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Heart rot and root rot in *Acacia mangium*: identification and assessment

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Abstract

Heart rot in *Acacia mangium* is a typical white rot caused by hymenomycetes, which attack cellulose and lignin. Its development is associated with changes in colour, texture and appearance of rotted wood. These were used as the basis for the rapid assessment of the incidence and severity of heart rot on harvested log-ends in the field. The results are compared with previous survey reports based on longitudinal sectioning of logs. An assessment of two trials, one in Riau, the other in South Sumatra, showed that provenance could influence heart-rot incidence but that this was not correlated with wood extractive content. Root rots are characterised according to the colour of the infected fungal tissues/roots and are associated with various basidiomycetes. Molecular technology has identified *Ganoderma philippii* as the causative agent of red root rot. Root-rot diseases are associated with crown dieback, reduced growth and tree death. When root rot is first detected, infected trees or disease foci tend to be randomly distributed but then enlarge and may aggregate. The rate of disease progress appears positively related to the initial incidence of root rot. Accurate surveys to investigate spread should record above-ground symptoms, inspect the extent of root infection, and observe patterns of disease infection. However, these types of surveys, especially over extensive and difficult terrain, are operationally laborious and costly. Future options for disease survey based on remote sensing are discussed.

Surveys to evaluate diseases of tropical Acacia plantations have concluded that heart rot, root rot and phyllode rust (respectively, infection of heartwood, roots and leaves by fungi) are the main threats (Old et al. 2000). Heart rot in *Acacia mangium* Willd. is a saprotrophic fungal decay of heartwood which reduces wood quality but the tree is not killed and is, in most cases, externally asymptomatic. Heart-rot fungi are wound basidiomycete parasites that enter trees through injuries and branch stubs and do not preferentially attack living tissue. Root-rot disease in *A. mangium* is a decay of roots caused by various basidiomycete pathogens, which attack living root tissue and may result in tree death or symptoms of crown decline. The disease is spread by the contact of a diseased root or infested woody debris with a healthy root. Assessments of heart-rot and root-rot diseases require different approaches. For practical management in plantation forests, methods need to be fast, accurate and easily repeatable by staff with a minimum of training.

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Heart rot

Internal symptoms of heart rot in *A. mangium*

When healthy *A. mangium* trees are dissected, sound sapwood is tan to bright yellow in colour, while sound heartwood is pale brown to grey brown. In *A. mangium* the juvenile wood is pale coloured and of low density. It is located in the centre of the log, is often soft, and can be mistaken for heart-rotted wood. Like most fast-growing trees, *A. mangium* possesses a high proportion of juvenile wood. It usually forms in the stem of the live crown and has been known to constitute up to about 10% by volume of the wood present in 8–9-year-old trees (Ivory 1993).

The first symptom indicative of fungal infection is discoloration; heartwood becomes purple/black, sapwood becomes green/brown. Incipient decay in heartwood is difficult to detect but the wood colour is intermediate between that of sound and decayed wood, i.e. it is usually of darker colour than normal heartwood. Heart rot in *A. mangium* is typical of white rot caused by hymenomycetes (a group of basidiomycetes; Hood (2006)), which attack both cellulose and lignin, finally leaving behind a yellowish-white, spongy or stringy mass. Lee and Maziah (1993) described seven types of heart rot from *A. mangium* based on differences in colour, texture and general appearance of the rotted wood. The authors attributed each type to different stages of decay as well as characteristics of the individual fungi involved. Isolated decay-columns may form in the heartwood. In extreme cases, heartwood can completely rot away leaving a hollow core.

The infection courts for heart-rot fungi in *A. mangium* are dead branch stubs, dead/broken branches and stem cankers/unhealed or slowly healing wounds such as those caused by pruning (Mahmud et al. 1993; Ito and Nanis 1994, 1997; Barry et al. 2004). Infection courts (i.e. branch stubs) are not often associated with external signs or symptoms such as fruitbodies, and heart rot can be seen only after the bolts of wood are split. Molecular techniques have greatly increased the ability to identify isolates obtained from diseased wood by matching the DNA of such isolates to that of named fruitbodies (Glen et al. 2004).

Methods of detection and assessment

Since it is not possible to assess heart rot from the external features of the living tree, most surveys of *A. mangium* heart rot have utilised destructive methods. In five major studies, the merchantable stem length was sectioned into 1 m logs that were each sliced longitudinally to allow detection and quantification of heart-rot incidence and severity (Mahmud et al. 1993; Zakaria et al. 1994; Ito and Nanis 1994; Basak 1997; Ito 2002). While destructive methods are extremely valuable for gaining exact measures of heart rot and understanding paths of fungal entry into the stem (Lee et al. 1988; Mahmud et al. 1993; Ito and Nanis 1994, 1997), they are labour intensive. This necessitates that replicate tree numbers within treatments are reasonably low; for example, 5–6 trees per 13 plantations in Bangladesh (Basak 1997) or 10 trees per 20 plots of different age in Sabah (Mahmud et al. 1993). For regular monitoring, a quicker method of heart-rot survey is desirable.

Barry et al. (2004) developed a quick and easily repeatable method of heart-rot survey to screen large numbers of logs in different regions of Indonesia. At most sites, logs were surveyed during harvest operations at the end of the rotation, generally at age 8 years, but at age 6 years in East Kalimantan. In West Java, some trees were surveyed at harvest at age 8 years (60 trees), and others at age 3 years during thinning (39 trees). The number of compartments and logs per compartment surveyed were based on availability of harvested material.

Log-ends were assessed where logs were stacked after harvest. Typically, approximately 100 logs were in each pile and 3–4 logs could have been derived from an individual tree. For example, in East Kalimantan, logs were about 3.5 m long and 3–4 logs of this length were produced from an individual tree. Therefore, logs in the piles were not uniform in size and could have come from a number of positions in the tree. The logs chosen to assess from each log pile were selected randomly by using a line transect (a piece of string placed horizontally at random), which typically selected 10–15 logs (Figure 1). Since *A. mangium* wood discolours rapidly upon cutting, logs were assessed as soon as possible after harvest. Discoloration related to heart rot can appear similar to oxidative discoloration, and this is therefore a potential source of confusion. The diameter of each log selected was measured and if a heart-rot-related defect was observed this was categorised on a 1–4 scale (Figure 1) and its maximum diameter measured. Logs with no heart rot were scored as 0. Where more than one defect type was present on one log-end, the highest rating was recorded and the widest diameter of the total defect was recorded.

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Figure 1. Heart-rot defect scale and log stack showing line transect method of Barry et al. (2004)

Comparing results of the log-stack method to other studies

In the Indonesian study by Barry et al. (2004), the East Kalimantan and South Sumatra sites were associated with the lowest heart-rot incidence (Figure 2) and the lowest average defect diameters. Lower heart-rot incidence would be expected for the East Kalimantan site, mainly because the trees were 2 years younger than at the other sites (Figure 2). This age-related trend has been evident in other studies of *A. mangium*, with positive correlations between heart-rot incidence and tree age (Zakaria et al. 1994) as well as between heart-rot diameter and tree diameter (Basak 1997). Apart from tree age, other factors such as climate and management practices may influence heart-rot incidence and spread.

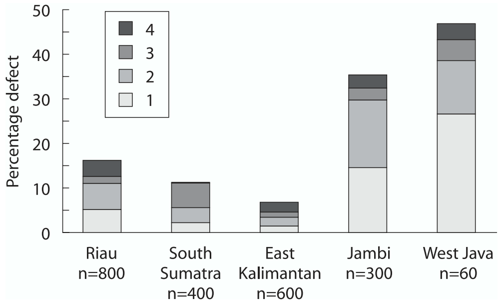

Figure 2. Percentage of logs in each defect class (1–4) for the five survey sites

Previous Malaysian surveys using destructive methods of analysis have detected higher incidences of heart rot than those found by Barry et al. (2004) in Indonesia. This difference could be due to the method used in Indonesia, which may underestimate heart-rot incidence as it examines only one cross-section of each log (although it surveys a larger number of logs). As such, it is not possible to compare the results from Barry et al. (2004) with surveys conducted by other methods. Surveys by Maurits et al. (2001) found volume losses to heart rot of 0.7–14.1% in *A. mangium* in East Kalimantan. Correlating the different methods would require a destructive analysis of a sub-sample of logs following the survey of the same logs with Barry et al.'s method. However, it is very possible that there are real differences in incidence between the various studies. For example, seed stock has improved markedly in the 15 years between the first Malaysian studies and the more recent Indonesian surveys (C. Harwood, pers. comm.) and these improvements may also reflect an associated reduction in susceptibility to heart rot; trees have become straighter, branches smaller and less numerous, thus reducing the frequency of suitable infection courts presented by broken or dead branches, especially those of large diameter (Lee et al. 1988; Mahmud et al. 1993; Ito and Nanis 1994, 1997; Lee 2002).

Assessment of intra and inter specific susceptibility to heart rot in acacia

It has been suggested that provenance affects susceptibility to heart rot (Ito and Nanis 1994). As mentioned above, provenance differences in tree architecture, especially branching, may influence heart rot. A comparison of polyphenols between

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A. mangium (heart-rot susceptible) and *A. auriculiformis* (heart-rot resistant) showed that some components are toxic to heart-rot fungi when at certain concentrations (Barry et al. 2005; Mihara et al. 2005). Wood extractive content may also vary intra-specifically with provenance and result in differing levels of heart rot.

Two trials clearly demonstrated that the effect of provenance was statistically significant for heart-rot incidence (Barry et al. 2006). The larger study in Riau assessed natural heart-rot incidence by felling trees and assessing a stem disk at 1.5 m height. In the smaller provenance trial in South Sumatra, trees were artificially inoculated. This involved creating stem wounds (drill holes), which were then inoculated with fungi capable of causing heart rot. This method offered a controlled way of testing for provenance susceptibility, as the fungal species inoculated and the size of the infection court were standardised. However, a range of other fungi infected the wounds after inoculation. While both trials revealed that provenance could influence heart-rot incidence, wood extractive content was not correlated with heart rot.

Root rot

Signs

Several types of woody root rots have been recognised in *A. mangium* and are characterised as red, brown, black or white root diseases according to the colour of the fungal tissue and/or roots that are infected. These diseases are associated with various basidiomycete fungi including *Amauroderma* cf. *parasiticum*, *Ganoderma* spp. (red rot), *Phellinus noxius* (brown rot)*, Rigidoporus lignosus* (white rot) and *Tinctoporellus epimiltinus* (brown rot) (Almonicar 1992; Old et al. 2000; Lee 2002; Glen et al. 2006). Species of *Ganoderma*, however, have been reported as the most frequent root-rot causal agents in *A. mangium* in both Malaysia and Indonesia (Lee 2002). Until now, identification of the *Ganoderma* species associated with root disease has been based on morphological and taxonomic features of fruitbodies (Figure 3a). Roots affected by *Ganoderma* spp. may be covered by a reddish-brown rhizomorphic skin (Figure 3b) that is visible after the roots are washed clean of associated soil. Using molecular technology, *Ganoderma philippii* was unequivocally identified as a causative agent of red root rot (Glen et al. 2004, 2006). A white mottling pattern of mycelium is seen on the underside of the infected bark (Figure 3b) and there is a very characteristic odour. In fast-grown plantations, characteristic fruitbodies may be absent in disease centres (Lee 2000; Old et al. 2000). A species of the *G. lucidum* complex is associated with a more rubbery rhizomorphic skin than that found in red root rot, a skin which is yellow and brown on the outside with a blistered appearance and rubbery white on the inside when pulled away from the root wood (M. Glen, pers. comm.).

Symptoms

Most root-rot diseases cause similar, generally non-specific, above-ground symptoms in the host, including crown dieback and reduced growth. There is a general decline in the crown condition and the growth rate is poor. In particular, the foliage of affected trees becomes chlorotic (paling of the green

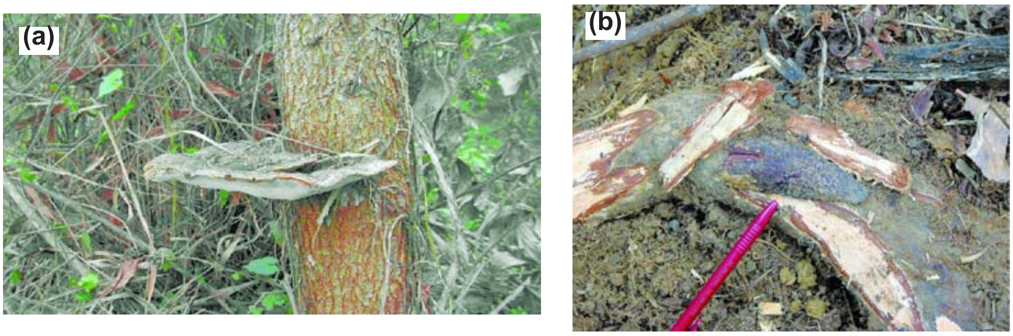

Figure 3. (a) *Ganoderma philippii* basidiocarp at the base of a dead *Acacia mangium* tree growing in East Kalimantan, Indonesia; (b) characteristics of red root rot (red bumpy skin when soil is washed away) caused by *G. philippii* on *A. mangium* with white mottling of mycelium seen on underside of bark

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coloration), much reduced in size and sparse due to reduced water and mineral uptake. Young shoots may wilt and, in trees in advanced states of root rot, foliage loss increases and trees become very susceptible to wind throw (Ariffin et al. 2000; Kile 2000; Leckie et al. 2004; Morrison et al. 2000; Old et al. 2000).

In forest stands, diseased trees tend to be clustered in patches that are roughly circular, due to the spread of root rot from around an initial inoculum source (Figure 4). Trees with advanced infections are located at the infection centre, while trees with less-advanced infections are around the periphery. These circular disease centres increase in diameter as root contact occurs between neighbouring diseased and healthy trees (Bolland 1984; Garbelotto et al. 1997; Kile 2000).

Quantitative detection using ground-based surveys

Surveys are essential as a management tool to determine if disease incidence is severe enough to warrant control practices, but also as a study tool, or for epidemiological modelling. Surveys can utilise the above-ground symptoms of root rot (e.g. crown condition, resin exudates on bark) or involve checking for signs of root infection by excavating around roots. Field-based surveys of root rot can be completed quickly for small areas or trials, but are time-consuming at the large scale of a commercial plantation. It is therefore useful to investigate efficiencies of different survey methods to save monitoring time and costs.

Some surveys have utilised a mixture of above-ground symptoms and root-infection inspections. Irianto et al. (2006) conducted a survey at different sites in Indonesia by recording the incidence of root rot in two adjacent rows of *A. mangium*, missing the next three rows and then repeating this survey pattern until a certain count was reached to represent a 40% sub-sample of a randomly selected area of the compartment. In East Kalimantan, for example, trees were assessed until a count of 200 was reached, the count therefore representing a 40% sub-sample of 500 trees. Roots were uncovered and inspected for typical symptoms of root rot (red) in trees that were standing dead, or exhibited chlorotic/yellowing foliage, loss of foliage, or fruitbodies on the stem. Trees in which root rot was confirmed by this method, plus any missing trees, were scored as a positive result. Missing trees were attributed to root rot. Results were recorded as presence/absence of root rot, then the numbers in each of the two categories were summed and expressed as a percentage. During field surveys, observations on the pattern of root-rot infections (i.e. size of root-rot disease foci) were recorded. While this survey method was time-consuming, it ensured a very accurate assessment of root-rot incidence.

Figure 4. Typical circular patch of tree mortality (3–5 trees) in a 4–5-year-old *Acacia mangium* plantation, East Kalimantan, Indonesia

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Surveys are useful not only to provide quantitative data from one time point but also as a basis for model development (Nandris et al. 1996). Barry et al. (2005) modelled six years of spatial survey data of rubber trees infected with *Rigidoporous lignosus* and *Phellinus noxius.* Using the spatial information that was collected while testing different control methods, models were determined to estimate root-rot spread and effectiveness of control measures. Successive surveys conducted in *A. mangium* plantations infected by *Ganoderma* spp. (Lee 2000) showed that the rate of disease progression in Malaysian plantations was dependent on the initial incidence of root rot. Root-rot foci enlarged over time.

Assessment of root rot in an *A. mangium* provenance/progeny trial in Indonesia (Irianto et al. 2006) revealed that infected trees were randomly distributed at a first time point but these trees or disease foci tended to become aggregated by the time of a second survey. This highlighted the high probability that exists of rapid vegetative spread by the fungus after its initial introduction to the site; the incidence of tree death doubled between 2003 and 2004. While this provenance/progeny trial is a non-commercial plantation, the results have implications for the potential rate of spread of root rot in plantations. Lee (2000) found that for first-rotation plantations grown on lowland ex-forest sites, mortality due to root rot in *A. mangium* in Malaysia could double within one year. The incidence of other root-rot fungi such as *Armillaria ostoyae* in pine forests has also been reported to double within one year (Lung-Escarmant and Guyon 2004).

Detection methods for the future

As ground surveys are time-consuming, aerial or remote methods may be suitable for detection of root rot. Remote sensing of plant health is currently based mainly on detection of chlorophyll content. Foliage thinning and chlorosis are common symptoms of root rot and, in Douglas-fir, chlorophyll *a*, nitrogen and moisture were consistently reduced in trees infected by *Phellinus weirii* (Thomson et al. 1996). In beech trees infected with the root rot caused by *Phytophthora* spp., total chlorophyll was reduced three-fold in heavily infected plants compared with controls (Fleischmann et al. 2004). The application of a high-resolution multi-spectral imagery was recently shown to be a feasible for detecting laminated root-rot centres in Douglas-fir in Canada (Leckie et al. 2004). While remote sensing methodologies require considerable development for reliable detection of specific diseases, they offer the potential for rapid and robust quantification. The symptoms of root rot in *A. mangium* are suitable for adaptation to remote sensing.

Conclusions

For both of these important diseases of *A. mangium*, assessment methods need to be rapid and accurate. Heart rot requires destructive assessment, but this can be done during thinning operations or at harvest. Root rot can be assessed non-destructively but root excavation is required for verification of the disease. Root-rot assessment methodology is therefore both laborious and costly, more suited to research investigations which do not necessarily require full spatial coverage of a forest plantation estate. Remote sensing of root-rot incidence and severity could offer 100% coverage. Knowledge of disease incidence and severity (and patterns of spread in the case for root rot) is important for developing effective disease management strategies and for calculating economic impact.

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