 0 | | |
| | 5 | 21.0 | 2.9 | 8.3 | 6.3 | 18.2 | 2 | | |
| | 6 | 22.1 | 3.3 | 10.4 | 6.3 | 18.2 | 4 | WO | |
| | 7 | 22.2 | 2.5 | 11.8 | 7.8 | 17.5 | 1 | | |
| | 8 | 21.9 | 2.2 | 7.7 | | 18.2 | 3 | BR, WO | |
| | 9 | 22.4 | 2.7 | 7.7 | 9.8 | 23.2 | 2 | | |
| | 10 | 20.9 | 3.3 | 14.2 | 7.0 | 15.6 | 3 | BR, WO | |
| | Ave. | 22.1 | 2.9 | 11.8 | 8.4 | 18.5 | 2.3 | | |

TH : Total tree height.

DH : Height to the lowest dead branch.

LBH : Height to the lowest living branch.

FH : Height to focked part.

DBH : Diameter at breast height.

Point of invasion : BR = Branch, WO = Wound.

Remarks : SQ = Squirrel damage
 IN = Insect (pin-hole) damage
 CA = Canker
 DI = Die-back of top

Table 5. Disease severity and incidence of heart rot in each plot.

| Plot | Disease severity | | | | | Average Disease Severity | % of 3 and 4 |
|-------|------------------|---|---|---|---|--------------------------|-------------------------|
| | 0 | 1 | 2 | 3 | 4 | | |
| A - 1 | 9 | 1 | 0 | 0 | 0 | 0.1 | 0 |
| 2 | 10 | 0 | 0 | 0 | 0 | 0 | 0 |
| B - 1 | 5 | 5 | 0 | 0 | 0 | 0.5 | 0 |
| 2 | 7 | 3 | 0 | 0 | 0 | 0.3 | 0 |
| C - 1 | 7 | 1 | 1 | 1 | 0 | 0.8 | 10 (1/10) |
| 2 | 4 | 0 | 2 | 3 | 1 | 1.7 | 40 (4/10) 25 (5/20) |
| D - 1 | 5 | 2 | 1 | 1 | 1 | 1.1 | 20 (2/10) |
| 2 | 0 | 4 | 2 | 4 | 0 | 2.0 | 40 (4/10) 30 (6/20) |
| E - 1 | 1 | 3 | 2 | 3 | 1 | 2.0 | 40 (4/10) |
| F - 1 | 1 | 1 | 3 | 3 | 2 | 2.4 | 50 (5/10) |
| 2 | 2 | 1 | 3 | 3 | 1 | 2.0 | 40 (4/10) 45 (9/20) |
| G - 1 | 1 | 1 | 3 | 2 | 3 | 2.5 | 50 (5/10) |
| 2 | 3 | 2 | 0 | 3 | 2 | 1.9 | 30 (5/10) |
| 3 | 1 | 2 | 2 | 3 | 2 | 2.3 | 60 (5/10) 50 (15/30) |

$$\text{Average disease severity} = \frac{0 * N1 + 1 * N2 + 2 * N3 + 3 * N4 + 4 * N5}{N1 + N2 + N3 + N4 + N5}$$

$$N1 + N2 + N3 + N4 + N5 = 10$$

N : each tree number

Table 6. Infection count in heart rot of *A. mangium*.

| Infection count | Percentage (%) |
|-------------------------|----------------|
| Dead branch stubs | 29.4 |
| Dead branch | 20.6 |
| Unhealed pruning wounds | 19.1 |
| Unhealed branch stubs | 8.8 |
| Forked injuries | 7.4 |
| Squirrel damage | 5.9 |
| Unknown | 8.8 |

Table 7. Description of sampled trees.

| Plot | Tree number | TH (m) | DH (m) | LBH (m) | FH (m) | DBH (cm) | Remarks |
|-------|-------------|--------|--------|---------|--------|----------|------------|
| H - 1 | 1 | 20.1 | 2.2 | 12.6 | 6.1 | 20.2 | IN |
| | 2 | 18.6 | 1.6 | 8.6 | 7.8 | 22.5 | IN, SQ |
| | 3 | 19.8 | 1.7 | 11.2 | 4.3 | 20.4 | IN, CA |
| | 4 | 19.9 | 1.9 | 14.4 | 5.5 | 22.0 | IN, AN |
| | 5 | 19.5 | 2.0 | 7.4 | 5.3 | 22.0 | IN, CA |
| | 6 | 19.8 | 3.2 | 10.3 | 9.9 | 20.0 | IN |
| | 7 | 20.0 | 2.2 | 9.8 | 7.4 | 22.2 | IN |
| | 8 | 19.2 | 1.5 | 9.4 | 6.0 | 19.6 | IN |
| | 9 | 18.9 | 2.3 | 6.6 | 6.3 | 21.1 | IN |
| | 10 | 19.0 | 1.7 | 6.3 | - | 19.5 | IN, CA |
| | 11 | 19.1 | 1.8 | 5.8 | - | 19.6 | IN, CA, AN |
| | 12 | 21.9 | 2.2 | 11.7 | 8.2 | 18.0 | IN |
| | 13 | 22.5 | 1.7 | 6.1 | 6.3 | 22.6 | CA, AN |
| | 14 | 22.8 | 1.4 | 11.0 | - | 21.8 | IN |
| | 15 | 21.9 | 1.2 | 8.1 | 7.5 | 24.0 | IN, AN |
| | 16 | 22.7 | 1.7 | 8.0 | 12.3 | 24.4 | IN |
| | 17 | 21.8 | 1.8 | 12.0 | 8.6 | 23.7 | IN |
| | 18 | 21.2 | 1.6 | 10.4 | - | 17.4 | |
| | 19 | 20.0 | 1.3 | 11.5 | 9.8 | 20.1 | IN |
| | 20 | 17.9 | 1.5 | 11.1 | - | 18.4 | IN |
| | Ave. | 20.3 | 1.8 | 9.7 | 7.6 | 21.0 | |
| H - 2 | 1 | 13.4 | 0.6 | 11.9 | 9.0 | 14.2 | IN |
| | 2 | 18.1 | 0.5 | 12.3 | 9.4 | 15.0 | |
| | 3 | 16.9 | 1.6 | 7.7 | - | 14.1 | |
| | 4 | 12.9 | 0.7 | 11.8 | 9.9 | 14.8 | |
| | 5 | 15.7 | 0.9 | 9.2 | 5.9 | 13.5 | |
| | 6 | 15.8 | 1.0 | 10.0 | 6.3 | 14.0 | |
| | 7 | 14.4 | 1.1 | 11.0 | 7.4 | 15.5 | |
| | 8 | 14.7 | 1.2 | 9.2 | 7.5 | 17.0 | |
| | 9 | 18.3 | 1.5 | 8.8 | 6.9 | 17.3 | |
| | 10 | 14.2 | 0.6 | 10.2 | 7.9 | 14.1 | IN |
| | 11 | 13.3 | 0.5 | 9.7 | 7.2 | 12.7 | |
| | 12 | 16.7 | 0.5 | 10.3 | - | 18.5 | IN |
| | 13 | 16.3 | 0.8 | 10.9 | 6.6 | 13.2 | |
| | 14 | 15.3 | 1.3 | 6.9 | 9.0 | 18.6 | IN |
| | 15 | 17.9 | 1.1 | 10.2 | 13.3 | 14.3 | |
| | 16 | 17.5 | 0.6 | 9.6 | - | 16.6 | |
| | 17 | 15.9 | 0.2 | 10.6 | 8.7 | 16.6 | |
| | 18 | 15.8 | 0.6 | 9.3 | 5.9 | 14.2 | |
| | 19 | 15.1 | 0.6 | 9.2 | 7.6 | 13.9 | IN |
| | 20 | 16.7 | 0.6 | 10.7 | 9.3 | 14.1 | |
| | Ave. | 15.7 | 0.8 | 10.0 | 8.3 | 14.9 | |

TH Total tree height.

DH Height to the lowest dead branch.

LBH Height to the lowest living branch.

FH Height to the forked part.

DBH Diameter at breast height.

Remarks: IN = Insect (pin-hole),

CA = Canker,

SQ = Squirrel,

AN = Ants.

Table 8. Evaluation of disease index and volumes of wood affected in discoloration and decay in sampled trees.

| Plot | Tree number | Disease Index | Discoloration | Volume affected (%) Heart-rot | Total |
|-------|-------------|---------------|---------------|----------------------------------|-------|
| H - 1 | 1 | R2 | 7.2 | 1.4 | 8.6 |
| | 2 | R4 | 12.8 | 2.9 | 15.7 |
| | 3 | R2 | 9.0 | 1.7 | 10.7 |
| | 4 | R2 | 9.5 | 0.7 | 10.2 |
| | 5 | R3 | 18.5 | 6.3 | 24.8 |
| | 6 | R3 | 14.2 | 7.1 | 21.3 |
| | 7 | R3 | 9.9 | 4.2 | 14.1 |
| | 8 | R3 | 10.0 | 3.5 | 13.5 |
| | 9 | R3 | 14.9 | 5.5 | 20.4 |
| | 10 | R3 | 11.5 | 5.2 | 16.7 |
| | 11 | R2 | 8.4 | 2.0 | 10.4 |
| | 12 | R3 | 11.8 | 3.7 | 15.5 |
| | 13 | R3 | 14.8 | 7.3 | 22.1 |
| | 14 | R3 | 11.5 | 4.0 | 15.5 |
| | 15 | R3 | 18.6 | 2.8 | 21.4 |
| | 16 | R3 | 10.7 | 2.6 | 13.3 |
| | 17 | R3 | 9.1 | 3.4 | 12.5 |
| | 18 | R2 | 8.9 | 1.3 | 10.2 |
| | 19 | R3 | 11.3 | 4.9 | 16.2 |
| | 20 | R3 | 15.2 | 6.3 | 21.5 |
| H - 2 | 1 | R2 | 5.9 | 0.1 | 6.0 |
| | 2 | R3 | 15.1 | 5.0 | 20.1 |
| | 3 | R2 | 10.1 | 1.6 | 11.7 |
| | 4 | R1 | - | - | - |
| | 5 | R2 | 8.1 | - | 8.1 |
| | 6 | R2 | 13.8 | 0.1 | 13.9 |
| | 7 | R2 | 8.1 | 1.3 | 9.4 |
| | 8 | R0 | - | - | - |
| | 9 | R3 | 8.8 | 2.9 | 11.7 |
| | 10 | R2 | 20.8 | 6.9 | 27.7 |
| | 11 | R2 | 5.0 | 3.3 | 8.3 |
| | 12 | R2 | 11.9 | 2.2 | 14.1 |
| | 13 | R2 | 4.3 | 0.5 | 4.8 |
| | 14 | R3 | 19.6 | 10.7 | 30.3 |
| | 15 | R0 | - | - | - |
| | 16 | R3 | 13.6 | 4.1 | 17.7 |
| | 17 | R0 | - | - | - |
| | 18 | R3 | 13.6 | 2.8 | 16.4 |
| | 19 | R2 | 5.0 | - | 5.0 |
| | 20 | R2 | 11.9 | 0.1 | 12.0 |

- R0 Sound wood or less than 1 m of discolored part is observed.
R1 Length of discolored part extends more than 1 m.
R2 Some part of wood, less than 1 m, are decayed.
R3 Length of decayed part extends more than 1 m.
R4 Decayed part is softened and easily removed.

Table 9. Description of study plots.

| Plot | Locality | Tree Age (years) | Date of planting | Spacing (cm) | Date of sampling | Remarks |
|-------|----------|------------------|------------------|--------------|------------------|----------------------------------|
| I - 1 | Kinarut | 5 | Oct. 1988 | 1.0 x 1.0 | Aug. 16 1993 | Spacing trial |
| - 2 | Kinarut | 5 | Oct. 1988 | 2.1 x 2.1 | Aug. 16 1993 | |
| - 3 | Kinarut | 5 | Oct. 1988 | 4.2 x 4.2 | Aug. 16 1993 | |
| J - 1 | Kinarut | 5 | Nov. 1988 | 3.0 x 3.0 | Aug. 21 1993 | Provenance Australia (Whyarbell) |
| - 2 | Kinarut | 5 | Nov. 1988 | 3.0 x 3.0 | Aug. 16 1993 | PNG (Balamuk) |
| - 3 | Kinarut | 5 | Nov. 1988 | 3.0 x 3.0 | Aug. 17 1993 | PNG (Barum) |
| - 4 | Kinarut | 5 | Nov. 1988 | 3.0 x 3.0 | Aug. 21 1993 | Malaysia (Sabah - Ulu Kukut) |
| - 5 | Kinarut | 5 | Nov. 1988 | 3.0 x 3.0 | Aug. 17 1993 | Malaysia (Sabah - SSS6) |
| K - 1 | Kinarut | 5 | Oct. 1988 | 3.0 x 3.0 | Aug. 10 1993 | Pruning only |
| - 2 | Kinarut | 5 | Oct. 1988 | 3.0 x 3.0 | Aug. 10 1993 | Paint treatment |
| - 3 | Kinarut | 5 | Oct. 1988 | 3.0 x 3.0 | Aug. 10 1993 | Topzin treatment |
| - 4 | Kinarut | 5 | Oct. 1988 | 3.0 x 3.0 | Aug. 10 1993 | No pruning |
| L - 1 | Kinarut | 5 | Oct. 1988 | 2.5 x 2.5 | July 28 1993 | Species <i>A. mangium</i> |
| - 2 | Kinarut | 5 | Oct. 1988 | 2.5 x 2.5 | July 28 1993 | <i>A. auriculiformis</i> |
| - 3 | Kinarut | 5 | Oct. 1988 | 2.5 x 2.5 | July 28 1993 | Hybrid |

Table 10. The incidence of heart rot in spacing trial plots.

| Plot | Tree No. | TH (m) | DH (m) | LBH (m) | FH (m) | DBH (cm) | Disease severity | Point of invasion | Remarks |
|-------|----------|-----------|-----------|------------|-----------|-------------|---------------------|----------------------|---------|
| I - 1 | 1 | 17.7 | 0.8 | 10.0 | | 11.1 | 3 | BR | |
| | 2 | 21.2 | 0.9 | 9.4 | | 11.3 | 3 | BR, WO | SQ |
| | 3 | 16.3 | 1.3 | 10.1 | | 10.6 | 3 | WO | |
| | 4 | 16.6 | 1.4 | 9.4 | | 10.1 | 2 | | |
| | 5 | 16.9 | 0.7 | 9.4 | | 11.5 | 2 | | |
| | Ave. | | 17.7 | 1.0 | 9.7 | | 10.9 | 2.6 | |
| I - 2 | 1 | 16.1 | 0.6 | 5.8 | | 14.3 | 2 | | |
| | 2 | 18.0 | 0.8 | 7.4 | | 13.8 | 3 | BR | SQ |
| | 3 | 16.4 | 0.8 | 2.7 | | 15.8 | 2 | | SQ |
| | 4 | 16.0 | 1.0 | 8.7 | | 14.3 | 2 | | SQ |
| | 5 | 14.1 | 0.9 | 4.1 | | 14.3 | 1 | | SQ |
| | Ave. | | 16.1 | 0.7 | 5.7 | | 14.5 | 2.0 | |
| I - 3 | 1 | 15.0 | 0.5 | 0.9 | | 15.7 | 1 | | |
| | 2 | 15.7 | 0.4 | 2.3 | | 17.0 | 2 | | SQ |
| | 3 | 14.6 | 0.6 | 1.6 | | 16.9 | 3 | BR | SQ |
| | 4 | 13.3 | 0.6 | 2.3 | | 15.1 | 3 | BR | SQ |
| | 5 | 12.0 | 0.4 | 2.1 | 5.0 | 15.5 | 0 | | SQ |
| | Ave. | | 14.2 | 0.5 | 1.8 | 5.0 | 16.0 | 1.8 | |

I - 1 : Spacing is 1.0 x 1.0 m

I - 2 : Spacing is 2.1 x 2.1 m

I - 3 : Spacing is 4.2 x 4.2 m

TH : Total tree height.

DH : Height to the lowest dead branch.

LBH : Height to the lowest living branch.

FH : Height to forked part.

DBH : Diameter at breast height.

Point of invasion : BR = Branch, WO = Wound

Remarks : SQ = Squirrel damage.

Table 11. The incidence of heart rot in provenance trial plots.

| Plot | Tree No. | TH (m) | DH (m) | LBH (m) | FH (m) | DBH (cm) | Disease severity | Point of invasion | Remarks |
|------|----------|-----------|-----------|------------|-----------|-------------|---------------------|----------------------|---------|
| J-1 | 1 | 10.3 | 0.8 | 1.1 | | 11.5 | 2 | | SQ |
| | 2 | 10.7 | 1.1 | 1.8 | | 11.6 | 2 | | SQ |
| | 3 | 11.3 | 1.7 | 2.3 | | 12.8 | 2 | | SQ |
| | 4 | 11.6 | 1.2 | 3.1 | | 14.2 | 2 | | SQ |
| | 5 | 10.0 | 0.6 | 1.7 | | 12.4 | 2 | | SQ |
| | Ave. | | 10.8 | 1.1 | 2.0 | | 12.4 | 2.0 | |
| J-2 | 1 | 10.0 | 0.2 | 2.6 | 5.0 | 13.8 | 3 | BR | SQ |
| | 2 | 12.1 | 0.2 | 5.4 | | 15.6 | 2 | | |
| | 3 | 13.4 | 0.6 | 4.3 | | 15.5 | 3 | BR, WO | SQ |
| | 4 | 12.4 | 0.4 | 3.7 | | 13.7 | 2 | | SQ |
| | 5 | 14.7 | 0.3 | 1.4 | | 14.2 | 3 | BR | SQ |
| | Ave. | | 12.5 | 0.4 | 3.5 | 5.0 | 14.7 | 2.6 | |
| J-3 | 1 | 15.5 | 0.4 | 7.8 | | 13.3 | 3 | BR | SQ |
| | 2 | 14.1 | 1.2 | 4.9 | | 12.6 | 2 | | |
| | 3 | 12.9 | 0.7 | 3.3 | 5.2 | 13.4 | 2 | | |
| | 4 | 10.5 | 0.5 | 2.8 | | 13.0 | 3 | BR | SQ |
| | 5 | 11.7 | 1.0 | 2.7 | 5.6 | 13.3 | 2 | | |
| | Ave. | | 12.9 | 0.8 | 4.3 | 5.4 | 13.1 | 2.4 | |
| J-4 | 1 | 16.0 | 0.6 | 6.1 | | 15.4 | 2 | | |
| | 2 | 16.7 | 0.7 | 3.5 | 7.4 | 16.6 | 2 | | |
| | 3 | 13.5 | 0.9 | 6.3 | | 14.0 | 1 | | SQ |
| | 4 | 12.0 | 0.9 | 5.6 | | 14.0 | 1 | | SQ |
| | 5 | 16.3 | 0.5 | 6.1 | | 16.3 | 2 | | SQ |
| | Ave. | | 14.9 | 0.7 | 5.6 | 7.4 | 15.3 | 1.6 | |
| J-5 | 1 | 11.4 | 0.4 | 3.9 | | 14.4 | 1 | | SQ |
| | 2 | 16.2 | 1.6 | 7.4 | 6.6 | 14.4 | 2 | | SQ |
| | 3 | 14.8 | 0.2 | 7.0 | | 15.8 | 2 | | SQ |
| | 4 | 16.2 | 0.9 | 7.3 | | 15.6 | 1 | | |
| | 5 | 16.3 | 0.8 | 2.7 | | 14.1 | 2 | | |
| | Ave. | | 15.4 | 0.8 | 5.6 | 6.6 | 14.9 | 1.6 | |

- J-1 : Seed provenance is Whyanbell in Australia.
 J-2 : Seed provenance is Balamuk in Papua New Guinea.
 J-3 : Seed provenance is Barum in Papua New Guinea.
 J-4 : Seed provenance is Ulu Kukut (Sabah) in Malaysia.
 J-5 : Seed provenance is SSSB (Sabah) in Malaysia.

TH : Total tree height.
 DH : Height to the lowest dead branch.
 LBH : Height to the lowest living branch.
 FH : Height to forked part.
 DBH : Diameter at breast height.
 Point of invasion : BR = Branch, WO = Wound.
 Remarks : SQ = Squirrel damage.

Table 12. Effect of chemical treatment on the healing of wounds by pruning.

| Plot | Block | 0 month ¹⁾ Jan. 5 '92 ²⁾ | 4 months May 21 '92 | 8 months Sep. 18 '92 | 12 months Jan. 5 '93 | | | | |
|------|-------|---|------------------------|-------------------------|-------------------------|-----------|----|-----------|----|
| K-1 | 1 | 1.12 (100) | 0 | 0.8 (71) | 0 | 0.33 (29) | 20 | 0.13 (12) | 50 |
| | 2 | 1.26 (100) | 0 | 1.08 (86) | 0 | 0.59 (46) | 0 | 0.3 (24) | 50 |
| | 3 | 1.08 (100) | 0 | 0.86 (80) | 0 | 0.40 (37) | 0 | 0.10 (9) | 53 |
| | Ave. | 1.15 (100) | 0 | 0.91 (79) | 0 | 0.44 (38) | 0 | 0.18 (15) | 53 |
| K-2 | 1 | 1.27 (100) | 0 | 1.08 (71) | 0 | 0.59 (46) | 10 | 0.14 (11) | 60 |
| | 2 | 1.08 (100) | 0 | 0.98 (91) | 0 | 0.64 (59) | 0 | 0.29 (27) | 30 |
| | 3 | 1.43 (100) | 0 | 1.07 (75) | 0 | 0.48 (32) | 0 | 0.07 (5) | 70 |
| | Ave. | 1.26 (100) | 0 | 0.88 (54) | 0 | 0.56 (44) | 0 | 0.17 (13) | 53 |
| K-3 | 1 | 1.43 (100) | 0 | 0.81 (43) | 0 | 0.11 (8) | 60 | 0.2 (1) | 90 |
| | 2 | 1.11 (100) | 0 | 0.75 (68) | 0 | 0.32 (29) | 10 | 0.22 (20) | 30 |
| | 3 | 1.27 (100) | 0 | 0.55 (10) | 10 | 0.12 (9) | 80 | 0.09 (7) | 70 |
| | Ave. | 1.27 (100) | 0 | 0.61 (50) | 0 | 0.18 (14) | 43 | 0.11 (9) | 63 |

K-1 : Pruning

K-2 : Paint treatment after pruning

K-3 : Topzin treatment after pruning

() : Percentage of no-healing wounds

1) : Months after pruning, 2) : Date of assessment

Each block has ten trees and each tree has five fixed pruning wounds.

Each branch was pruned on 5th January, 1992.

Table 13. Effects of pruning and chemical treatments on the occurrence of discoloration or decay in knots.

| Treatment (Plot No.) | Percentage of discolored or decayed knots (%) |
|--------------------------|--|
| No treatment (K - 1) | 25.6 |
| Paint treatment (K - 2) | 38.4 |
| Topzin treatment (K - 3) | 22.0 |
| No pruning (K - 4) | 47.8 |

Pruning and chemical treatment were conducted on 5th January, 1991.

Assessment was done on 3rd December 1991.

Table 14. Percentage of discolored or decayed knots.

| Plot | Sound | discoloration | decay |
|-------|-------|---------------|-------|
| K - 1 | 57.1 | 28.6 | 14.3% |
| K - 2 | 64.3 | 14.3 | 21.4 |
| K - 3 | 76.3 | 13.2 | 10.5 |
| K - 4 | 30.0 | 30.0 | 40.0 |

K - 1 : Pruning

K - 2 : Paint treatment after pruning

K - 3 : Topzin treatment after pruning

K - 4 : No-pruning

Branch was pruned on 5th January 1992.

Assessment was conducted on 10th August, 1993.

Table 15. Detailed results of heart rot survey in pruning trial plots.

| Plot | Tree No. | TH (m) | DH (m) | LBH (m) | FH (m) | DBH (cm) | Disease severity | Point of invasion | Remarks |
|------|----------|-----------|-----------|------------|-----------|-------------|---------------------|----------------------|---------|
| K-1 | 1 | 16.7 | 2.9 | 6.4 | | 14.8 | 1 | | |
| | 2 | 17.5 | 2.9 | 7.1 | | 15.1 | 1 | | |
| | 3 | 16.0 | 3.7 | 6.1 | 6.7 | 14.8 | 3 | BR | SQ |
| | 4 | 12.2 | 2.8 | 4.4 | | 14.3 | 3 | BR | SQ |
| | 5 | 14.8 | 2.8 | 5.7 | | 15.0 | 3 | BR, WO | SQ |
| | 6 | 18.2 | 2.5 | 6.2 | | 16.6 | 2 | | |
| | 7 | 16.3 | 2.8 | 5.4 | 7.4 | 14.5 | 1 | | SQ |
| | 8 | 16.2 | 3.0 | 6.0 | | 14.6 | 0 | | |
| | 9 | 14.5 | 2.7 | 4.9 | | 15.0 | 2 | | SQ |
| | 10 | 12.4 | 3.6 | 4.8 | | 15.8 | - | | SQ, TE |
| | Ave. | 15.4 | 3.0 | 5.9 | 8.1 | 15.0 | 1.8 | | |
| K-2 | 1 | 18.0 | 3.2 | 7.8 | | 14.9 | 2 | | |
| | 2 | 16.2 | 3.0 | 6.7 | | 14.3 | 2 | | SQ |
| | 3 | 18.7 | 3.6 | 11.7 | | 14.1 | 0 | | |
| | 4 | 14.9 | 3.7 | 6.7 | | 15.3 | 3 | BR | SQ |
| | 5 | 16.1 | 3.3 | 7.7 | | 14.0 | 3 | BR | |
| | 6 | 15.9 | 3.3 | 7.4 | | 14.0 | 2 | | |
| | 7 | 11.3 | 2.6 | 2.8 | 4.8 | 14.0 | 2 | | SQ |
| | 8 | 15.9 | 3.2 | 7.7 | | 14.5 | 3 | BR | |
| | 9 | 13.5 | 3.2 | 5.6 | | 14.0 | 2 | | SQ |
| | 10 | 13.9 | 3.4 | 4.9 | | 17.0 | - | | SQ, TE |
| | Ave. | 15.6 | 3.3 | 6.8 | 4.8 | 14.6 | 2.2 | | |

Table 15. (Continued)

| Plot | Tree No. | TH (m) | DH (m) | LBH (m) | FH (m) | DBH (cm) | Disease severity | Point of invasion | Remarks |
|-------|----------|-----------|-----------|------------|-----------|-------------|---------------------|----------------------|---------|
| K - 3 | 1 | 17.6 | 2.4 | 4.3 | | 15.0 | 0 | | |
| | 2 | 19.0 | 2.9 | 7.5 | | 15.5 | 2 | | |
| | 3 | 18.9 | 3.2 | 7.6 | | 14.1 | 0 | | |
| | 4 | 18.8 | 3.3 | 6.0 | | 14.6 | 2 | | SQ |
| | 5 | 10.3 | 3.2 | 5.3 | 6.0 | 15.0 | 0 | | SQ |
| | 6 | 14.0 | 3.2 | 7.3 | | 14.6 | 1 | | SQ |
| | 7 | 14.7 | 3.5 | 6.0 | | 14.5 | 1 | | SQ |
| | 8 | 15.0 | 3.5 | 5.6 | 5.9 | 14.1 | 1 | | SQ |
| | 9 | 14.4 | 3.4 | 5.3 | | 14.8 | 1 | | SQ |
| | 10 | 14.5 | 3.0 | 6.4 | | 14.0 | 2 | | SQ |
| | Ave. | 15.5 | 3.1 | 6.3 | 5.9 | 14.8 | 1.2 | | |
| K - 4 | 1 | 12.9 | 1.2 | 4.2 | 15.0 | 13.9 | 1 | | SQ |
| | 2 | 15.6 | 1.4 | 5.4 | | 15.6 | 3 | BR | SQ |
| | 3 | 19.5 | 2.3 | 7.6 | | 15.6 | 1 | | |
| | 4 | 14.3 | 0.3 | 6.2 | 7.4 | 15.2 | 2 | | SQ |
| | 5 | 17.6 | 0.3 | 8.6 | | 14.5 | 2 | | |
| | 6 | 19.3 | 0.7 | 7.7 | | 15.3 | 2 | | |
| | 7 | 14.9 | 2.3 | 5.1 | | 14.0 | 2 | | BQ |
| | 8 | 10.4 | 0.7 | 4.2 | | 13.3 | 2 | | SQ |
| | 9 | 14.9 | 1.2 | 5.6 | | 14.6 | 3 | BR | SQ |
| | 10 | 16.0 | 0.9 | 7.4 | 7.0 | 15.0 | 3 | BR | |
| | Ave. | 15.5 | 1.1 | 6.2 | 9.8 | 15.0 | 2.1 | | |

K - 1 : Pruning

K - 2 : Paint treatment after pruning

K - 3 : Topzin treatment after pruning

K - 4 : No-pruning

T H : Total tree height.

D H : Height to the lowest dead branch.

L B H : Height to the lowest living branch.

F H : Height to forked part.

D B H : Diameter at breast height.

Point of invasion : BR = Branch, WO = Wound

Remarks : SQ = Squirrel damage, TE = Termites

Table 16. The incidence of heart rot in *A. manglum*, *A. auriculiformis* and *Acacia* hybrid

| Plot | Tree No. | TH (m) | DH (m) | LBH (m) | FH (m) | DBH (cm) | Disease severity | Point of invasion | Remarks |
|------|----------|-----------|-----------|------------|-----------|-------------|---------------------|----------------------|---------|
| L-1 | 1 | 15.2 | 2.4 | 5.9 | | 13.7 | 1 | | |
| | 2 | 16.7 | 1.1 | 6.6 | | 13.3 | 0 | | SQ |
| | 3 | 15.0 | 2.3 | 2.4 | | 17.5 | 2 | | SQ |
| | 4 | 15.1 | 2.6 | 5.9 | | 13.8 | 2 | | SQ |
| | 5 | 19.1 | 2.3 | 9.2 | 9.8 | 14.2 | 4 | BR | |
| | 6 | 18.2 | 1.7 | 8.9 | | 16.6 | 3 | BR | |
| | 7 | 20.2 | 2.3 | 12.5 | 11.2 | 14.7 | 1 | | |
| | 8 | 19.3 | 2.9 | 8.9 | 9.6 | 18.4 | 3 | BR | SQ |
| | 9 | 20.0 | 3.5 | 9.6 | | 16.0 | 3 | BR | |
| | 10 | 19.2 | 3.1 | 7.2 | 9.7 | 16.4 | 3 | BR | SQ |
| | Ave. | 17.8 | 2.4 | 7.7 | 9.6 | 15.5 | 2.2 | | |
| L-2 | 1 | 14.0 | 0.8 | 2.5 | 1.4 | 14.9 | 0 | | |
| | 2 | 14.6 | 0.7 | 8.8 | | 9.3 | 1 | | |
| | 3 | 14.5 | 1.5 | 5.1 | 0.9 | 12.1 | 1 | | SQ |
| | 4 | 11.8 | 1.0 | 3.9 | 1.5 | 13.0 | 1 | | SQ |
| | 5 | 17.5 | 1.5 | 5.3 | 1.9 | 14.8 | 2 | | |
| | 6 | 16.0 | 0.6 | 6.3 | 1.6 | 16.1 | 2 | | |
| | 7 | 13.2 | 1.2 | 6.0 | | 10.8 | 0 | | SQ |
| | 8 | 13.7 | 1.6 | 6.7 | 2.9 | 11.8 | 1 | | SQ |
| | 9 | 13.3 | 0.9 | 5.8 | 2.3 | 11.4 | 0 | | SQ |
| | 10 | 15.6 | 2.2 | 9.0 | | 10.6 | 0 | | SQ |
| | Ave. | 14.4 | 1.2 | 6.8 | 1.7 | 12.5 | 0.6 | | |
| L-3 | 1 | 14.6 | 0.8 | 3.2 | | 11.8 | 2 | | |
| | 2 | 15.6 | 0.5 | 6.6 | 0.8 | 13.8 | 1 | | SQ |
| | 3 | 18.9 | 1.2 | 5.6 | | 14.7 | 0 | | |
| | 4 | 17.3 | 0.8 | 7.6 | 2.3 | 15.0 | 0 | | SQ |
| | 5 | 20.3 | 1.0 | 9.4 | 7.7 | 17.0 | 2 | | SQ |
| | 6 | 16.1 | 1.5 | 11.8 | 9.3 | 14.3 | 0 | | |
| | 7 | 18.5 | 1.4 | 10.9 | 5.7 | 12.3 | 1 | | SQ |
| | 8 | 17.8 | 1.0 | 9.8 | 8.2 | 13.8 | 2 | | |
| | 9 | 18.6 | 1.2 | 6.9 | | 13.7 | 0 | | |
| | 10 | 15.1 | 0.7 | 7.0 | | 11.9 | 2 | | SQ |
| | Ave. | 17.5 | 1.0 | 7.9 | 6.7 | 13.6 | 1.0 | | |

L-1 : 5 year-old *A. manglum*.L-2 : 5 year-old *A. auriculiformis*.L-3 : 5 year-old *Acacia* Hybrid

T H : Total tree height.

D H : Height to the lowest dead branch.

LBH : Height to the lowest living branch.

F H : Height to forked part.

DBH : Diameter at breast height.

Point of invasion : BR = Branch, W = Wound.

Remarks : SQ = Squirrel damage.

9. Explanation of plate

Plate 1. *Acacia mangium* and heart rot.

- A : The oldest *A. mangium* planted in Sabah
- B : Incidence of heart rot in cultivated *A. mangium* from plantation for pulp log

Plate 2. Discoloration and decay of heartwood in *A. mangium*.

- A : Discoloration
- B : Decay, disease index is Ra.
- C : Advanced decay, disease index is Ra.
- D : Hollow of heartwood by heart rot

Plate 3. Infection courts of heart rot in *A. mangium*.

- A : Dead branch stub
- B : Dead branch
- C : Unhealed pruning wound
- D : Unhealed branch stub
- E : Forked injuries
- F : Squirrel damage
- G : Fire scar

Plate 4. Other diseases in *A. mangium*

- A : Symptom of sooty mold on leaf
- B : Symptom of die back in *A. mangium* plantation
- C : Dead part observed in inner bark of die back tree
- D : Tree mortality occurred in *A. mangium* plantation
- E : Cross section of diseased rot
- F : Symptom of red root disease on the root surface of diseased *A. mangium*.

Plate 1

A



B

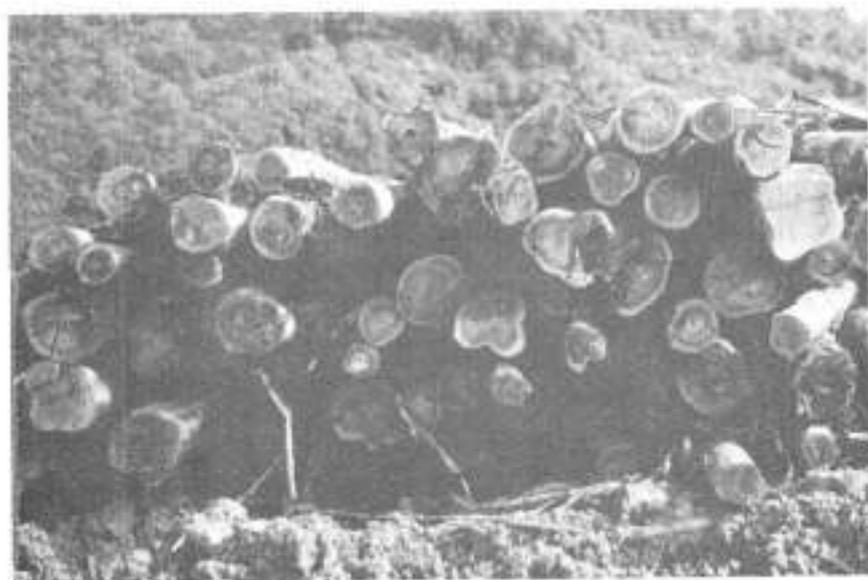
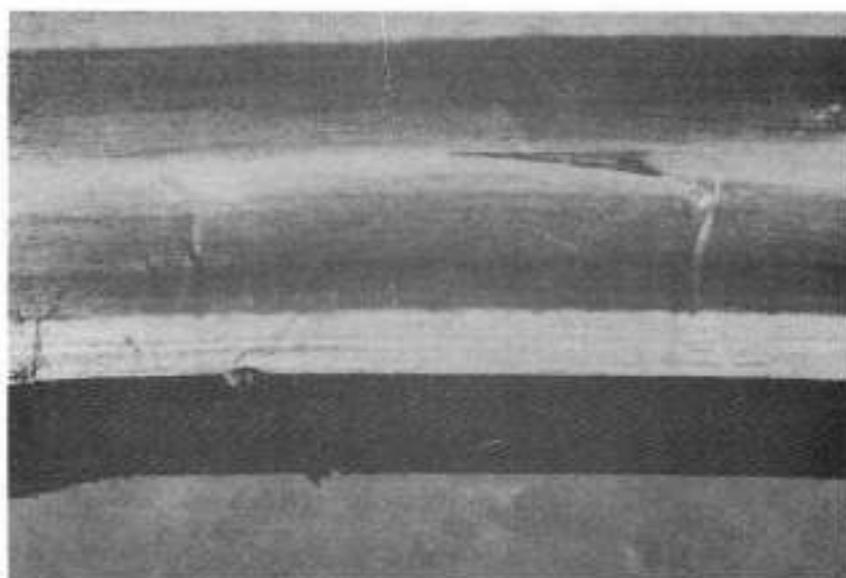
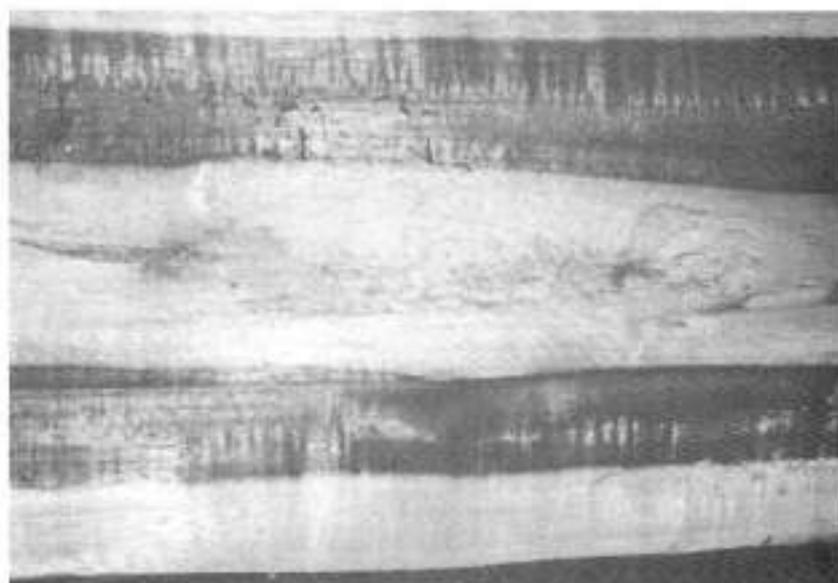


Plate 2

A



B



C



D



Plate 3

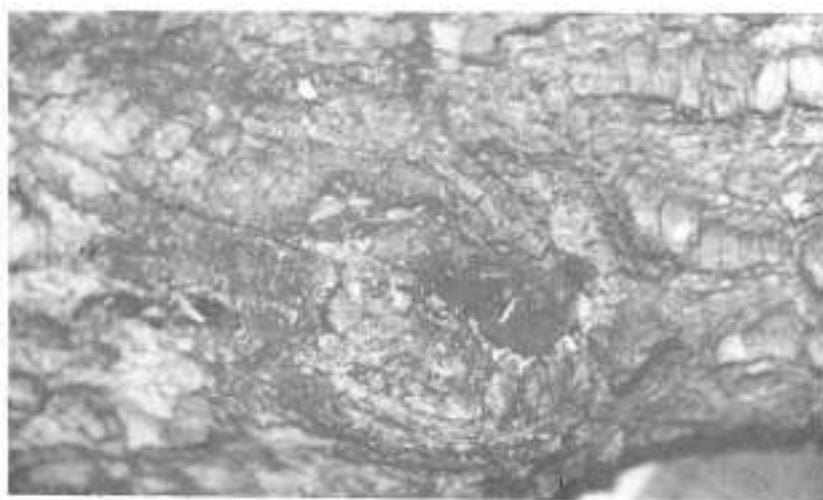
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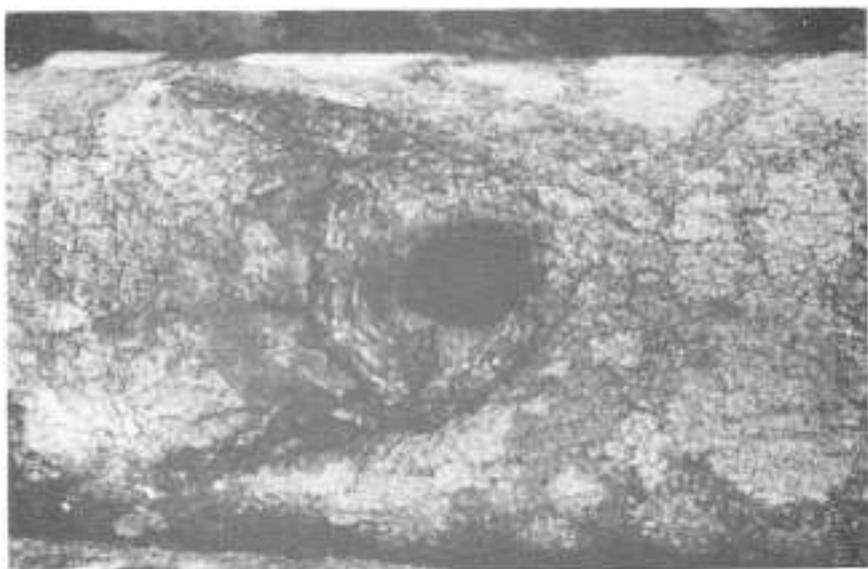
B



C



D



E



F

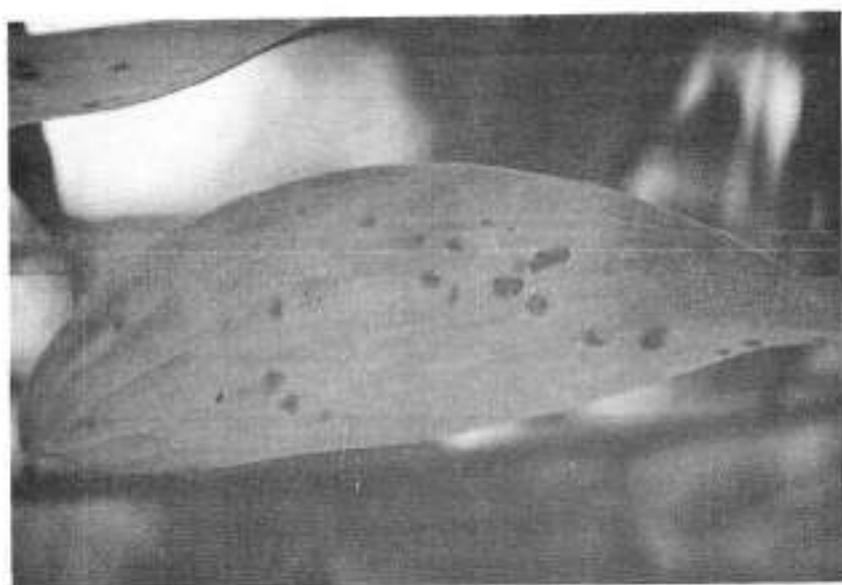


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Plate 4

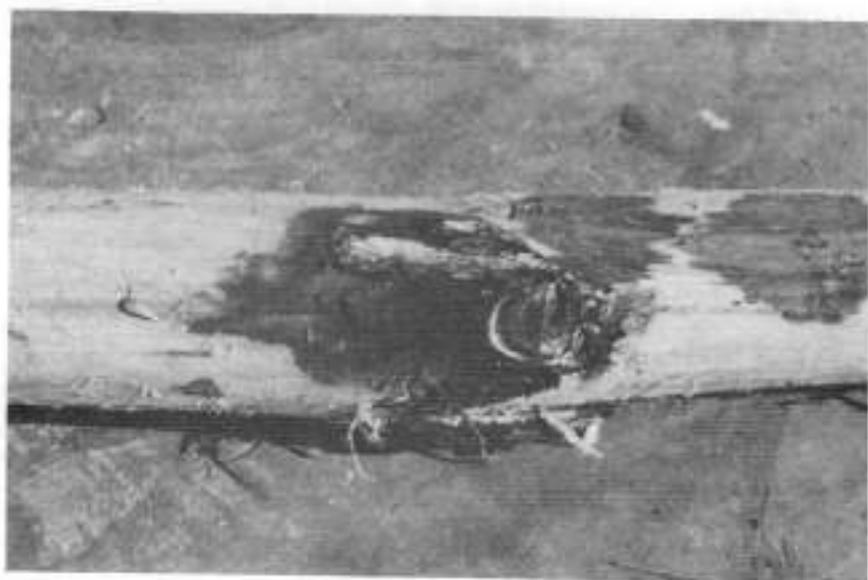
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B



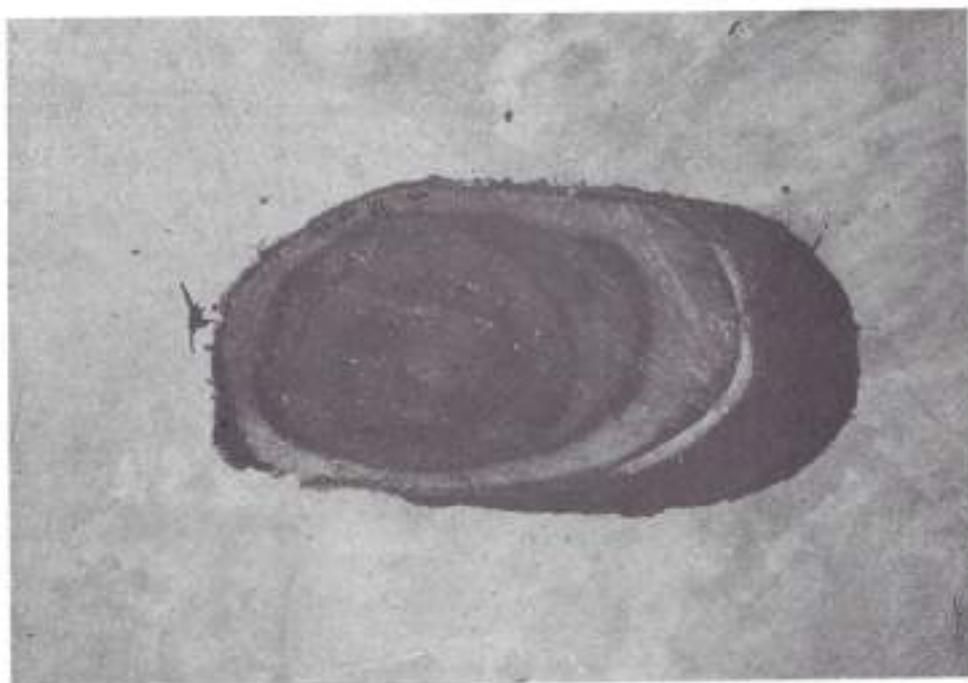
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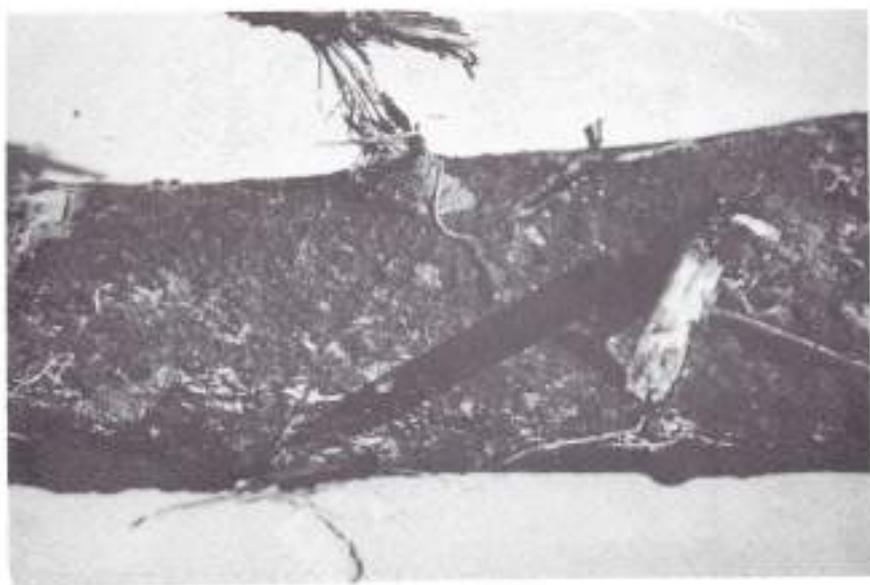
D



E



F



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