

# 7

## Managing Phytophthora Diseases



# 7.1 Principles of Phytophthora Disease Management

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## Abstract

In order to limit the incidence and severity of diseases caused by *Phytophthora*, effective management strategies are needed. Management of phytophthora diseases is based on a number of principles such as avoiding infection through basic hygiene, limiting susceptibility through drainage and irrigation, improving soil health, use of disease-resistant germplasm, and biological and chemical control. Although the components are discussed here in a sequential order, effective control of phytophthora diseases is often only achieved through the integrated use of a number of these strategies.

## Introduction

There are more than 60 described species of *Phytophthora* and all known species are plant pathogens. Each species can cause disease in from a few to over a 1000 different plant species. Hence, there are a few thousand diseases in a wide range of plants caused by the various species within the genus *Phytophthora*. Each of these diseases will have its own characteristics, which makes it difficult to generalise disease-control methods. However, it is important to understand the most common contributing factors that underpin the control of phytophthora diseases. Only an in-depth understanding of these underlying factors, coupled with a detailed understanding of the agronomics of the crop will allow one to develop effective, integrated disease control methods. The aim of this chapter is to provide an underlying basis for disease control by discussing a wide range of management practices available under the following headings: (1) cultural practices, (2) resistance breeding, (3) biological control, (4) fungicides, and (5) phosphonates.

## Cultural practices

The effectiveness of control strategies depends on the ability of an individual species of *Phytophthora* to survive, either as a saprophyte or as dormant spores. Generally, mycelium and zoospores survive for only a few weeks, while chlamydospores may survive for 6 years, and oospores for 13 years (Erwin and Ribeiro 1996). Some species, however, such as *P. cinnamomi*, appear to have a high saprophytic ability (Zentmyer 1980) while others such as *P. palmivora* do not (Ko 1971).

## Quarantine, nursery and orchard hygiene

Quarantine is the only means of preventing the introduction of a new pathogen into an area. Quarantine is also extremely important in nurseries where millions of plants are produced each year, providing opportunities for the rapid spread of *Phytophthora*. In areas where *Phytophthora* has not been recorded, exclusion is essential. Exclude animals by fencing, minimise the movement of vehicles and people through the orchard, remove soil from vehicles, boots and tools before they are brought into the orchard, plant only disease-free and resistant trees, and divert water run-off from adjacent orchards (Broadley 1992).

In nurseries, potting mixes should be steamed to kill *Phytophthora* inoculum, and only certified *Phytophthora*-free planting material should be used (Chapter 7.2). Good hygiene in orchards is a

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fundamental component of effective pest management. It is virtually impossible to eradicate *Phytophthora* from the soil. Therefore, if *Phytophthora* is present, metalaxyl should be used to minimise disease development. Roadways, interrows and equipment should be kept clean. The site should be well-drained to avoid water from forming ponds that may subsequently allow *Phytophthora* to proliferate. Orchards should also be kept free of rotting plant debris that may be infected with *Phytophthora* (Broadley 1992).

### Drainage and irrigation

Excess irrigation and rainfall are considered to be the most important factors that increase the severity and spread of *Phytophthora*-incited diseases. In turn, the duration of free water, in soil or on foliage or fruit is the most important environmental factor in the development of disease caused by *Phytophthora* because it is during this time that propagules proliferate and infect (Erwin and Ribeiro 1996). In addition, zoospores, cysts and chlamydospores travel in the soil in irrigation water, rainfall run-off and movement of soil. Orchards should be established on land that is well-drained and not subject to flooding. Therefore, sloping ground is preferable. Ideally, the soil should be drained to a depth of 1.5 metres. Mounding of the soil around the tree promotes good drainage (Broadley 1992). Row crops should be planted on raised beds to prevent free water from contacting the plants (Erwin and Ribeiro 1996). To reduce the rate and extent of build-up of inoculum, plants should be irrigated less frequently so that free water drains away (Lutz et al. 1989). In areas where rainfall is the main source of water, optimal horizontal and vertical drainage are necessary to prevent water-logging. Spraying water on the trunks of trees should be avoided as constantly wet bark may encourage the development of cankers.

### Organic amendments and mulching

Mulching stimulates plant root growth, increases nutrient uptake, decreases evaporation from the soil, increases soil-water holding capacity, reduces surface water run-off, facilitates drainage, regulates soil temperature, and provides a high level of nutrients for soil microbes (Aryantha et al. 2000). Amendments can either enhance or suppress disease, depending on their nature. *Phytophthora* is inhibited by alfalfa meal, cotton waste, soybean meal, wheat straw, chicken manure and urea. Ammonia and volatile organic acids released by decomposing organic matter kill *Phytophthora*, and the residual organic matter stimulates competitive

and antagonistic microorganisms in the soil (Lazarovits et al. 2001). While these mechanisms suppress the growth of *Phytophthora*, they may also create phytotoxicity to the plant roots, making them less attractive to colonisation by the pathogen (Erwin and Ribeiro 1996). Aryantha et al. 2000 showed that the addition of fresh or composted chicken manure to potting mix significantly reduced the survival of *P. cinnamomi* and the development of disease in lupin seedlings. Chicken manure more effectively suppressed *P. cinnamomi* and plant-disease symptoms than did cow or sheep manure. All composts increased soil organic matter, total biological activity, and populations of antagonistic actinomycetes, fluorescent pseudomonads, and fungi. However, chicken manure also stimulated the production of endospore-forming bacteria, which was positively correlated with lupin seedling survival. The addition of composted manures is necessary for disease development but it is not sufficient for biological control. Mulches may also reduce the impact of phytophthora root rot if used from the time of orchard establishment or if the disease is not too far advanced. The 'Ashburner system', based on improved drainage and mulches, has been successfully employed to manage phytophthora root rot of avocados (Broadley 1992). Chapter 7.3 reports that mulches are also effective in managing phytophthora root rot of papaya.

### Companion and cover cropping

Companion cropping can reduce the impact of phytophthora diseases. For example, in the subtropics of Australia, banana and avocado are planted together. The bananas provide mulch and reduce soil water after heavy rain. This system reduces the impact of root rot caused by *P. cinnamomi*. Care must be taken to choose a companion crop that does not compete too heavily with the orchard crop. Cover crops, when incorporated into the soil, increase the amount of organic material, which encourages the growth of microbes that suppress *Phytophthora* (Broadley 1992).

### Fertilisers

Some forms of nitrogen have been shown to favour an increase in disease, while other forms suppress disease (Schmitthenner and Canaday 1983). Generally, the role of fertilisers or nutrients in controlling or suppressing phytophthora diseases is unclear. Some reports indicate that fertilising improves plant vigour and hence resistance to disease, while others indicate that pathogen infection is favoured because of improved plant vigour (Erwin and Ribeiro 1996).

### Suppressive soils

Soils that favour the expression of disease are conducive, while those that are inhospitable to plant pathogens are suppressive. The principal cause of suppressiveness is an increase in the population of antagonistic bacteria, fungi and actinomycetes. *Phytophthora*-suppressive soils have been reported in orchards and natural forests where, frequently, other soil-borne pathogens are also suppressed. Direct lysis of hyphae and inhibition of germination of chlamydospores of *P. cinnamomi* has been observed in suppressive soils. Suppression is attributed to the activities of soil-borne antagonists that may produce antibiotics active against *Phytophthora* (Halsall 1982). There are also a number of microorganisms which hyperparasitise oospores of *Phytophthora*.

### Resistance

The success of resistance to *Phytophthora* in the field is determined by the interaction between the host, pathogen and the environment. Inoculum concentration and environmental conditions ultimately determine how effective host resistance will be in minimising disease. Generally, it is more difficult to find host resistance to pathogens that have a wide rather than a narrow host range. Resistance in the majority of hosts to different species of *Phytophthora* is non-specific in nature. However, a few species such as *P. fragariae*, *P. infestans*, *P. sojae* and *P. vignae* have gene-for-gene interactions with their hosts, and hence resistance is race-specific and frequently controlled by a single dominant gene in the host. Cultivar-specific resistance to *P. capsici* and *P. nicotianae* has been observed, and the mechanisms of resistance appear to be related to the physiology of the cultivars. There are three components of general resistance to *Phytophthora*: (i) resistance to penetration, (ii) restriction of growth of the fungus in the host, and (iii) reduced sporulation of the fungus on the host.

The use of resistant rootstocks to combat soil-borne diseases in perennial crops is a vital component of an integrated disease-management program. In avocado, resistance has been identified from *Persea americana* and some non-commercial relatives of avocado. However, under conditions that favour *P. cinnamomi*, such as soil waterlogging, good control is not achieved even with resistant or tolerant rootstocks (Erwin and Ribeiro 1996). A disadvantage of clonal rootstocks of avocado is that they can be more difficult and slower to establish than seedling rootstocks. Some rootstocks limit the rate of disease development by rapidly regenerating feeder roots;

in others, infection of the root is minimised due to natural resistance mechanisms (Broadley 1992). General resistance to *P. citrophthora* and *P. nicotianae* has been developed in many rootstocks onto which grafts of commercial citrus species can be made (Erwin and Ribeiro 1996).

Resistant rootstocks can be obtained from seedlings generated from selected resistant/tolerant cultivars or by using marcotted seedlings developed from selected cultivars. Marcotted seedlings have been used to produce disease-tolerant rootstocks of durian (Lim 1998). Using *Phytophthora*-resistant or tolerant rootstocks as planting material has the added advantage of producing uniform trees (Broadley 1992). In New Guinea, efforts aimed at identifying resistance to pod rot in cocoa have been largely unsuccessful, and cultural and chemical management strategies remain the most viable methods of control (Holderness 1992). Resistance to bud rot and nut fall caused by *P. palmivora* and *P. nicotianae* has been identified in coconut (Mangindaan et al. 1992).

Phytoalexins are antifungal compounds produced by plants in response to the invasion of a pathogen. These compounds are widely associated with host resistance. Phytoalexins are non-specific in their inhibitory action, and can be induced by physical and chemical treatments and by non-pathogens. Their production can be elicited in response to compounds commonly produced by pathogens, such as complex carbohydrates from fungal cell walls, and lipids, enzymes and polypeptides. Elicitation of phytoalexin production by *Phytophthora* infection has been demonstrated in a number of hosts (Erwin and Ribeiro 1996). The salicylic acid analogue, Bion (acibenzolar-S-methyl), activates systemic acquired resistance in plants and can increase resistance to *Phytophthora* (Ali et al. 2000).

### Biological Control

Many of the experiments performed on biological control of *Phytophthora* have been centred on in vitro studies or pot trials and not field situations. Research on biological control has encompassed large-scale screening efforts without seeking further understanding of the interaction between biological control agents and *Phytophthora*. If disease management is to be heavily based on biological control, the research effort in this area will need to be significantly increased, as there are very few choices of biocontrol agents for *Phytophthora* or effective techniques to apply them. However, biological control does provide an attractive and

environmentally friendly option to control or suppress the development of phytophthora diseases.

Recent developments in biological control include the identification of biocontrol agents such as actinomycetes (You et al. 1996), and fungi including *Trichoderma* spp. (Chambers and Scott 1995), *Penicillium funiculosum* (Fang and Tsao 1995), *Gliocladium* spp. (Lim and Chan 1986; Heller and Theilerhedtrich 1994; Chambers and Scott 1995) and *Chaetomium globosum* (Heller and Theilerhedtrich 1994). These agents have all suppressed growth of *P. cinnamomi*, mostly by hyphal lysis, but can also promote the growth of the host (El-Tarabily et al. 1996). Numerous studies have examined biological control of *P. palmivora* in cocoa, using microbial antagonists such as *Bacillus* spp., *Aspergillus tamarii*, *A. giganteus*, *Botryodiplodia theobromae*, *Penicillium purpurescens* and *Pseudomonas fluorescens*, with some success (Galindo 1992). Two species of the soil-dwelling genus *Myrothecium* were found to reduce leaf rot caused by *P. palmivora* and *P. katsurae* in coconut. This fungal genus is found in both temperate and tropical soils, and hence provides a possible option for biocontrol of bud rot in coconut (Tuset et al. 1992).

Biological control activity can be manipulated by adding exotic antagonists to the soil, or by stimulating the activity of endogenous antagonists through the addition of mulches or composts (Erwin and Ribeiro 1996). For example, the use of organic media (mulches, composted pine bark etc.) that have high microbial activity and low pH (Hoitink and Fahy 1986; You and Sivasithamparam 1995), provide promising options to control *P. cinnamomi* in container-grown plants in nurseries. Organic amendments have also been successfully extrapolated to the field; for example, in the control of apple replant disease (Utkhede and Smith 1994). Mycorrhizae may also provide biological control against *P. cinnamomi* as identified in pines (Marais and Kotze 1976) and pineapple (Guillemin et al. 1994).

A range of endophytic fungi have been shown to protect cocoa against fungal pathogens, including *Phytophthora*. The primary mode of action of these endophytes appears to be through direct antagonism (Arnold et al. 2003). The possibility therefore exists to identify active endophytes and to inoculate seedlings at the nursery so that they are protected in the field.

## Fungicides

### Protectant

#### *Bordeaux mixture*

This is perhaps one of the oldest known fungicides, formulated in 1885 by Millardet to control the Oomycete *Plasmopara viticola*, which causes downy mildew on grapevine (Millardet 1885). Bordeaux mixture has been used to successfully control many diseases caused by different species of *Phytophthora*. The fungicide adheres well to foliage, but has a disadvantage in that its active ingredient, copper, can have a significant toxic affect in some plants and non-target organisms (Brown et al. 1998). In addition, Bordeaux mixture is a combination of copper sulphate and calcium hydroxide, and thus is somewhat labour-intensive to prepare and apply (Erwin and Ribeiro 1996). Also, in tropical areas with high rainfall, the fungicide may be washed off.

### Systemic

#### *Phenylamides (acylanilides)*

This group of chemicals includes furalaxyl (Fongarid), metalaxyl (Ridomil) and benalaxyl (Galben). All three chemicals are active against the Peronosporales, but metalaxyl is the most widely used (Erwin and Ribeiro 1996). This fungicide is a xylem-translocated compound with an upward movement in plants in the transpiration stream (Edgington and Peterson 1977). Thus, metalaxyl and related acylanilide compounds have no effect on root diseases if applied as a foliar spray because they are not transported to the roots. Metalaxyl is usually applied as a soil drench and it is very effective (Guest et al. 1995). Due to its systemic nature, metalaxyl is transferred from seed, roots and leaves to new growth (Cohen and Coffey 1986) and is therefore effective at controlling infection beyond the roots. Metalaxyl is water soluble, and is effective against all species of *Phytophthora* in vitro at much lower doses than protectant fungicides. The biochemical mode of action of metalaxyl involves inhibition of RNA synthesis. It is highly inhibitory to sporangium formation, and also reduces chlamydospore and oospore formation (Cohen and Coffey 1986). It also has a high level of persistence within the plant. The presence of metalaxyl within the plant can prevent colonisation of leaf tissue by mycelium, because it inhibits the growth of hyphae (Erwin and Ribeiro 1996).

There are several disadvantages of using metalaxyl and related compounds: (i) root drenching is a wasteful method of fungicide application; (ii) chemicals are released into soil and water systems; (iii) soil microorganisms rapidly degrade metalaxyl,

reducing its persistence and effectiveness (Guest et al. 1995); and (iv) resistance has developed to it among populations of *Phytophthora*, particularly *P. infestans* (Cohen and Coffey 1986). The issue of metalaxyl-resistance has been partially addressed by application of metalaxyl in combination with a protectant fungicide, limited application of metalaxyl during a given growing season, and not using the fungicide for curative or eradication purposes (Erwin and Ribeiro 1996).

### Phosphonates

This group of compounds is active against the Peronosporales. The term 'phosphonate' refers to the salts and esters of phosphoric acid that release the phosphonate anion in solution. Phosphonates are prepared by partially neutralising phosphorous acid ( $H_3PO_3$ ) with potassium hydroxide. In this text, phosphonates will be referred to in a general context, and mention will also be made of a specific formulation of phosphonate, fosetyl-Al. Marketed under the name Aliette, this compound contains an aluminium salt of phosphonate (Cohen and Coffey 1986).

Phosphonates are xylem- and phloem-translocated (Ouimette and Coffey 1990), with both downward and upward movement in the host. They are non-persistent in the environment, as they are readily oxidised to phosphate by soil microbes, and they also have very low mammalian toxicity. The precise mode of action of phosphonates is unknown, but it is believed that they disrupt phosphorus metabolism in the pathogen, causing fungistasis and the consequent activation of the host defence responses (Guest et al. 1995).

The presence of phosphonate at concentrations below those required to inhibit mycelial growth *in vitro* disrupts the virulence of the pathogen, causing the release of stress metabolites that elicit host defences. The consequence is that many plant species treated with phosphonates respond to inoculation as though they were resistant. Hence, the effectiveness of phosphonates against plant diseases caused by Oomycetes depends on both the sensitivity of the pathogen to phosphonate and the capacity of the defence responses of the host. Therefore, there is a 'complex mode of action' in response to phosphonate treatment (Guest et al. 1995).

Because of the complex mode of action of phosphonates, results obtained from one host-cultivar combination cannot be extrapolated from results with analogous combinations. This is because of the great variation in sensitivity of

different isolates of a single *Phytophthora* species. In addition, phosphonate efficacy differs among host cultivars or species, perhaps due to differences in the type or extent of defence responses in the hosts (Guest et al. 1995). Although the fungistatic effect of phosphonates is not confined to the Oomycetes, it is inexplicably variable in its effect against some species of *Phytophthora*. For example, fosetyl-Al is active against tuber rot caused by *P. infestans*, but is not very effective in controlling the foliar phase of late blight of potato (Erwin and Ribeiro 1996), possibly indicating the activation of tissue-specific resistance mechanisms.

Because phosphonates are phloem-translocated, they can be applied to any part of the plant and theoretically be transported to all other plant parts according to source-sink relationships in the growing plant. Phosphonates spread rapidly throughout plant tissue; within a few minutes for small plants such as tomato, and within days for large trees such as avocado. Phosphonates can be applied either as a drench, foliar spray, stem-canker paint, or trunk injection for direct systemic control. Fungicides applied as foliar sprays and drenches are often limited in their effectiveness. This is because fungicide uptake into the plant tissue is generally poor, fungicide activity is rapidly lost due to degradation by soil and phylloplane microbes, and fungicides are lost to the environment through leaching and wash-off (Guest et al. 1995). Pressurised trunk injection forces the chemicals into the trees, minimising wastage and environmental contamination, and achieving maximum persistence (Darvas et al. 1984). For each host species and each disease, the injection rate, number of injection sites and the timing and frequency of injection need to be optimised. Although phosphonates persist very well in plant tissue, sequential applications are required to maintain concentrations essential to effective and durable disease control, especially in perennial crops.

Most of the hosts on which phytophthora diseases have been controlled by phosphonates are perennial fruit crops. Treatment is particularly effective because the fruits are strong metabolic sinks for the translocation of phosphonates, and because reduced disease in one season reduces the inoculum available in the following season. Trunk injection can be used to treat *Phytophthora* infections of roots, leaves, stems and fruits (Guest et al. 1995).

There do not seem to be many problems associated with phosphonate usage. Unlike metalaxyl, phosphonate-resistant isolates of *Phytophthora* have not been detected after more than 20 years of use.

Although some studies have shown that soil drenches of fosetyl-Al and phosphonates inhibit root growth and subsequent colonisation of the roots by mycorrhizal fungi, others have shown that application of fosetyl-Al enhances mycorrhizal colonisation (Guest et al. 1995). It is important to remember that phosphonates will not eradicate the pathogen or eliminate disease, but remain an excellent, cost-effective option for control of phytophthora diseases.

## Conclusions

Effective disease control is rarely achieved through the application of a single disease-control method. In order to limit the risks associated with outbreaks of disease we need to use a number of different approaches in an integrated manner. Starting with disease-free planting material, site preparation and establishing good drainage will not only limit phytophthora disease severity but, also, the improved soil health will benefit the host plant directly. The planting of resistant material, if available, is a highly cost-effective way to control disease, but these trees will also benefit from improved drainage and good soil health. Chemicals can be used as a last option, as their use often involves a significant cash outlay for equipment and fungicides. The use of fungicides also requires knowledge about optimal timing of sprays, rates of application, additives and application methods, in order to be applied effectively. Throughout this monograph we have tried to give practical advice on how to integrate the different components of disease control in an effective manner to reduce losses due to *Phytophthora*.

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## 7.2 Nursery Practices and Orchard Management

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### Abstract

Orchards are usually established using grafted planting material obtained from specialised nurseries. It is paramount that such planting material and accompanying potting mix is of high quality and free of disease. This chapter outlines the steps involved in the production of disease-free nursery stock. Healthy planting stock should also be planted in healthy soil, and the impact of fertiliser, water and canopy management options on disease are discussed. The Ashburner system, originally developed to manage *Phytophthora* in avocado orchards, is also outlined and its wider relevance to perennial horticulture is discussed.

### Introduction

Plant disease epidemics are extremely rare in nature and when they do occur they are invariably associated with human activity. On farms and in orchards, plants are usually grown in monocultures with very limited genetic diversity, and are cultivated for maximum yield. The emphasis on growth rate, precocity and yield often imposes unnatural stresses on plants. Cultivated plants are propagated and transported to new regions or continents and immediately confront new environments and populations of pests, pathogens and other organisms. Conversely, the movement of plants sometimes introduces pests and pathogens as passengers into new environments, where they discover previously unknown hosts.

*Phytophthora* is a genus that has benefited from these agricultural and horticultural practices and has been the agent of several major plant disease epidemics in the last two centuries. To understand these epidemics and to develop management practices to manage the impact of these pathogens, it is essential to understand how the biology of *Phytophthora* enables it to successfully exploit agricultural and horticultural practices. The

development of successful management practices requires a thorough understanding of the life and disease cycles of *Phytophthora* species on each host plant in each environment. The aim of most disease management practices is to exclude or reduce the amount of primary inoculum and to reduce the rate of epidemic development by suppressing secondary inoculum.

Of all the disease management strategies available to farmers, the most fundamental is to use healthy planting material in a healthy soil under conditions that favour the growth and development of the plant. A wise investment of effort, time and money to establish a healthy orchard will lay the foundation for decades of sustainable production. Nursery practices that ensure disease-free planting material, thoughtful site preparation to encourage successful orchard establishment, and management practices based on a thorough appreciation of how to manage a sustainable orchard ecosystem will also minimise production costs, social costs and environmental damage.

### Nursery Practices

All species of *Phytophthora* are at least to some extent soil-borne pathogens that are primarily dispersed in contaminated soil, water or, less commonly, in infected planting material. Therefore, nursery practices designed to prevent the dispersal of *Phytophthora* pathogens should focus on preventing

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the introduction and subsequent movement of infested soil and water.

The rapid expansion of the avocado industry in Australia in the 1970s created a shortage of planting material and exposed serious deficiencies in standard nursery practice that were directly responsible for the spread of dieback disease throughout the major avocado-growing regions of north-eastern New South Wales and south-eastern Queensland. As a result, a strict set of standards was developed through the establishment of a pioneering nursery accreditation scheme. Growers soon recognised that the extra cost of purchasing certified planting stock from a recognised nursery was compensated in a short period of time by the absence of dieback, lower disease-management costs, higher yield, higher quality and longer tree life. Nurseries recognised that their reputation was enhanced by supplying only certified, disease-free plants and that their extra costs were rewarded with price premiums. Those that chose not to invest in improving their practices quickly lost their business as growers purchased elsewhere.

The accreditation scheme is based on a sound understanding of the biology of the pathogen, and the role of soil and water in its dissemination (Pegg 1978). The key elements are:

- preventing the exposure of pots, plants, tools and irrigation hoses to contaminated soil by paving all walkways and surfaces and suppressing dust
- placing pots and containers on raised benches, preferably made from galvanised wire mesh
- sterilising all pots, containers, and tools, and storing them where there is no chance of contamination by soil or water
- using a soil-free or pasteurised growth medium
- regularly testing irrigation water
- regularly inspecting, roguing, containing and destroying diseased plants
- quarantining newly acquired propagating material
- restricting access to all nursery areas to prevent the introduction of contaminated soil or water
- training nursery workers in hygienic practices, including refraining from eating, drinking or smoking in the quarantine area.

Any soil or river-sand based potting mix, or substrates containing cocopeat, may potentially harbour *Phytophthora*. These substrates can be avoided, but as they are readily available and relatively inexpensive, they are the most common potting mixes used in many tropical countries. Alternatively, these substrates can be disinfested before use.

Pasteurisation is an effective technique that eradicates soil-borne inoculum in potting mixes, however it requires a significant capital expenditure for nursery operators. The potting mix is moistened to field capacity overnight, then heated to at least 60°C, but less than 82°C, for 30 minutes using a pressurised steam-air mixture. Solarisation, which involves heating moist potting mix to temperatures of 45–50°C at 20 cm depth under sheets of clear plastic, using the heat of the sun for a week or more, provides many of the growth benefits of both methyl bromide fumigation and pasteurisation if carefully monitored. Solarisation is a promising technique for tropical areas because of the low cost and technical requirements, but has the potential to generate a lot of waste plastic if the plastic sheets are of such low quality that they cannot be reused.

Another technique that eradicates pathogens from potting mix is anaerobic fermentation, using organic additives such as chicken manure, green silage and microbial supplements. Chicken manure releases ammonia and volatile acids, before stimulating the activity of antagonistic and hyperparasitic microbes, creating an actively suppressive soil ecosystem (Aryantha et al. 2000; Lazarovits et al. 2001). Methyl bromide fumigation is also effective but is no longer acceptable because of its adverse effects on human health and its role in the depletion of the ozone layer. Ultimately the safest, but most expensive, method is to use freely draining, soil-free potting mix, based on mineral substrates such as vermiculite, perlite or rice husks and composted hardwood bark. There is a great need to develop low-technology, low-cost, pathogen-free potting substrates for nurseries in Southeast Asia.

## Orchard Establishment

There is little point purchasing disease-free planting material if the orchard soil is infested with the pathogen. Site selection is critical. A study of the previous cropping history will indicate the presence of soil-borne pathogens, and the threat these pathogens pose to the new crop. *Phytophthora* spp. thrive in soils with low organic-matter contents, low biological activity, and low water-holding-capacity soils that are prone to temporary ponding, and aerial dissemination is favoured in environments or microclimates with long periods of high relative humidity.

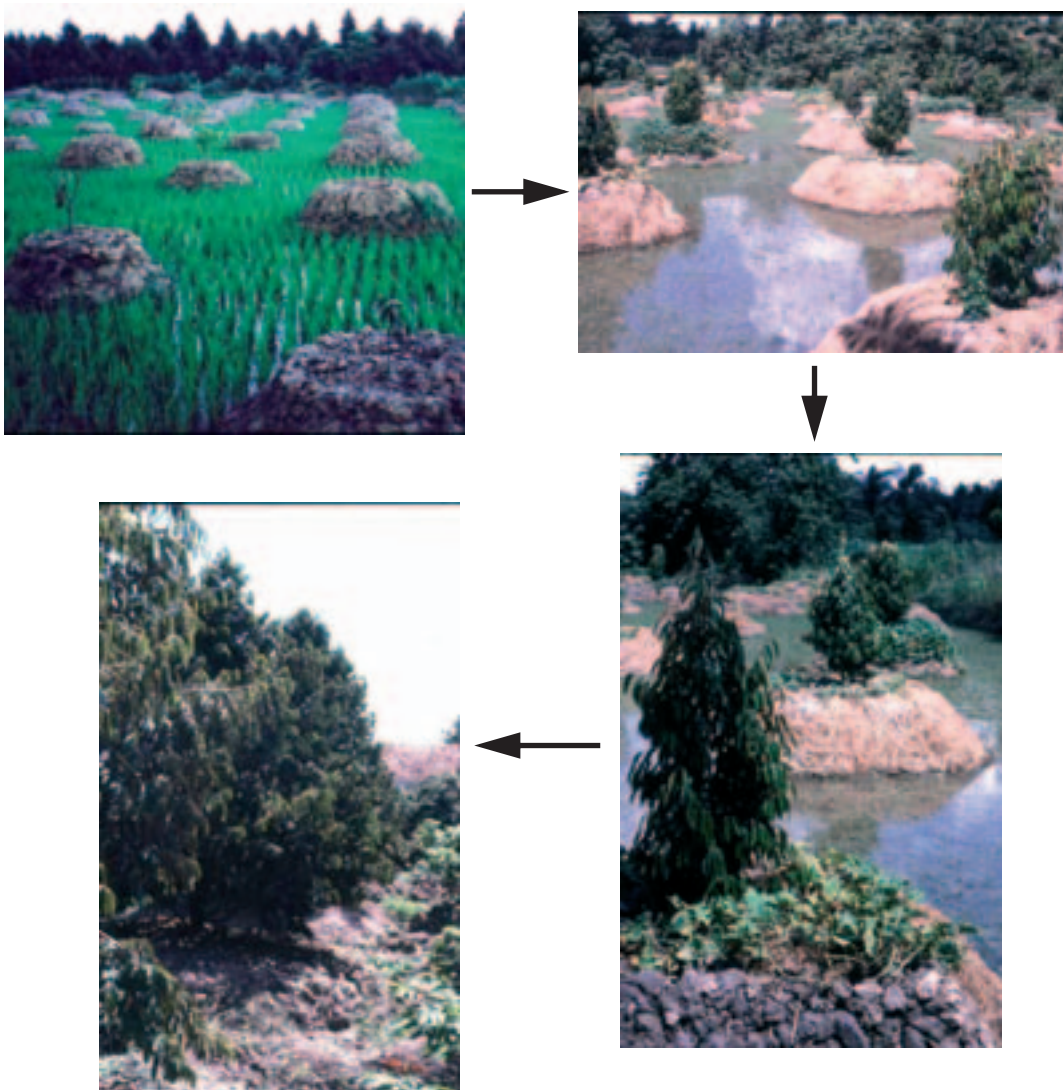
Once a site containing suitable soil has been identified and the orchard layout decided upon, drainage has to be attended to so that flooding and ponding is avoided, while appropriate irrigation is designed, if necessary. Planting on mounds or ridges

is widely practised and effective, especially in low-lying orchards or where the watertable is high. An extreme example is the transformation of rice paddies in the Mekong Delta to durian orchards by transplanting young trees on top of mounds in the paddy (Figure 7.2.1). Over successive seasons, the trees grow and the mounds are built wider until the canopy closes and rice is replaced. The flooding of rice paddies creates anaerobic soils, and eradicates *Phytophthora*, so that the planting site starts out free from the pathogen.

In orchards where the pathogen is known to exist from previous cropping experience or positive soil tests, the planting hole can be prepared to suppress or eradicate the pathogen from the root zone (Broadbent and Baker 1975). A practice common around Ba Ria-Vung Tau in Vietnam, where durian orchards are planted on old rubber plantations

where *Phytophthora palmivora* is present, is to dig holes approximately 50 cm deep and 100 cm in diameter, fill each hole with fresh chicken manure and green compost, cover with soil and compact (Figure 7.2.2). These develop into small silage pits that eradicate the pathogen over a period of 3–4 months, and also break any hardpans or impermeable laterite subsoils that may impede drainage. A small planting hole is excavated for the young tree. This practice will, however, only be effective in the long term if sufficient organic material is placed in the planting hole and a well-drained mound of sufficient height is created to allow effective drainage of water.

Where irrigation is necessary, methods that involve flooding bare ground, while convenient, should be avoided because they create 'swimming pools for zoospores' (Somsiri Sangchote, pers. comm.) (see



**Figure 7.2.1** Transformation of rice paddy to a durian orchard over several years in the Mekong Delta, Vietnam.

Figure 6.6.6), and expose delicate feeder roots to bare soil and damaging solar radiation which leads to poor soil structure in the top soil. This is especially detrimental to many tree species originating from rainforest environments which tend to have rather shallow root systems. If spray irrigation is used, spray nozzles should be directed away from the base of trees to avoid wetting the bark, and around the drip zone where most roots are located. Drip and microjet irrigation uses water efficiently and avoids ponding, but is expensive to install and maintain. Irrigation water should be tested regularly to ensure that it is pathogen-free. Water from rivers and canals that run through orchards are an important source of primary inoculum.

Phytophthora diseases sometimes utilise root and stem damage caused by cyclones and storms. Appropriate windbreaks may help to protect trees from damage as well as disease epidemics. This is particularly important for large, shallow-rooted trees like durians. A severe epidemic of phytophthora patch canker followed a hurricane in south-eastern Thailand in 1994. Evidence is presented in Chapter 4.2 that wounds caused by wind damage attract zoospores and provide entry sites that initiate infections.



**Figure 7.2.2** Transplanting of durians into prepared pits at Ba Ria-Vung Tau, Vietnam. These pits are maintained as bare soil and used to contain flood irrigation water during the dry season.

## Orchard Management

### Soil health

Healthy trees grow from healthy soils. *Phytophthora cinnamomi* causes a devastating dieback disease in the dry sclerophyll forests of south-eastern and south-western Australia, yet is a relatively minor pathogen in nearby wet sclerophyll rainforests or in the tropical highland rainforests of Southeast Asia where it is thought to have evolved (Cook and Baker 1983). A key difference between these ecosystems is the organic-matter content and biological activity of the disease-conducive and disease-suppressive topsoils. *Phytophthora* is a relatively poor saprophytic competitor that struggles to survive in soils rich in organic matter that supports an active and abundant microflora.

The Ashburner system developed in Australia attempts to simulate disease-suppressive soils in horticulture by increasing soil biological activity and biodiversity (Pegg 1977; Baker 1978; Cook and Baker 1983; Erwin and Ribeiro 1996). An annual cycle is established before transplanting, where a green manure crop, such as lupin, is planted at the end of the wet season, then slashed and lightly incorporated with chicken manure and nitrogen-phosphorus-potassium (NPK) fertiliser in spring. Lablab, corn or sorghum is planted over the wet season, then again slashed with chicken manure and NPK fertiliser, followed by lupins in the dry season, *ad infinitum*. Dolomite lime is added to maintain soil pH around 6.0. The cycle is continued for several years until the orchard is established and leaf litter, supplemented with straw and chicken manure, maintains the level of soil organic matter (Figure 7.2.3). This cycle continually replenishes the soil organic matter without disturbing surface roots and provides a mulch layer that dampens soil surface temperatures and preserves soil moisture.

The Ashburner system provides an excellent example of how to manage a healthy orchard in the presence of *Phytophthora*-infested soils, and can be readily adapted to other tree cropping systems. Konam and Guest (2002) showed that cocoa leaf-litter mulches stimulate antagonists and provide a physical barrier for rainsplash inoculum, reducing the incidence of black pod. Chicken-manure amendments are more effective at suppressing *Phytophthora* than other manures (Broadbent and Baker 1975; Aryantha et al. 2000).

Antagonists such as *Trichoderma*, *Gliocladium*, *Bacillus* and *Streptomyces* may be effective in controlled nursery environments, but are generally much less impressive in field trials. The effect of

these biological-control agents is enhanced by other measures aimed to improve soil health and organic matter. Biological control appears to be more effective following improvements to soil health, such as organic-matter amendments that stimulate indigenous suppressive microbes, than by simply adding beneficial microbes to poor soils.



**Figure 7.2.3** Young durian trees mulched with straw, Cape Kimberley, Australia.

### Fertiliser and water management

The basic aim of water and nutrient management in orchards is to encourage healthy vegetative growth and the sustainable production of high-quality fruit. The precise phenology of tree growth and seasonal variations in water and nutrient requirements must be studied and understood in each environment.

Some durian growers in northern Queensland report that overuse of inorganic fertilisers exacerbates diseases in durian caused by *P. palmivora*, while mulches and manures improve tree health. Tan (2000) studied the effects of a liquid inorganic fertiliser and composted chicken manure on the development of *P. palmivora* diseases in papaya and durian and concluded that indeed chicken manure significantly reduced disease incidence and severity compared to the use of inorganic fertilisers.

The survival of inoculated papaya seedlings was greater in soils amended with composted chicken

manure than in soils that received double the recommended rate of inorganic fertiliser. Root rot occurred in all treatments, however root regeneration occurred in the chicken-manure treatment but not in the inorganic-fertiliser treatments. One hundred per cent of 12-month-old durian seedlings planted in *P. palmivora*-infested, chicken-manure-amended potting mix survived, and the pathogen was eradicated from the soil. In unamended potting mix, the seedlings also survived but the pathogen could be re-isolated from the soil at the end of the experiment. The pathogen was readily isolated after one month from soils that had received regular applications of inorganic fertiliser, by which time all durian seedlings had died (Table 7.2.1).

The survival of the durian in, and the eradication of *P. palmivora* from, chicken-manure-amended potting mix coincided with the stimulation of microorganisms antagonistic to the pathogen that were introduced to the potting mix in the chicken manure. The amendment of potting mix with composted chicken manure led to higher biological activity, and levels of actinomycetes, endospore-forming bacteria and fluorescent pseudomonads over a 3-month period than in potting mix that received regular applications of inorganic fertiliser.

The study reinforces the value of chicken manure as a source of nutrients and biocontrol agents for *Phytophthora* spp. and supports the hypothesis of the growers in northern Queensland that over-fertilisation with inorganic fertilisers may exacerbate disease in durian caused by *Phytophthora*.

### Canopy management

Canopy management is also important because it enables farmers to reduce the relative humidity in the canopy, and to remove potential sources of inoculum. Regular harvesting of cocoa, for example, reduces secondary inoculum and is an important component of integrated disease management.

A complete understanding of the disease cycle reveals the importance of orchard hygiene. Diseased plant material, prunings, discarded fruit or unusable parts of fruit are significant sources of inoculum.

**Table 7.2.1** Survival of durian seedlings and *Phytophthora palmivora* in potting mix following one month of inorganic or organic fertiliser application.

Treatment		Surviving seedlings (%)	Re-isolation of <i>P. palmivora</i> (%)
Inoculation	Fertiliser		
none	none	100	0
+ <i>P. palmivora</i>	none	100	22.2
+ <i>P. palmivora</i>	2 × inorganic	0	100
+ <i>P. palmivora</i>	2.5% chicken manure	100	0

Orchard hygiene, if implemented rigorously and consistently, can significantly reduce disease pressure in orchards and on farms and, in some cases, may be all that is required to manage diseases caused by *Phytophthora*. More commonly though, hygiene is one essential component of an integrated disease management package (Chapter 8.7).

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## 7.3 The Use of Mounds and Organic and Plastic Mulches for the Management of Phytophthora Root Rot of Papaya in Northern Queensland

L.L. Vawdrey,<sup>1</sup> K.E. Grice<sup>2</sup> and R.A. Peterson<sup>2</sup>

### Abstract

Options for the control of root rot of papaya caused by *Phytophthora palmivora* were evaluated in a field experiment in northerly parts of Queensland, Australia. In the experiment, growing papaya on 0.75 m mounds reduced the incidence of root rot by 38.4% and significantly increased fruit yield. Soil covers of 2 m wide plastic mulch and organic mulch, in combination with 0.75 m mounds, further reduced plant losses by 20 and 10%, respectively. Plastic mulch on flat ground was as effective as the mounded treatments in reducing the incidence of root rot and increasing yield.

### Introduction

The northern Queensland papaya industry (latitudes 16°48'–17°26'S), which includes 90% of all papaya (*Carica papaya*) grown in Australia, consists mainly of farms of no more than 2 ha. However, the soil-borne pathogen *Phytophthora palmivora* Butler, which causes a decay of the taproot and eventual death of plants, is widespread in the growing area (Vawdrey 2001). Recommendations for the control of the disease involve papaya being planted on land not previously planted to papaya (Chay-Prove 2000). This situation has been a major constraint to the expansion of the papaya industry in the region.

The conventional method of growing papaya in all growing areas has involved planting seedlings into flat ground (Dunn 2001). Duniway (1979) concluded that the most important environmental factor influencing phytophthora-related root disease was the duration of saturation or near-saturation of soil.

Soil conditions such as these are known to favour the rapid formation of sporangia and infectious zoospores and a high level of disease. Although the most suitable papaya-growing soils in northern Queensland are well-drained loams, these soils are likely to remain saturated for prolonged periods during severe wet seasons. Improving soil drainage through mounding and mulch application has been used successfully in avocado to manage root rot caused by *Phytophthora cinnamomi* (Broadley 1992; Pegg and Whiley 1987).

This study reports on a field experiment that examined the effectiveness of mounds and organic and plastic mulches, with and without the chemical metalaxyl, in reducing root rot of papaya. The experiment was located at a site on a grower's property where *P. palmivora* had been recovered from papaya plants severely affected with root rot.

### Methods

#### Site description and experimental design

The experiment was established on 13 January 1997 in a kraznozom soil on a commercial papaya property at Innisfail, Queensland, Australia. The experiment was set up as a split/split plot in a randomised complete block design. There were

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three replicates each with two whole plots to which the mounding/flat ground treatments were applied. Each whole plot was divided into 3 subplots to which the cover treatments (1) plastic mulch, (2) organic mulch or (3) nil cover were applied. Each subplot was then divided into 2 sub-subplots where (a) metalaxyl or (b) a nil treatment was applied. There were 10 datum plants and 2 guard plants per sub-subplot.

### Treatment application

On the 8 January 1997 the experimental site was deep-ripped and rotary-hoed, and mounds (0.75 m high), each 1.5 m wide and 18 m long, were formed in the appropriate plots. Metalaxyl (Ridomil, 50 g/kg) treatments were broadcast evenly on the surface of the beds and lightly raked into the soil just before the application of the soil-surface mulches. Plots treated with organic mulch were covered to a depth of 7.5 cm with composted shredded tree bark obtained from the local council waste depot. The plastic mulch treatments (Table 7.3.1), consisting of 2 m wide black plastic sheets, were laid and then painted white to prevent sunscald damage to the newly planted seedlings.

### Plant establishment

Eight-week-old papaya seedlings (Hybrid 29) were transplanted from pasteurised potting mix into flat beds in the experimental area on 13 January 1997. Plants were thinned to 1 per position at flowering when the sex of the plant could be determined. Plants were irrigated as required using dripper lines positioned either side of the planting line. All plots received a basal fertiliser application of Crop King 55<sup>®</sup> (13.2% N, 14.7% P, 12.3% K, 1.5% S), and superphosphate (8.8% P, 20% Ca, 11% S), at rates of 55 and 110 kg/ha, respectively, and dolomite (16.5% CaCO<sub>3</sub> and 10% MgCO<sub>3</sub>) at 1100 kg/ha, and two

applications of urea (39 kg/ha) through the irrigation system during the growing of the crop.

### Data collection

Plant heights (cm) were recorded at 8, 13 and 17 weeks after transplanting. Plant infection counts were recorded as plants showed symptoms of wilting resulting from the decay of the taproot. Diseased plants were cut at ground level and moved to the inter-row. Samples of diseased roots and stems were obtained from each root-rot-affected plant to identify the causal organism. Sections of diseased roots and stems were surface sterilised in 70% ethanol for 1 minute, blotted dry with sterile paper then transferred to PDA plus 50 mg/L streptomycin sulfate, and the *Phytophthora* selective medium P<sub>10</sub>ARP+H (Jeffers and Martin 1986). On 6 November, fruit with a diameter greater than 7.0 cm was harvested and the total fruit number and total fruit weight per plot assessed.

### Results

Some seedlings died within 1–2 weeks of transplanting. *Rhizoctonia solani* was recovered from basal stem lesions on a few plants using PDA plus streptomycin sulfate culture medium, but the cause of most plant deaths was most likely due to physical damage to the taproot at transplanting. Planting sites where all plants had died were replanted within 4 weeks of the initial transplanting.

By 11 March, there were quantitative differences in plant growth between treatments (Table 7.3.1). Assessments conducted on 11 March and 22 April showed a significant mound × soil cover interaction, with the height of plants grown on flat ground with organic mulch significantly reduced ( $P < 0.05$ ) compared with all other treatments. The pre-plant application of metalaxyl had no effect on plant growth ( $P > 0.05$ ) except in the assessment conducted

**Table 7.3.1** Plant heights of papaya grown on mounds or flat ground, with organic and plastic mulches.

Treatment	Plant height (cm) <sup>a</sup>		
	11 March	22 April	20 May
Mound/plastic mulch	78.0 a	119.0 ab	176.0 a
Mound/organic mulch	67.0 a	95.0 c	142.0 abcd
Mound/bare soil	88.0 a	107.0 abc	137.0 bcd
Flat/plastic mulch	68.0 a	109.0 abc	161.0 ab
Flat/organic mulch	46.0 b	65.0 d	101.0 e
Flat/bare soil	73.0 a	88.0 c	108.0 de

<sup>a</sup> Means in the same column followed by the same letter are not significantly different ( $P > 0.05$ ).

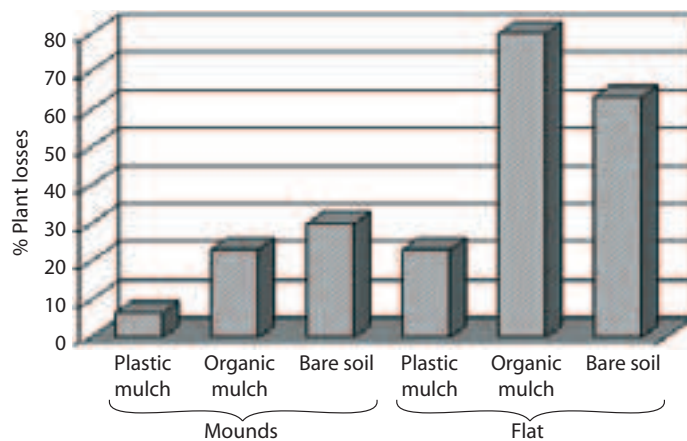


on 22 April, where the chemical improved plant growth ( $P < 0.05$ ) when applied to mounded soil with organic mulch. In this assessment, plant heights were 123 cm in mounded plots treated with organic mulch and metalaxyl, compared with 95 cm in mounded plots with organic mulch alone. The final assessment, conducted on 20 May, showed a significant mound  $\times$  soil cover interaction, with a significant increase in plant height ( $P < 0.05$ ) in mounded plots with both organic and plastic mulch compared with mounded plots with bare soil. Plants grown on mounds with and without mulches, and on flat ground with plastic mulch, were taller ( $P < 0.05$ ) than plants grown on flat ground with organic mulch or bare soil.

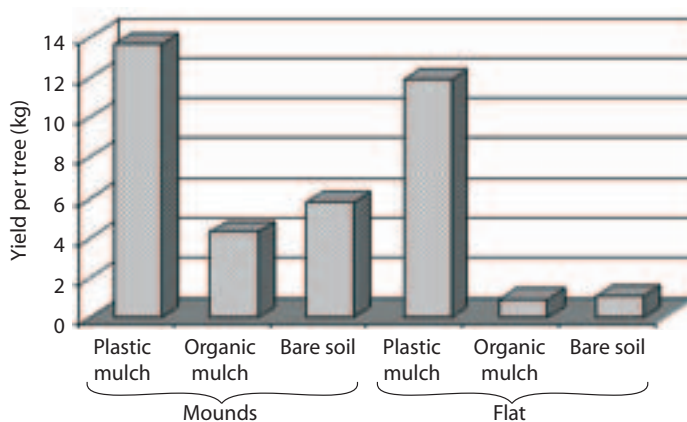
At the conclusion of the experiment, the use of mounds was shown to be very effective at reducing the incidence of root rot (Figure 7.3.1). The percentage of plants with root rot was significantly greater ( $P <$

$0.05$ ) in plots where plants were grown on flat ground with either organic mulch or bare soil compared with plants grown on mounds. There was no difference in survival ( $P > 0.05$ ) between plants grown on flat ground with plastic mulch and plants grown on mounds. The pre-plant application of metalaxyl granules had no effect ( $P > 0.05$ ) on reducing the incidence of root rot. *Phytophthora palmivora* was recovered from all root rot affected plants.

Larger, more mature fruit was obtained from larger, more vigorous plants, and fruit weight varied across the various treatments (Figure 7.3.2). Significantly heavier ( $P < 0.05$ ) fruits were harvested from plants grown on mounds, and on flat ground with plastic mulch, than from plants grown on flat ground with organic mulch or bare soil. The highest yield was obtained from plants grown on mounds with plastic mulch.



**Figure 7.3.1** Effect of growing papaya on mounds or flat ground with or without organic or plastic mulches, on the incidence of phytophthora root rot and plant losses.



**Figure 7.3.2** Effect on yield of growing papaya on mounds or flat ground with or without organic or plastic mulches.

## Discussion

In field situations where a soil-borne disease is well established, growers are generally encouraged to create a growing environment that is favourable for the host and less favourable for the pathogen. The persistence of free water in the soil has a major influence on the development of phytophthora-related disease as it favours the increase in *Phytophthora* populations (Duniway 1979). Therefore, optimising vertical drainage should effectively reduce the period of soil saturation and subsequent damage due to disease (Duniway 1983). The use of mounds in our field experiment achieved this result by reducing plant losses due to root rot and substantially increasing fruit yield.

Wide plastic mulch also reduced plant losses and increased fruit yield in both mounded and non-mounded plantings. This result was most likely due to reduced water infiltration into the soil rather than solarisation, as the plastic was painted white before transplanting, and the predominantly overcast conditions at that time of year would have reduced the heating effect. However, the cost of purchasing and laying plastic mulch, and environmental concerns about its disposal, are likely to prohibit its use. The use of shredded tree bark as organic mulch caused severe plant losses due to root rot, and substantially reduced fruit yield in all but mounded plots. This result was most likely due to increased soil moisture retention and the positive influence this has on increasing disease development (Vawdrey et al. 2002). Other types of organic mulch may be more effective, for example some types of bark suppress *Phytophthora*, while leaf litter, straws and manures may improve drainage as well as suppress the pathogen (Konam and Guest 2002; Ribeiro and Linderman 1991). Future research will evaluate the integration of single row mounds and foliar applications of potassium phosphonate for the management of phytophthora root rot of papaya.

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# 7.4 Root Infusion of Phosphorous Acid for the Control of Phytophthora Foot Rot in Black Pepper (*Piper nigrum* L.)

Mee-Hua Wong<sup>1</sup>

## Abstract

Phytophthora foot rot caused by *Phytophthora capsici* is the most devastating disease of pepper (*Piper nigrum* L.) in Sarawak. This paper outlines the symptoms and management of the disease. The application of phosphorous acid by the root infusion technique is described and its advantages over conventional application methods are discussed.

## Introduction

Pepper (*Piper nigrum* L.), which is popularly known as the 'king of spices', is the most important spice crop grown in Sarawak. Sarawak is the main producing state in Malaysia, contributing about 98% of the country's total production. It exported about 26,000 tonnes in 2001 valued at USD45m according to Sarawak's Department of Statistics. In Sarawak, pepper is cultivated as a monocrop in smallholdings with an area of 13,000 ha. Though the crop is planted throughout the state, the main areas are largely concentrated in the central and southwestern parts.

Pepper cultivation in Sarawak is affected by a number of fungal diseases that cause heavy losses in yield and reduce the economic lifespan of pepper vines. Among these diseases, foot rot caused by *P. capsici* is the most important and devastating.

## Symptoms

*Phytophthora* can infect both mature and immature plants, and symptoms of the disease may appear on all parts of the plant. The infection of pepper starts at the collar region of the vine. However, it is usually

not detected until the top portion of the vine shows signs of leaf yellowing and wilting, and the branches appear to droop. Once these symptoms are noticed, the infection is already advanced, with the underground stem having brownish-black lesions and extensive rotting of the roots. The lesion may extend upwards along the main stem of the vine. Infected berries turn brown, have a sunken appearance and may drop. As the disease progresses, leaves and branches turn brown. The shedding of leaves and breaking off of branches follows until only a skeleton of the vine remains.

Though the pathogen is soil borne and infection usually starts at the collar region or the underground part of the vine, aerial infection due to wind dispersal and rain-splash of spores sometimes occurs. In this instance, characteristic fimbriate-edged leaf lesions are observed on the leaves.

## Disease Management

At present there are no pepper cultivars with high levels of resistance to *P. capsici*. An integrated approach consisting of both cultural and chemical methods is needed to manage this disease.

As foot rot spreads very rapidly and the symptoms take some time to develop, it is difficult to control the disease. Therefore, the management of this disease needs to emphasise prevention based on good cultural practices.

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Field hygiene such as cleaning of farm tools and equipment should be practised. Eliminating the movement of infected soil into disease-free areas will prevent dissemination of the pathogen. Pruning of the lower branches that are in contact with the soil is recommended, especially during the rainy season. Field sanitation by roguing infected plants to prevent inoculum build-up and spread of the disease is also recommended. The garden should have proper drainage to prevent excess soil water and waterlogging, which is conducive for the development and spread of the zoospores. The use of planting materials from diseased gardens or high-risk areas should be avoided. It is important to be vigilant, so that prompt action can be taken to contain outbreaks.

Chemical control is an important component in managing the disease, especially when disease symptoms start to appear. Fungicides such as copper, fosetyl-aluminium or metalaxyl are being used. Kueh (1993) and Kueh et al. (1993) recommended control of the disease by the use of metalaxyl or phosphorous acid, applied either by foliar spraying, soil drenching or trunk injection. However, the conventional method of spraying is unsatisfactory due to wet weather conditions at the end of the year when the disease incidence is highest. The effect of soil drenches is short-lived

because phosphorous acid is oxidised by soil microorganisms that render it non-fungicidal (Whiley et al. 1987). Trunk injection causes injury to the vine and predisposes the plant to other pests and diseases. An alternative mode of applying phosphorous acid to control phytophthora foot rot was therefore developed.

### Root Infusion Technique

This aim of the root infusion technique is to increase the level of phosphonate in the root and vine tissue, which renders these plant parts increasingly tolerant to invasion by *Phytophthora*.

For successful implementation of the root infusion technique, the choice of root is important. The primary root chosen must be without any damage or wounds (Figure 7.4.1), and should be about 7.5–10 mm in diameter. The soil on the mound is dug out carefully with a hand spade. Following the direction of a primary root, the surrounding soil is loosened to isolate the root. After a suitable root is isolated, other secondary roots or rootlets on the primary root are trimmed off and soil on the root surface is also removed. The root is then cut with a sharp knife. The cut end is immediately inserted into an 80–100 mL plastic bottle that has been filled with 1–2% phosphorous acid (Figure 7.4.2). The root must reach



Figure 7.4.1 A primary root isolated for infusion



Figure 7.4.2 Root infusion in progress

the bottom of the bottle so that the acid can be absorbed. To keep the bottle in place at an angle, the surrounding soil is pushed and pressed near the bottle. Each vine should at least take up half the volume of the diluted acid.

The treatment is usually carried out in the morning, up until midday, as translocation is generally stronger that time of the day. While the treatment is in progress, each vine is checked to ensure that there is absorption. If there is no uptake, or the volume taken up is too low, the root should be replaced with another one. The time taken for complete absorption varies from vine to vine, with a range of 1 to 4 hours. After the treatment, the bottle is removed and the root is re-covered with soil.

Preliminary studies on the application of phosphorous acid through root infusion showed that disease spread was impeded and the productive life span of vines in the infected garden extended (Wong and Wong 1996).

### Advantages of the Technique

The application of phosphorous acid by the root infusion technique has many advantages over conventional methods of application.

- No wastage. The phosphorous acid that is absorbed by the root is directly translocated in the plant and, as a result, there is no chemical drift or spillage to non-target area causing excessive wastage of chemical. With no unnecessary loss of chemical, the quantity required is less and this brings cost savings.
- Less chemical hazard. As there is no problem of chemical drift, the risk of the operator being exposed to the chemical is reduced. In addition, phosphorous acid is a non-toxic compound, which further enhances the operator's safety.
- Protected from rain. As the phosphorous acid is infused through the root, it is protected from being washed off if rain follows the application.
- No environmental pollution and no interference with soil microorganisms. Foliar spraying and soil drenching of chemicals cause air pollution and contaminate the soil. These modes of application can also cause injury to non-target plants and are detrimental to soil microorganisms. Root infusion involves the direct absorption of phosphorous acid and therefore these problems do not arise.
- No damage to the vine. Though trunk injection is a popular way of administering phosphorous acid in many crops, it was found to be unsuitable for pepper vines. Drilling the stem causes injury that might predispose the plant to other pathogens.

Injection technology and injectors have been developed for trunk injection where longer diameter injection holes are not a problem. There is no physical damage observed in the vine when root infusion has been used.

- Simple tools and technique. This technique does not require any expensive or sophisticated tools, only plastic bottles. In cases when plastic bottles are not available, plastic bags or used cans could be used to improvise. The application technique is simple and easy to implement.

Minor disadvantages include the labour intensiveness and the problem of finding suitable roots, especially in gravel soils and when roots are already diseased. This techniques has also been used to threat phytophthora diseases in other plants, including coconut, but is especially suitable to perennial vines.

### Conclusion

Integrated disease management strategies with emphasis on preventive control should be adopted to manage phytophthora foot rot. Apart from good cultural practices, which are of the utmost importance in preventing the disease, chemicals such as phosphorous acid protect plants against infection. The root infusion technique has been shown to be a more efficient way of delivering phosphorous acid in the case of pepper vine. With its various advantages, this improved mode of application offers a practical alternative over other application methods and is an attractive economic proposition for the small pepper farmers.

### Acknowledgment

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## 7.5 Biological Control of Black Pod Disease on Cocoa in Malaysia

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### Abstract

In order to reduce losses due to black pod disease in cocoa, the efficacy of a number of biological control agents has been tested. One approach to biological control is to increase the number of beneficial bacteria on the surface of the cocoa pods. It is recognised that biological control of *Phytophthora palmivora* is just one part of an integrated disease management strategy.

### Introduction

Black pod disease caused by *Phytophthora palmivora* is one of the most important diseases of cocoa (*Theobroma cacao* L.) in Malaysia. The major economic losses are from the infection of the pod. Losses caused by black pod disease in Malaysia are estimated to be less than 5%, but at certain times could be over 70% (Tey and Bong 1990; Bong and Stephen 1999). Normally, black pod disease can infect cocoa pods at any stage of pod development, but the most significant economic losses arise from infection of the immature pods. Temperatures of between 15 and 30°C, relative humidities of 80 to 100% and high rainfall constitute conditions conducive for disease development. The management of this disease in Malaysia relies heavily on chemical control, which can be costly and labour intensive. Changing community attitudes towards the use of pesticides are driving a need for alternative approaches to the control of black pod disease. This paper discusses the current practices and the progress made in some of the research conducted at the Malaysian Cocoa Board towards sustainable management of black pod disease of cocoa.

### Biological Control

Biological control may offer an environmental friendly approach to the management of plant diseases and can be combined with cultural and physical controls and limited chemical usage for effective integrated disease management systems. Biological control avoids problems experienced with chemical controls, such as the development of chemical resistance in the pathogen. Biological control cannot completely eliminate the pathogen, may not work as rapidly as chemical methods and may provide only a partial level of control. Biological control also can be an important component in the development of sustainable agriculture management systems. Biological control includes the use of resistant varieties and the manipulation of biological competitors and antagonists.

Biological control agents isolated from healthy cocoa pods and the infected pod surface (resident antagonist) can interfere with the growth of the pathogen. Epiphytic microorganisms, especially bacteria, are capable of inhibiting the growth of *P. palmivora* (Bong et al. 1998; Bong and Stephen 1999). The humid conditions in which cocoa is cultivated provide a favourable environment for the development and survival of epiphytic microorganisms antagonistic to *P. palmivora* (Galindo 1992). Bacteria have been favoured because they are easy to handle, have a high reproductive rate and are the first colonisers of the phylloplane (Spurr and Knudsen 1985).

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## Screening for Resistance to *Phytophthora*

Recently, the focus of cocoa breeding by the Malaysian Cocoa Board has placed a high importance on black pod resistance. The Malaysian Cocoa Board is currently involved in international collaborative research programs with the Common Fund for Commodities (CFC)/International Cocoa Organisation (ICCO)/International Plant Genetic Resource Institute (IPGRI). The aim of these programs is to screen cocoa germplasm for resistance to *P. palmivora* through leaf disc and detached pod tests. Screening for resistance to black pod was devised and adapted from methods published elsewhere (Nyasse et al. 1995) in order to come up with a cheap and rapid leaf inoculation method for preliminary mass screening. It is also being used in host-pathogen interaction studies to compare the aggressiveness of various isolates of the pathogen and for determining the presence of a specific host-pathogen interaction, which is important in the deployment and management of black pod resistance in the host. A significant host-pathogen interaction was found, with some cocoa clones being more susceptible to some *P. palmivora* isolates and less sensitive to others.

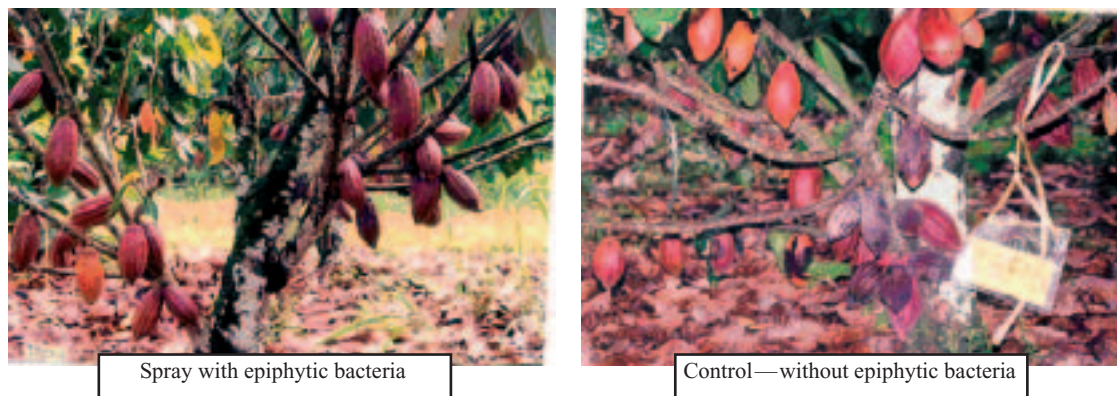
Numerous imported cocoa clones of the PBC, QH, SDS, UP and KKM series, and other local selections developed by various agencies and plantations, were tested against two *P. palmivora* isolates. Those found to have resistance comparable to or greater than that of PBC123, based on the leaf inoculation test, included BR25, K82 and P7. Others were consistently found to be more resistant than PBC123 to black pod phytophthora in leaf inoculation tests.

Resistance of rootstock to *Phytophthora* is also an important consideration in clonal plantings. A simple method that can be used to screen for resistant rootstock entails coating the seeds with the *P. palmivora* sporangia before germinating them (Ahmad Kamil and Yahya 2000). This is a destructive method for the selection of resistant rootstock and elimination of susceptible ones, a consideration not insignificant to the breeders. A start has been made in establishing a pool of resistant rootstock for breeders to further develop and form the basis of a study on compatibility of stock-scion interactions. Most of the rootstocks in recent new plantings has been derived from the most readily available source, seeds of PBC123 or BR25 obtained from commercial cocoa plantations. As observed in germination tests of seeds from open-pollinated pods of over 20 clones and hybrids (KKM 22, BAL 244, QH series of clones, TT 1, Desa

series, BR 25, PBC 123, UIT1 × EQX107, SDS18, PA300 × K82, EET 390 × K 82, PA20 × IMC 23, UIT1 × NA33 and LS4), germination rates of seeds coated with *P. palmivora* could be as high as 90% or as low as under 30% depending on the concentration of inoculum and the resistance to infection of the seeds (Ahmad Kamil and Yahya 2001).

## Development of Microbial Biocontrol Agents

The application of chemical control in the management of cocoa diseases is mainly practised in the control of black pod, which often shows explosive epidemics. In view of rising consumer concern with the environment and health, and the fact that premium prices are paid for organically grown products, the potential for environmental friendly and sustainable biological control methods using beneficial microbes to combat pathogens has been investigated. Fungal and bacterial antagonists were collected from the rhizosphere and phylloplane of cocoa. Recent research conducted in Sabah revealed that certain bacteria and fungi isolated from the surfaces of healthy and infected cocoa pods are antagonistic to *P. palmivora*. They include: *Gliocladium virens*, *Trichoderma harzianum*, *Pseudomonas putida* biotype A, *P. aeruginosa*, *P. spinosa*, *Burkholderia gladioli*, *Burkholderia* sp., *Bacillus sphaericus*, *B. polymyxa*, and *Serratia marcescens* (Bong et al. 1998; Ahmad Kamil and Yahya 1999; Bong and Stephen 1999; Shari Fuddin 1999). The fungal and bacterial antagonists selected for further study are screened for pathogenicity towards plants and animals. Two potential fungal and bacterial species are being further evaluated, and are now into their second season of field evaluation for efficacy in control of black pod trials established in Lahad Datu, Sabah. Introduced during the cropping period in the first season of the trial, the black pod incidence in treated plots was significantly lower than in the control. In terms of the effect on the progress of the epidemic of black pod, based on comparison of the apparent rates of infection, plots treated with the antagonists showed infection rates half those in the control (Figure 7.5.1). Hence, there is potential for further investigations. Research findings also demonstrated that the biocontrol agents could be produced in liquid culture. The use of bio-fermentation for mass production of biocontrol agents needs to be cost-effective, and they should cost less than chemicals. The method of application depends on the mode of action of bacteria and should be compatible with established crop-management practices.



**Figure 7.5.1** Field experimentation on the use of antagonist epiphytic bacteria in controlling black pod disease caused by *Phytophthora palmivora*.

### Diversity of Microorganisms and Their Roles in the Cocoa-based Agro-ecosystem

Among the microflora found on cocoa are both pathogens and beneficial microorganisms, the potential of most of which to act as a biocontrol agent has yet to be determined (Bong et al. 1998). It is important to know what is present, in order to improve the effectiveness of integrated disease management. Present in the soil, and in the cocoa rhizosphere in particular, are beneficial fungi and bacteria that may be effective antagonists of *Phytophthora*. As mentioned previously, many beneficial bacteria, particularly species of *Pseudomonas*, are resident microbes on pod surfaces.

Basic research is also conducted on microorganisms that have potential use in ecosystem-based disease management strategies for cocoa. Basic studies in this area are focused on the environmental influence on the growth of the pathogens and/or beneficial microbes. The optimal range of temperature for growth of the bacterial antagonists investigated was found to be 28–35°C, though a few species are thermophilic, surviving at temperatures up to 55°C. Most of the bacterial antagonists grow well at above pH4. Clearly, the key is to improve persistence and survival of biological control agents in the field.

### The Outlook for Black Pod Disease Management

From the results of many years of research aimed at controlling black pod disease, one has to conclude that there is no single solution. Better disease control has to be based on a combination of agronomic practices that hinder the development and spread of the pathogen, the use of effective biocontrol agents and more precise timing of spray applications, and

the use of resistant clones. It is also important to understand the range of environmental conditions, such as temperature and moisture, in which biocontrol agents are effective under field conditions. The environment in which cocoa is cultivated provides conditions favourable for epiphytic bacteria as biocontrol agents to multiply rapidly in the field. Host resistance will remain the cornerstone of a more sustainable, user and eco-friendly and less costly integrated disease-management strategy of cocoa with cultural, chemical and microbial control as supporting components.

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# 8

## *Phytophthora* in Durian



# 8.1 Botany and Production of Durian (*Durio zibethinus*) in Southeast Asia

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## Abstract

Durian originated in wet tropical Southeast Asia, where 30 species have been described. Wild *Durio* spp. are still found in Borneo and Sumatra, although rainforest destruction seriously threatens genetic diversity in the genus. One species, *Durio zibethinus* L., is widely cultivated, primarily for consumption of the fresh fruit, although other species and uses are described. Trees are usually grown in mixed home gardens for domestic consumption. Large-scale commercial orchard cultivation is practised in Thailand, Malaysia and Indonesia, while industries are developing in Vietnam, the Philippines and Australia. The seasonality of production causes significant fluctuations in supply and market prices, and creates opportunities for new plantings and cultural techniques that exploit the low supply of fruit during the off-season.

## Origin and Diversity of Durian

The genus *Durio* (Order Malvales, Family Bombacaceae) has a complex taxonomy that has seen the subtraction and addition of many species since it was created by the German botanist Georgius Everhardus Rumphius (1627–1702) in the 17th century. Currently 30 species are recognised, including 9 to 11 species with edible fruit (Lim 1990; Brown 1997; Lim and Luders 1997). However, there are many species for which the fruit has never been collected or fully described and it is likely that other species with edible fruit exist (Brown 1997). The most extensively grown and economically significant species is *Durio zibethinus* L. (Lim 1990; Nanthachai 1994; Brown 1997). Many cultivars and local selections are grown.

The Latin epithet *zibethinus* was given by Linnaeus, sight-unseen, from a description of durian in Rumphius’s posthumously published, classical work on Indonesian flora, *Herbarium Amboinense* (1741–1750), containing an explanation that the fruit was used to bait the civet cat (Brown 1997). Thus, the common misconception that *D. zibethinus* (durian) was named because it smells like the Indian civet cat (Watson 1984) – a feature that no doubt accounts for its Dutch name of ‘Stinkvrucht’ – is false. Brown (1997) also points out that Linnaeus is the correct authority for *Durio zibethinus*, not Murray. He notes that the confusion arose in the 1800’s when a simple error found its way into several major taxonomic works.

Borneo is thought to be the centre of diversity of the genus *Durio* and many species are indigenous to the Malay Archipelago, but over many hundreds of years it has been introduced into Thailand, Vietnam, Laos, Kampuchea, Myanmar (Burma), Sri Lanka, New Guinea, West Indies, Polynesian Islands, Hawaii, Florida, southern China (Hainan Island), and northern Australia (Lim 1990; Nanthachai 1994; Brown 1997; Lim and Luders 1997).

## Botany

Durian is a tall evergreen tropical tree with a buttressed base and straight trunk and almost horizontal upper

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branches. In its natural rainforest environment, it can grow to 60 m in height, but rarely exceeds 20 m when grown as grafted clones or rootstock in horticultural settings (Nanthachai 1994). Architecturally, the tree exemplifies Roux's Model with a tall, broadly conical frame tapering to an apex (Figure 8.1.1). The leaves are alternate and lanceolate, 10–15 × 3–5 cm, with a glossy upper surface and velvety, silver–golden lower surface (Figure 8.1.2), due to the dense covering of overlapping peltate and stellate hairs (Brown 1994; see also Chapter 3.2).

There are many excellent descriptions of the physical (Singh and Rao 1963; Davis and Bhattacharya 1974; Watson 1984; Lim 1990; Masri 1991; Nanthachai 1994; Yaacob and Subhadrabandhu 1995; Brown 1997) and micro-morphological characteristics of durian in the literature (Baas 1972; Rao and Singh 1964; Rao and Ramayya 1981; Hasan and Dodd 1989; Salma 1999). Cauliferous inflorescences are borne in clusters of 3–10 flowers over a period of about 2–3 weeks during the dry season (Figure 8.1.3). Pedicels, 5–7 cm long, support globose flower buds 2 cm in diameter, opening to reveal 5–6 cm long, greenish-white flowers. The tubular calyx has three to five triangular teeth surrounding five petals. Stamens are arranged in five bundles around a pubescent style and protruding capitellate stigma. Flowers open late in the afternoon and pollen release is complete before midnight. The stigma remains

receptive until early morning, facilitating pollination by bats and moths. Fruit development is sigmoidal and takes 95–130 days, depending on the species and cultivar. Under normal conditions, fruit ripening heralds the start of the rainy season (Table 8.1.1).

Durian is the most famous fruit in Southeast Asia and is renowned for its strong odour and unique taste. The durian fruit is large (between 2 and 5 kg), pendulous, round to oblong in shape, covered with strong sharp spines, and the pericarp is yellow–green to green or brown in colour and does not change significantly with ripening (Figure 8.1.4). Commercial orchards focus on a few popular cultivars and aim to produce medium-size fruit of about 2.5 kg in weight. The fruit usually comprises five locules, holding one to seven large brown seeds covered in the edible flesh (aril), which is cream to yellow in colour, depending on the variety (Figure 8.1.5; Lim 1990; Tinggal et al. 1994). The arils typically comprise 20–35% of the fruit weight, and are composed of 2.5% protein, 2.5% fat, 28% carbohydrate and 67% water, with smaller amounts of fibre, minerals and vitamins. The odour originates from a complex mixture of thiols, esters, ethers and sulfides.

Durian fruit is preserved by freezing, or in the form of a paste or cake that is used to flavour ice-cream, bread or pastries, or the fruit can be fermented,



**Figure 8.1.1** Shape of the mature durian tree, showing the tall, straight, buttressed trunk tapering to a conical apex.



**Figure 8.1.2** Lanceolate shape and distinct upper (a) and lower (b) surfaces of durian leaves.

salted or boiled in sugar syrup. Pre-packaged frozen durian arils, usually from Thailand, are becoming widely available in Asian supermarkets in Western countries, including Australia.

The seeds are sometimes eaten after boiling or roasting and young shoots and immature fruit can be cooked as vegetables. Fresh seed germinates within 3–8 days to produce a fast-growing seedling that shows strong apical dominance.

Fruit rind can be dried and used as a fuel. The wood is coarse, lightweight and is used in light construction and to make furniture and clogs, although it is not durable and is rarely used for construction (Lim 1990; Brown, 1994; Nanthachai 1994; Brown 1997).

### Fruit Production

Durian is strictly tropical and stops growing when mean daily temperatures drop below 22°C, which occurs frequently at the extremes of cultivation in Thailand and Queensland (Nanthachai 1994).

Annual rainfall of 1500 mm or more is required and supplementary irrigation may be necessary during the dry season. The tree prefers deep, well-drained loamy soils but is vulnerable to uprooting and damage during storms and cyclones and requires protection from strong winds.

Flowers are borne mostly on horizontal limbs and pruning is used to limit the number of plagiotropic limbs and to limit tree height. Flowering is naturally stimulated by the onset of the dry season, or can be induced out-of-season after drying the soil by covering with plastic sheets (Figure 8.1.6), or through the use of growth regulators. Flower buds are thinned, and fruitlets are thinned again to optimise the size of mature fruit and to remove fruit that are too high or at the extremities of lateral branches, as the weight of mature fruit is likely to cause branches to break.

Harvesting involves many challenges due to the height of the tree and weight and spikiness of the fruit. Ripe fruit falls to the ground, but is usually



Figure 8.1.3 Clusters of durian inflorescences.



Figure 8.1.5 Aril colour of *Durio zibethinus*.



Figure 8.1.4 Mature durian fruit.



Figure 8.1.6 Plastic mulches are used to induce out-of-season flowering (Ben Tre Province, Vietnam).

damaged in the process. Farmers sometimes tie near-ripe fruit to the branch so that it detaches but does not fall and can be harvested without damage (Figure 8.1.7a). Another method involves one harvester climbing the tree and dislodging ripe fruit while others hold a net underneath, catching dislodged fruit before it hits the ground (Figure 8.1.7b). Yields are erratic and variable, however the best orchards in Thailand produce 50 fruit per tree, or 10–18 t/ha, each year.

### Durian Cultivation in Southeast Asia and Australia

Durian has been cultivated for centuries at the village level — probably since the late 1700s, and commercially in Thailand since the mid 1900s (Alim et al. 1994). Since the early 1990s, the domestic and international demand for durian in the Association of South-East Asian Nations (ASEAN) region has increased dramatically, due in part to the rising wave of affluence in Asia (Nanthachai 1994; Lim and Luders 1997). Limited supply has driven a rapid expansion of the area under cultivation, particularly in Thailand, Malaysia and the Philippines (Alim et al. 1994; Nanthachai 1994). By 1997, the value of the industry worldwide was conservatively estimated at USD1.5 billion (Lim 1998). Durian is an economically and culturally important crop in Thailand, Malaysia, Indonesia, Brunei, Vietnam, Myanmar, Cambodia and Lao People's Democratic Republic (Alim et al. 1994; Lim and Luders 1997; Table 8.1.1). The leading exporters of durian in the world are Thailand, Malaysia and Indonesia in descending order, while the Philippines and Vietnam also produce durian for

domestic consumption (Alim et al. 1994; Lim and Luders 1997; Dr Nguyen Minh Chau, pers. comm.). Malaysia still imports a significant amount of durian in its off-season. Durian was introduced to Australia in 1975 by a small number of tropical fruit enthusiasts, and orchard plantings commenced in 1980 in northern Queensland and in 1984 in Darwin (Zappala and Zappala 1994), although it remains a boutique industry.

The majority of production occurs in short seasons of two or three months, although there are two fruiting seasons in Malaysia and Indonesia because the fruit is grown in different localities affected by either the north-east or north-west monsoon. Production in Thailand, Peninsular Malaysia, Kalimantan and Sulawesi is highest between June and July, while harvest peaks in the Philippines in August–November, and Sabah, Sarawak, Java and northern Australia between October to February (Table 8.1.2; see also Alim et al. 1994; Graef and Klotzbach 1995; Brown 1997). The seasonality of durian generates significant opportunities for trade between areas where the fruit is in season and areas where it is not, or in cities and non-producing countries.

### Indonesia

Most of the fruit is produced in Java, Sumatra, Kalimantan and Sulawesi (Alim et al. 1994). Indonesia exported 331 t of durian in 1993 — its main market being Singapore (Graef and Klotzbach 1995). Indonesia's durian industry is concentrated on Sumatra, Java and to a lesser degree Kalimantan. In 1992, the area planted was estimated to be 36,000 ha with production of 152,500 t (Alim et al. 1994).



Figure 8.1.7 Methods of preventing damage to mature fruit: (left) tied fruit; (right) catching fruit.

**Table 8.1.1** Seasonality of durian harvests (shaded) in durian-producing regions (Lim and Luders 1997).

Production area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Western Malaysia												
Eastern Malaysia												
Thailand												
Indonesia												
Vietnam												
Lao PDR												
Cambodia												
The Philippines												
Brunei												
Myanmar												
Singapore												
Northern Queensland												
Northern Territory												

**Table 8.1.2** Production of durian in selected Southeast Asian countries.

Country, year and reference	Area planted (ha)	Production (t)	Value (USD million)	Major markets
Indonesia, 1992 (Alim et al. 1994)	36,024	152,000	36-780	Singapore
Malaysia, 1992 (Alim et al. 1994)	61,000	384,000	840-1020	Singapore
Philippines, 1993/94 (Nanthachai 1994)	8000	145,000	325-522	Domestic
Thailand, 1999 (Salakpetch 2000)	138,024	927,200	448-2686	Hong Kong
Vietnam, 1993/94 (Chau 1994 <sup>a</sup> )	10,000	110,000	33-330	Domestic, Taiwan

<sup>a</sup> Dr N.M. Chau, pers. comm., 1994

## Malaysia

Durian is grown in Peninsular Malaysia, Sarawak and Sabah. Like Thailand, there are more than 200 varieties of durian registered, but only 20 are widely used. Durian has traditionally been produced in small orchards, 0.5-1.0 ha in size, but more recently, 12-120 ha commercial orchards have been established (Alim et al. 1994). In 1991, Malaysia exported USD16.3 million worth of fresh durian, with about 90% going to Singapore (Graef and Klotzbach 1995). Durian fruit is produced in most states of Malaysia and, in 1992, 384,000 t of fruit was produced from the 61,000 ha under cultivation, which comprises 31% of the total area planted to fruit in the nation (Alim et al. 1994). Most of the fruit produced in Sabah and Sarawak is consumed locally, however some fruit is exported to Brunei and Singapore. During the off-season in Malaysia, fruit is imported from Thailand (Lim and Luders 1997).

## The Philippines

Durian is a high-value crop with great prospects for export from the Philippines, as the harvest season is later than in other Southeast Asian countries. The

Philippines is actively expanding durian production, especially in the typhoon-free areas in Mindanao. An estimated additional 30,000 ha of durian would be required to meet domestic demand if consumption rose from the current 0.2 kg to 2 kg per capita, let alone the 14 kg per capita consumption in Thailand.

## Thailand

The Thai durian industry started in the provinces around Bangkok, but was almost destroyed by a series of catastrophic events in the 1940s and 1950s (Alim et al. 1994). Durian production in Thailand is now concentrated in the east (49% of the total cultivated area, with Chanthaburi and Rayong provinces being the major producers) and south (44% of the total cultivated area, with Chumporn the major producer) of the country. In 1999, Thailand produced 927,200 t of fruit from 138,000 ha of orchards, almost half of the world's durian production. About 5.5% of this is exported as fresh and frozen fruit. In 1993, approximately 10% of exports were frozen product. The main market for fresh durian is Hong Kong, as well as Malaysia,



Taiwan, Canada, the United States of America, Singapore, Brunei, Australia, Japan and Indonesia, representing 80% of the world export trade, worth USD48 million in 1996 (Graef and Klotzbach 1995; Lim and Luders 1997).

In 1995, the area planted to durian was approximately 128,000 ha, which accounts for 11% of the total area planted for fruit production in Thailand. Most of the durian production is based on four commercial cultivars, although there are more than 200 cultivars in use. Flowers are hand-pollinated to improve fruit set and yield. Because of the diversity of cultivars and growing regions, the harvest season spans from April to September, with a constant supply between May and August.

### Vietnam

The durian industry in Vietnam is quite small, catering mainly for the domestic market, with some export trade with Taiwan (Dr N.M. Chau, pers. comm.). Durian was introduced to southern Vietnam approximately 30 years ago from Thailand and the Philippines, and is now a key element in the reconstruction of horticulture in the Mekong Delta. In the five-year agricultural strategy of the Vietnamese government (1996–2000), durian was identified as a priority crop. In 1993–1994, Vietnam produced 110,000 t of durian for local consumption from about 10,000 ha, mainly in the lowlands of the Mekong Delta (Tien Giang, Can Tho, Soc Trang, Vinh Long, Ta Vinh and Ben Tre provinces). However, the fruit is also produced on the well-drained soils of the highlands in the south-east (Ho Chi Minh City, Dong Nai, Binh Duong, Lam Dong, Ba Ria Vung Tau provinces), Dak Lak Province in the central highlands, and Thua Thien-Hue Province on the central coast.

In the past, durian orchards were established from seedlings rather than from selected varieties, but grafting onto rootstocks has become more popular. Many of the nurseries that provide the grafted material, however, do not choose the most favourable rootstocks and do not use sterile potting media. In the Mekong Delta, durian seedlings are established in raised beds, while in the south-east, seedlings are planted directly into the soil. Young plants are carefully shaded and irrigated after planting. The trees are also fertilised regularly with both organic and inorganic fertilisers. However, trees are rarely pruned and flowers are not hand-pollinated as they are in Thailand. On some farms, the trees are actively water-stressed so that off-season flowering is induced. The farmer can then receive a premium price for off-season fruit.

Intercropping is a common practice among Vietnamese durian growers. Longan, papaya, coffee and langsat are planted during the establishment of the durian orchard, both to provide shade and to provide additional income in the years before the durian trees bear fruit. Durian is increasingly intercropped with rice in the lowlands of the Mekong Delta in the early stages of orchard establishment.

### Australia

In 1999–2000, an industry census identified approximately 12,000 grafted durian trees in the Darwin region of the Northern Territory and northern Queensland (Tully to Cape Tribulation) in Australia, but none in the tropical north of Western Australia (Zappala and Zappala 1994; Zappala et al. 2002). The identification of clones with greater tolerance to cool temperatures would be required for the area of production to expand any further south along the Queensland coast (Zappala et al. 2002). A vigorous Australian industry has the potential to fill seasonal production gaps in Southeast Asia between January and April, but as plantings are yet to reach maturity, annual production is currently less than 50 t (Zappala et al. 2002).

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## 8.2 Occurrence, Distribution and Utilisation of Durian Germplasm

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### Abstract

Durian is a domesticated Asian rainforest tree that has been selected for fruit quality and yield. A few genotypes now dominate commercial cultivation. This narrow genetic base limits the expansion of durian cultivation, and exposes a serious vulnerability to pests and diseases in these new environments. The remaining natural diversity of durian genotypes is threatened by habitat destruction. Naturally occurring disease resistance is one key aspect of this diversity that remains to be fully exploited, in part due to the lack of reliable bioassays. This chapter catalogues the diversity of the genus and assesses the potential for new cultivars.

### Introduction

Although it is commonly believed that *Durio* spp. evolved in Peninsular Malaysia, Borneo and Sumatra, durian (*Durio zibethinus* L.) is commercially grown as far west as Madagascar and India to Papua New Guinea in the east (Kostermans 1958; Subhadrabandhu and Ketsa 2001; Figure 8.2.1). Of the 30 recorded species (Table 8.2.1), 19 are found on the island of Borneo (total of Sabah, Sarawak and Kalimantan in Table 8.2.1), 16 on Peninsular Malaysia, and eight on Sumatra.

*Durio zibethinus* is the only species cultivated on a large scale commercially, but since this species is open-pollinated, it includes considerable diversity in fruit colour, aril size, seed size and tree phenology (Figure 8.2.2). A further eight species yield edible fruit (Tinggal et al. 1994; Voon Boon Hoe 1994):

- *D. graveolens* Becc., ‘durian burung’, ‘durian kuning’, ‘durian merah’, ‘tabelak’ or red-fleshed durian, has sweet, crimson-coloured arils and a fragrance of roasted almonds (Figure 8.2.3)
- ‘durian suluk’ is probably a natural hybrid between *D. zibethinus* and *D. graveolens*, and retains the flavour and texture of *D. zibethinus* with subtle burnt caramel overtones reminiscent of *D. graveolens*



**Figure 8.2.1** Distribution of *Durio* species: solid line represents the native occurrence, while the dashed line represents the current extent of commercial production.

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Table 8.2.1 Distribution of *Durio* spp.

Species	Pen. Mal. <sup>a</sup>	Sabah	Sarawak	Kalimantan	Sumatra	Java-Java	Myanmar	Celebes	Philippines	Thailand	New Guinea	Indo-China
<i>D. acutifolius</i>	+	+	+	+								
<i>D. affinis</i>		+	+	+								
<i>D. beccarianus</i>												
<i>D. carinatus</i>	+		+		+							
<i>D. crassipes</i>		+	+									
<i>D. dulcis</i>		+	+	+					+			
<i>D. excelsus</i>			+	+								
<i>D. grandiflorus</i>	+	+	+						+			
<i>D. graveolens</i>	+	+	+	+	+				+			
<i>D. griffithii</i>	+	+	+	+	+							
<i>D. johoricus</i>	+											
<i>D. kinabaluensis</i>		+										
<i>D. kutejensis</i>		+	+	+		+			+			
<i>D. lanceolatus</i>		+	+	+								
<i>D. lissocarpus</i>			+	+								
<i>D. lowianus</i>	+				+							
<i>D. macrantha</i>					+							
<i>D. macrolepis</i>	+											
<i>D. macrophyllus</i>	+											
<i>D. malaccensis</i>	+				+							
<i>D. mansoni</i>							+					
<i>D. oblongus</i>			+									
<i>D. oxleyanus</i>	+	+	+	+	+				+			
<i>D. perakensis</i>	+											
<i>D. pinangianus</i>	+											
<i>D. purpureus</i>				+								
<i>D. singaporensis</i>	+											
<i>D. testudinatum</i>		+	+	+								
<i>D. wiyatt-smithii</i>	+											
<i>D. zibethinus</i>	+	+	+	+	+	+	+	+	+	+	+	+

<sup>a</sup> Pen. Mal. = Peninsular Malaysia

- 'durian simpor' is a mild-flavoured, yellow-fleshed variant of *D. graveolens*
- *D. testudinarum* Becc. (syn. *D. macrophyllus* Ridley), the 'tortoise' or 'kura kura' durian, is a self-pollinated species, and thus less variable, that has an extended flowering season. The fruit ripens from green to yellow and the aril is pale yellow, sweet and has a strong aroma (Figure 8.2.4)
- *D. oxleyanus* Griff., 'durian sukan', 'durian beludu', 'isu' or 'kerontangan', is a very tall tree that produces small, round, green fruit adorned with long spines. The aril is yellow, smooth-textured and sweet (Figure 8.2.5)
- *D. kutejensis* (Hassk.)Becc., 'durian pulu', 'durian merah', 'nyekak' or 'lai', is a species that bears fruit late in the season. The flowers emit a strong carrion smell at anthesis, and the fruit has thick, golden arils with a mild, sweet taste and creamy texture (Figure 8.2.6)
- *D. dulcis* Becc., 'durian marangang', the red, 'tutong', or 'lahong' durian, produces fruit with attractive long red spines, and although the aril surrounding the shiny black seeds is thin, it has a sweet flavour and pleasant turpentine odour (Figure 8.2.7)
- *D. lowianus* Scort. Ex King, 'durian duan' has red flowers and elongated, oval-shape fruit containing white to yellow arils (Figure 8.2.8).

Numerous cultivars of durian have arisen in Southeast Asia over hundreds of years of selection from open-pollinated seedlings for fruit quality and yield (Lim and Luders 1997). The following attributes are more recently sought in current germplasm assessment schemes (Lim and Luders 1997):

- aril recovery of  $\geq 30\%$
- yellow to deep yellow, firm, creamy aril
- small seed
- high (70 to 100 fruit per tree) and consistent yield
- resistance to major pests and diseases.

Historically, durian used to be grown from seeds with superior taste and texture but at present cultivars are propagated by either layering, marcotting or, more commonly, by a variety of grafting methods, including bud, veneer, wedge, whip or U-grafting onto seedlings of random rootstocks (Chapter 8.3; Lim and Luders 1997). In Thailand, the *D. zibethinus* cultivar Chanee is the preferred rootstock due to its observed resistance to infection by *Phytophthora palmivora*. Many superior selections have been identified in Malaysia through competitions held at the annual Malaysian Agriculture, Horticulture and Agrotourism Shows. The use of durian competitions to identify superior varieties and promoting extension has also being adopted in Vietnam by the Southern Fruit Research Institute (Figure 8.2.9).



Figure 8.2.2 Fruit diversity in *Durio zibethinus*.



Figure 8.2.3 Fruit of *Durio graveolens*.



Figure 8.2.4 Fruiting tree of *Durio testudinarum*, with inset showing internal view of the fruit.

More than 200 varieties of *Durio zibethinus* are recognised in Thailand and most originate from seedlings of open-pollinated fruits, however there are often only minor differences between varieties (Tinggal et al. 1994). There are many variations in the

spelling of Thai durian cultivars. For consistency, we have used the same spelling as Nanthachai (1994). Table 8.2.2 provides some of the alternative spellings that we have encountered for the most common varieties. Where Thai varieties have been introduced into other countries, there are yet more spelling variations, e.g. in the Philippines, Monthong is called Otong and Chanee is called Kani. Many attempts have been made to group the varieties according to either: (i) time to fruit-bearing from planting; (ii) fruit characteristics and origin of the variety; or (iii) length of time to fruit maturity (Tinggal et al. 1994; Lim and Luders 1997).

Hiranpradit and colleagues in 1992 proposed the following six groups by classifying varieties on leaf and fruit spine characteristics and fruit shape (Tinggal et al. 1994; Lim and Luders 1997):

- Kob – containing 38 varieties
- Luang – containing 7 varieties, including Chanee
- Kanyao – containing 7 varieties, including Kanyao
- Kumpun – containing 11 varieties, including Monthong
- Tongyoi – containing 12 varieties
- Miscellaneous – containing 47 varieties including Kradoom.

Tinggal et al. (1994) present photographs of fruit representative of each group, while Lim and Luders (1997) give detailed descriptions.

Despite the large number of varieties, the area under cultivation in Thailand's world-leading export industry is dominated by just four varieties: 41% Monthong, 33% Chanee, while Kanyao and Kradoom represent about 8.5% of the cultivated area (Alim et al. 1994; Zappala 2002). Thai varieties have been introduced to many other durian-producing countries and Monthong and Chanee are recommended varieties in Malaysia and the Philippines.

Like Thailand, Malaysia has a multitude of open-pollinated varieties but only a small number are cultivated on a commercial basis. Two organisations in Malaysia have hybridisation programs using

Table 8.2.2 Alternative spellings of common Thai durian varieties.

Variety name	Alternative spellings			
Kob	Kop	Gob		
Luang	Lueng			
Kanyao	Gaan Yao(w)	Karn-Yao	Kan Yau	
Kumpun	Kampun	Gumpun		
Monthong	Montong	Mon Thong		
Kradoom	Kadoom	Kradum Thong	Kra-dum-tong	Gradumtong

popular local varieties as parents — the Malaysian Department of Agriculture (MDA) and the Malaysian Agriculture Research and Development Institute (MARDI) (Lim and Luders 1997). The MDA program started in the 1960s, registration of hybrids occurred in the 1980s and the first reports of commercial success with the hybrids came in the early 1990s (Brown 1997; Lim and Luders 1997), demonstrating the long-term investment required for breeding programs. Lim and Luders (1997) describe the origins and fruit characteristics of over 100 Malaysian varieties, including the ones recommended for cultivation by MDA. MARDI now has one of the largest *Durio* germplasm collections in the world, containing approximately 400 accessions (Brown 1997).

Lim and Luders (1997) also describe over 40 of the recognised Indonesian varieties, including the 15 superior varieties that have been released and recommended by the Indonesian Department of Agriculture. Tinggal et al. (1994) describe the six cultivars recommended for planting in the Philippines, the three varieties grown in Singapore and some of the other *Durio* species cultivated for local consumption in Brunei, including *D. graveolens*,

*D. testudinarum*, *D. oxleyanus*, *D. kutejensis*, *D. dulcis* and 'durian suluk'.

There is very little detailed information readily available on the commercial varieties available in countries like Cambodia, Laos, Myanmar (Burma), Sri Lanka and Vietnam (Lim and Luders 1997). However, Vietnamese local selections are numerous and show large variations in yield, fruit quality and disease susceptibility. The area of durian under cultivation is expanding rapidly in southern Vietnam, generating significant new wealth and improving living standards for farmers.

All the varieties currently found in Australia have been introduced from Southeast Asia. In contrast to other durian-producing countries where industry development has been strongly promoted by government, the effort to establish a viable industry in Australia has been driven mostly by enthusiastic farmers (Lim and Luders 1997). Durian production in northern Queensland is a relatively new industry with approximately 9000 trees grown from Cooktown (16°S) to Tully (18.5°S) along the wet tropical coast.



Figure 8.2.5 Fruit of *Durio oxleyanus* (above and right).



Figure 8.2.6 Fruit of *Durio kutejensis*.

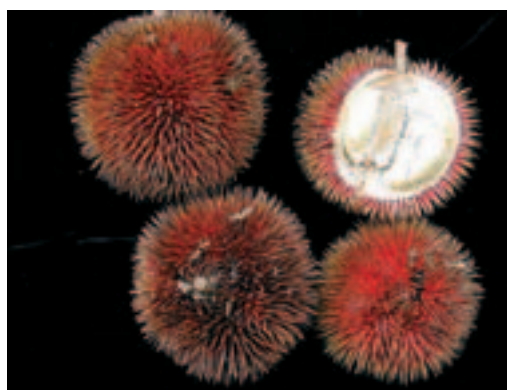


Figure 8.2.7 Fruit of *Durio dulcis*.

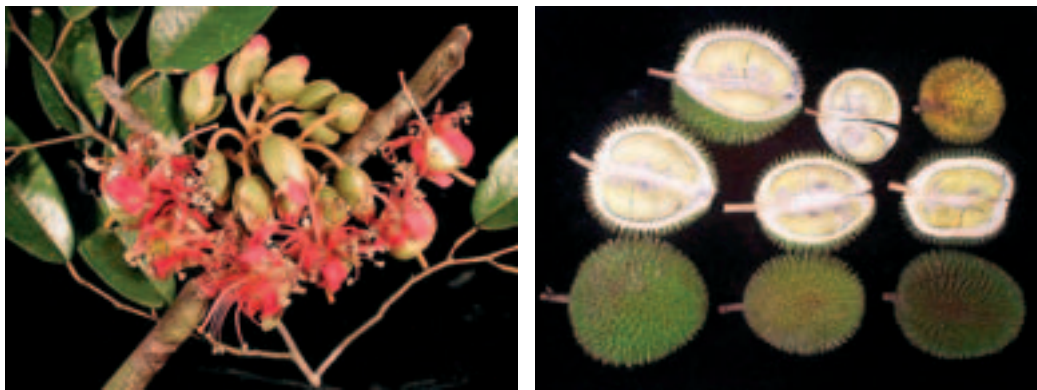


Figure 8.2.8 Flowers and fruit of *Durio lowianus*.

Durian seeds were first imported into Australia in the early 1970s from Malaysia, Indonesia and Thailand (Watson 1984). As growers gained a taste for, and a commercial interest in, durian, budwood and grafted trees were imported. Approximately 40 clones of *Durio zibethinus* and seven other *Durio* species have been introduced into Australia, including *D. dulcis*, *D. kutejensis*, *D. oblongus*, *D. oxleyanus*, *D. testudinarum*, *D. macrantha* and *D. graveolens* (Lim 1998). In addition, over 50 cultivars of *D. zibethinus* and 30 clones from guaranteed sources in Malaysia, Thailand and Indonesia were evaluated for suitability to Australian conditions (Zappala 2002).



Figure 8.2.9 Durian competition at the Southern Fruit Research Institute, Vietnam.

Varieties that are showing promise and being grown in commercial orchards include Monthong (Thailand), Luang (Thailand), D24 (Malaysia), D2 (Malaysia), Hew 2 and 7 (Malaysia), Hepe and Permasuri (Indonesia). A number of local seedling selections have been made and include Limberlost and Chong. Several other *D. zibethinus* clones (D 175, DPI Monthong, Hawaiian Monthong, D190 and Kradum Thong) and *D. macrantha* should also be considered for commercial production in northern Queensland (Zappala 2002).

Some of the durian material introduced in the 1970s and 1980s did not exhibit true varietal characteristics, and recent DNA fingerprinting has confirmed their initial misidentification (Zappala et al. 2002). Misidentification of the germplasm has been a major constraint to the establishment of a successful and credible industry in Australia.

### Genetic Erosion of *Durio* Germplasm

Brown (1997) expressed concern about the genetic erosion of *Durio*. Despite what seems like a lot of variety within *D. zibethinus*, the trend in Indonesia, Malaysia, Thailand and Vietnam toward cultivating clonal material of a few popular commercial varieties is interpreted as contributing to this genetic attrition. Furthermore, there is great scope for improvement and further development of durian cultivars. The ideal tree would be small to facilitate management and harvesting, would be precocious and have a long bearing season, and would bear fruit with a mild odour, large arils and good flavour. The tree would also be environmentally tolerant and resistant to the major diseases and pests.

There are many known species that have not yet been fully described, and the existence in wild populations of other species with edible fruit, resistance to pathogens and other desirable agronomic characteristics remains unexplored. For example, *D. lowianus*, a wild durian from southern Thailand, is apparently more resistant to *P. palmivora* than many commercial cultivars. However, massive deforestation in the centre of diversity of *Durio* seriously threatens the survival of this diversity, and some wild species are probably already extinct.

Scientists must preserve genetic diversity for use in breeding programs. Current germplasm collections should be supplemented by the preservation of large tracts of forest in which wild species are growing, as the genetic conservation of *Durio* using conventional methods is limited because:



- collection sites are limited because durian cultivation is restricted to the humid tropics
- durian is either unknown or not highly regarded outside Southeast Asia
- seeds have a short period of viability and thus conservation in a conventional seedbank is unsuitable
- cryopreservation of seed and callus is still being investigated but is not yet reliable
- attempts to regenerate durian callus have so far been unsuccessful
- trees are very large, making a 'living germplasm' collection impractical and costly for the maintenance of a large numbers of accessions
- germplasm collections kept in high density and in suboptimal environmental conditions can be severely affected by pests and disease
- in order to maintain the diversity present in open-pollinated varieties, a significant number of trees needs to be maintained on an on-going basis.

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## 8.3 Screening for Resistance to *Phytophthora*

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### Abstract

Identifying and evaluating disease resistance depends on rapid, reliable and robust bioassays that can rapidly screen large numbers of genotypes and breeding progenies. We developed seedling, leaf and stem bioassays to screen durian germplasm from Thailand, Vietnam and Australia for resistance to *Phytophthora palmivora*. Detached leaf assays segregated durian cultivars into classes consistent with field observations, and are recommended as an early screen in breeding programs. Durian cultivar Chanee emerged as the least susceptible cultivar in Thai and Vietnamese tests.

### Screening Germplasm for Tolerance to *Phytophthora*

Disease-resistant varieties are central to the integrated management of *Phytophthora palmivora* in durian. Lim (1998a) suggested that wild *Durio* spp. evolving in damp, low-lying areas may be potential sources of genes for disease resistance against *Phytophthora*. The relatively few resistance studies reported suggest that resistance in durian is polygenic (Lim 1998b). One of the major aims of Australian Centre for International Agricultural Research (ACIAR) Project PHT/1995/134, ‘Management of *Phytophthora* diseases in durian’, was to develop a rapid and reliable resistance screening bioassay to identify sources of resistance

in the germplasm collections of Thailand, Vietnam and Australia.

The resistance screening of a perennial crop such as durian might involve pot trials in which whole plants are artificially inoculated, or field trials in which trees at infested sites are assessed over time for disease development and survival. These tests are time-consuming and expensive, and considerable savings could be made if more rapid assays enabled more cultivars to be screened. Preliminary screening bioassays designed to identify cultivars with promising disease-resistance characteristics, or with high levels of susceptibility, have been successfully developed for other crops using detached plant organs.

One of the major diseases of cocoa is black pod, caused by *Phytophthora* spp., and screening bioassays have been developed using detached whole leaves, leaf-discs (Nyasse et al. 1995) and detached cocoa pods (Iwaro et al. 1997). Such bioassays have been used to expedite the identification of resistant genotypes that are suitable for cocoa breeding programs, or susceptible genotypes that should be excluded. Cocoa typically produces two pod flushes a year, with the main cropping season lasting up to six months. With such long production cycles, cocoa pods can be available for screening experiments most of the year. The distinct and relatively short fruiting period of durian makes fruit bioassays less practical as a

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routine tool. Additionally, the large size and the high value of durian fruit can make the design of statistically valid screening experiments difficult.

The variation in the pathogen population means that testing of cultivars at more than one place is necessary. At present, it is unclear if different pathogenic races or differences in aggressiveness occur among *P. palmivora* populations in Southeast Asia and Australia. In addition to differences in pathogen populations, we also have to consider differences in environmental conditions and soil types which occur at a local level and may have a significant influence on the expression of resistance in durian cultivars.

## Bioassay Development

### Entire leaf versus leaf-strip

Some durian cultivars have very large leaves, making the use of entire leaves in a bioassay unwieldy. Leaf-strips (approximately 6 cm long by 2.5 cm wide) cut from either side of the main vein can be used as an alternative. Although we found no difference in the rate or magnitude of lesion development between entire leaves and leaf-strips, there were disadvantages using leaf-strips. Fungal contamination at the cut edge of the leaf-strip was common, particularly if the leaves had been sourced from an orchard rather than from glasshouse-grown seedlings. We reduced contamination by surface-sterilising leaf-strips in a mixture of 10% ethanol and 3% a.i. sodium hypochlorite for 1 minute, followed by thorough rinsing in sterile deionised water before inoculation. However, the production and surface sterilisation of individual strips makes this a time-consuming process.

### Wounded versus non-wounded leaf material

Ideally a bioassay includes wounded and non-wounded treatments so that tissue susceptibility to penetration and infection can be assessed independently. However, in bioassay experiments in Australia (Tan 1999) and Thailand, non-wounded durian leaves did not develop disease symptoms reliably when inoculated with *P. palmivora*. Consequently, a wounding device was designed to deliver a consistent wound to leaves (Figure 8.3.1) before inoculation with an agar plug from the edge of a colony of *P. palmivora*.

### Incubation conditions

Where ambient temperatures were too cold or variable for infection to occur, incubation was carried out in constant-temperature cabinets at 26°C. Tissue desiccation was successfully avoided by incubating whole detached leaves on wire mesh

platforms over free water, in sealed Tupperware® containers. However, incubating leaf-strips over free water, as described above, did not prevent desiccation. While desiccation was reduced by laying the leaf-strips on paper-towel moistened with sterile water, cross-contamination was common due to accidental contact between the leaf-strips, or colonisation of the towel by the pathogen. Tissue desiccation and cross-contamination were prevented when leaf-strips were inoculated at one end and the non-inoculated ends were placed vertically into slots made in a layer (75 mm deep) of solidified water agar and incubated in a sealed Tupperware® container (Figure 8.3.2). Although more time-consuming, an additional advantage of placing the strips vertically rather than horizontally was that many more strips could be accommodated in a single tray, increasing the number of samples that could be tested in a single bioassay.



**Figure 8.3.1** Wounding device, constructed from a clothes peg and thumb-tack, designed to standardise the wounding of leaves.



**Figure 8.3.2** Inoculated durian leaf-strips standing vertically in water agar to keep them turgid during incubation.

### Symptom assessment in leaves

Depending on incubation conditions, it may take up to three days from inoculation to the appearance of the first disease symptoms. Measurement commences as soon as symptoms appear. When entire leaves are inoculated, lesion diameter is measured. As lesions are often not concentric, it is recommended that the diameter be measured in more than one direction, then averaged. In leaf-strips, the length of the lesion from the wound to the leading edge of the lesion should be measured.

### Stem bioassay

Detached-stem bioassays are better for comparing clonal lines of *Eucalyptus marginata* for susceptibility to *Phytophthora cinnamomi* (Hüberli 2002) than for comparing pathogenicity between isolates of the pathogen (Hüberli 2001). Durian stems are readily available, can be obtained from large trees without undue injury, and as such should be suitable for use in a bioassay. However, attempts to develop a bioassay for durian using detached stems were unsuccessful.

Green stems (stems in which periderm formation had not yet occurred), with diameters 0.50–1.25 cm, were obtained from durian orchards in northern Australia. Each stem was cut to a length of 15 cm before surface sterilisation for 2 minutes in the solution described above. The holes in non-draining test-tube racks were half filled with washed/sieved sand and 2 mL water that contained 50 µg/mL benzimidazole. The rack was autoclaved and a stem placed upright into each of the holes. A plug of inoculum mycelium/sporangia was placed onto the end of each stem and the rack was then put into a Tupperware® container and sealed for incubation.

Despite a more rigorous surface sterilisation, the stems were rapidly colonised by secondary invaders. Unlike *E. marginata*, lesions were not visible from the outside of the inoculated durian stem. Even when the epidermis was scraped away, it was difficult to see the lesions, and, if visible, to determine the lesion boundary. When the stems were split longitudinally, the pith often appeared orange but this may have been due to oxidation of the exposed tissues. Due to the difficulty of definitively identifying and measuring lesions, the stem was dissected into 1 cm segments, which were plated sequentially onto selective agar to calculate how much of the tissue was colonised by the pathogen. A bioassay using excised stems as described above is time-consuming, expensive and consequently considered unsuitable as a rapid and inexpensive screen for resistance in durian.

In summary, leaves are the most practicable durian organ to use in a detached-organ screening bioassay. Where incubation space is not limiting, the use of entire leaves is recommended due to the labour-intensiveness of producing strips or discs. Where incubation space is limiting, leaf-strips or discs can be used but surface sterilisation must be rigorous to minimise contamination and interference by secondary pathogens.

### Germplasm Screening in Thailand

Field observations in Thailand indicate that durian cultivar Chanee is moderately resistant to infection by *P. palmivora*, while Kadoom, Kanyao and Monthong are susceptible. The four cultivars were screened in controlled experiments using the following methods:

- attached leaves, wound inoculated with mycelium/sporangia
- attached stem, wound inoculated with mycelium/sporangia
- detached fruit, wound inoculated with mycelium/sporangia
- attached unwounded root, inoculated with a sporangial suspension for five days
- measurement of zoospore production from sporangial suspension into which seedling roots were immersed (Figure 8.3.3).



**Figure 8.3.3** Germinated durian seeds immersed in a sporangial suspension.

Controls were inoculated with sterile agar or water. Percentage disease incidence was measured in leaf, stem and fruit by estimating the amount of the tissue covered by lesions. In roots, disease incidence was calculated by plating sequential segments of the roots onto selective media and calculating the number of pieces from which the pathogen grew. Additionally, colonisation of the root was assessed through examination under a dissecting microscope,

looking for mycelium and sporangia and expressed as a percentage of the root examined.

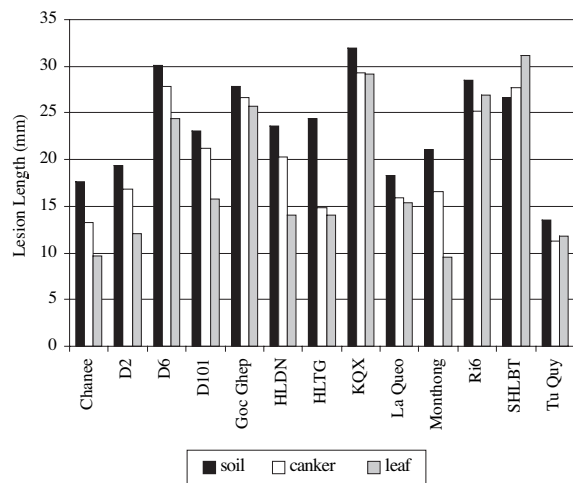
Symptoms were similar for all cultivars in that lesions produced on leaves were dark brown, and on fruit were light brown and soft. Lesions did not develop at the point of inoculation on stems, rather the terminal part of the inoculated branch wilted and leaves abscised.

The disease incidence in the screening bioassays agrees with the field performance of cultivar Chanee. Leaf, stem, fruit and root tissues were less susceptible than Kadoom, Kanyao or Monthong (Table 8.3.1). Similarly, *P. palmivora* colonised significantly fewer Chanee roots, and produced fewer zoospores.

### Germplasm Screening in Vietnam

A leaf-strip bioassay was performed on durian cultivars Chanee, D2, D6, D101, Goc Ghep, Hat Lep Dong Nai, Hat Lep Tien Giang, Kho Qua Xanh, La Queo, Monthong, Ri6, Sua Hat Lep Ben Tre and Tu Quay. The cultivars were screened against three isolates of *P. palmivora* obtained from (i) soil, (ii) stem canker and (iii) leaf in diseased orchards of Tien Giang Province. Controls were inoculated with sterile agar. A second bioassay in which leaf-strips and detached stems were screened against the soil isolate was conducted on the same cultivars, with the replacement of cultivar Goc Ghep with Kho Qua V. Controls were inoculated with sterile agar. In both bioassays, lesions were measured five days after inoculation.

The soil isolate was more virulent than either the canker or the leaf isolates, and in general the canker isolate was more virulent than the leaf isolate (Figure 8.3.4). Based on the symptoms produced by the virulent soil isolate, cultivars Tu Quy, Chanee and La Queo were less susceptible to the pathogen. The commercially popular Ri6 and Sue Hat Lep Ben Tre emerged as two of the most susceptible cultivars.



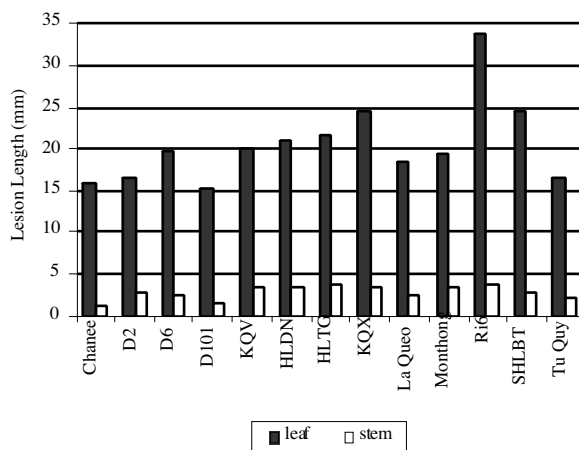
**Figure 8.3.4** The length of lesions (mm) on leaf strips of durian cultivars Chanee, D2, D6, D101, Goc Ghep, Hat Lep Dong Nai (HLDN), Hat Lep Tien Giang (HLTG), Kho Qua Xanh (KQX), La Queo, Monthong, Ri6, Sua Hat Lep Ben Tre (SHLBT) and Tu Quay, five days after inoculation with isolates of *Phytophthora palmivora* from either soil, canker or leaf. Controls were inoculated with axenic agar.

**Table 8.3.1** Disease incidence (%) in attached leaves, attached stems and detached fruits of durian cultivars Chanee, Kanyao, Kadoom and Monthong inoculated with *Phytophthora palmivora*, as well as disease incidence and colonisation of the roots, and zoospore production (time in minutes to zoospore release and numbers of zoospores) in 0.5 mL sporangial suspension in the presence of roots.

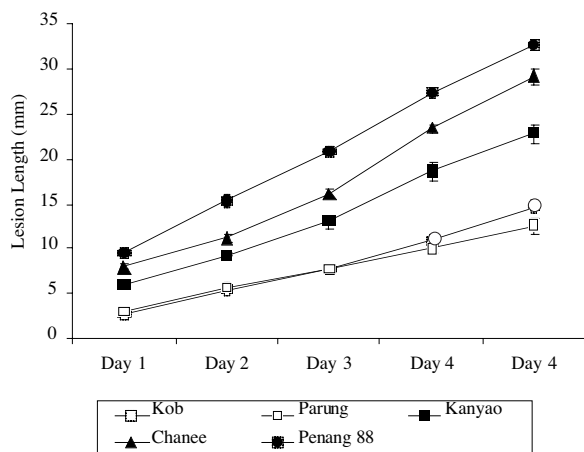
Durian cultivars	Field observations	Attached leaves	Attached stems	Detached fruit	Attached roots		Zoospore production	
					Incidence	Colonisation	Number of zoospores	Time to zoospores
Chanee	MR	47a	20a	20a	10a	60a	76a	45
Kanyao	S	100b	100b	100b	45b	100b	119b	30
Kadoom	S	100b	100b	100b	50b	100b	124b	15
Monthong	S	100b	100b	100b	50b	100b	190c	15

Note: means followed by the same letter are not significant difference at the 5% level by Duncan's multiple range test (DMRT); MR = moderately resistant, S = susceptible.

In the second bioassay, pathogen growth in the detached stems was limited (Figure 8.3.5). However, taken together with the results of the first screening, results from the detached leaves indicate that Tu Quy and Chanee may be suitable for use as rootstocks, while Ri6 is inappropriate because of its susceptibility (Figure 8.3.5).



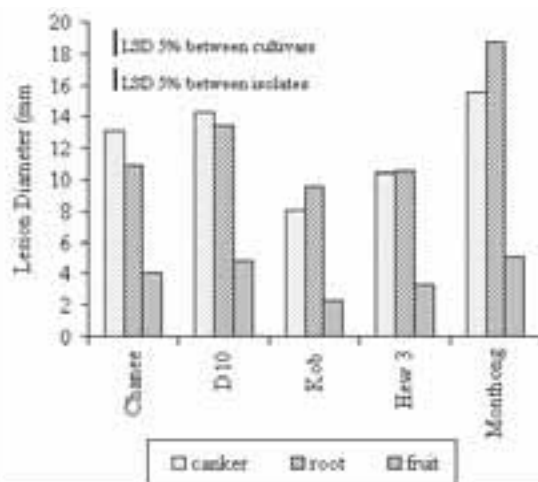
**Figure 8.3.5** The length of lesions (mm) on leaf strips and detached stems of durian cultivars Chanee, D2, D6, D101, Kho Qua V (KQV), Hat Lep Dong Nai (HLDN), Hat Lep Tien Giang (HLTG), Kho Qua Xanh (KQX), La Queo, Monthong, Ri6, Sua Hat Lep Ben Tre (SHLBT) and Tu Quay, five days after inoculation with an isolate of *Phytophthora palmivora* soil. Controls, which were inoculated with axenic agar, did not develop lesions and are not shown in this graph.



**Figure 8.3.6** Mean lesion diameter (mm) in durian (*Durio zibethinus*) cultivars Chanee, Kanyao, Kob, Parung and Penang 88 in a detached-leaf bioassay. The remaining 14 cultivars screened – Chompoosee, D10, D24, D98, D102, D123, Kob, Kumpun, Hew 3, Kradoom, Luang, Limberlost, Red Prawn and Sunai – and *Durio macrantha* fell between Kanyao and Penang 88. Controls, which were inoculated with axenic agar, did not develop lesions and are not shown in this graph. Vertical bars are standard errors of the means.

### Germplasm Screening in Australia

In summer 2000/2001 at the Centre for Wet Tropics Agriculture, *Durio macrantha* and 19 cultivars of *D. zibethinus* were screened in a detached-leaf bioassay against a locally obtained trunk-canker isolate of *P. palmivora*. The durian cultivars screened were Chanee, Chompoosee, D10, D24, D98, D102, D123, Kanyao, Kob, Kob Yao, Kumpun, Hew 3, Kradoom, Luang, Limberlost, Parung, Penang 88, Red Prawn and Sunai. Controls were inoculated with sterile agar. In autumn 2002, Chanee, D10, Kob, Hew 3 and Monthong were screened against the canker isolate and a root isolate, as well as a fruit isolate which showed low virulence in preliminary trials (Tan 1999). Controls were inoculated with sterile agar. In both bioassays, lesion extension was measured daily from two to six days after inoculation. The summer screening indicated that Kob and Parung were less susceptible to infection by *P. palmivora* than the other cultivars (Figure 8.3.6). The ranking of isolates that were screened twice was the same for the summer and autumn bioassays, from Kob, the least susceptible cultivar, to D10, the most susceptible cultivar, with Hew 3 and Chanee displaying intermediate susceptibility. In the autumn screening, the largest lesions were produced in Monthong, which is in agreement with published and anecdotal evidence stating that it is highly susceptible. The fruit isolate caused significantly smaller lesions than either the canker or root isolates (Figure 8.3.7), confirming the results of Tan (1999).



**Figure 8.3.7** Mean lesion diameter (mm) in durian cultivars Chanee, D10, Kob, Hew 3 and Monthong in a detached-leaf bioassay with isolates of *Phytophthora palmivora* from either canker, root or fruit. Controls, which were inoculated with axenic agar, did not develop lesions and are not shown in this graph. Vertical lines represent the least significant difference (LSD).

Chanee emerged as one of the most susceptible cultivars tested (Figure 8.3.6 and 8.3.7) in Australia, which contradicts the experimental evidence from Thailand and Vietnam. Cultivar D10 also developed extensive lesions indicating high susceptibility, which is in contrast with previous reports (Lim 1998b). As discussed earlier in this paper, these discrepancies could arise from pathogen differences between Australia and Thailand, or due to erroneous identification and labelling of durian germplasm imported into Australia in the 1970s and 1980s (Lim 1998a). DNA testing confirmed that the originally introduced Chanee had been misidentified on introduction to Australia (Zappala et al. 2002).

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## 8.4 Durian Propagation and Nursery Practice

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and David I. Guest<sup>3</sup>

### Abstract

This paper details nursery best practice procedures to ensure the supply of adequate quantities of vigorous, disease-free seedlings to the durian industry. Procedures adopted in Vietnam and Australia are compared and contrasted.

### Introduction

Best practice in durian nurseries is fundamental to the establishment of healthy durian orchards. In Vietnam, the durian industry is rapidly expanding, but there is a general shortage of selected durian cultivars. As has been seen in other rapidly expanding horticultural industries, high demand for planting material can lead to shortcuts being taken in nursery practice, resulting in poor-quality and variable planting material. This can be a serious problem when soil-borne pathogens such as *Phytophthora* species, are spread from infected nursery stock to newly established orchards. As a consequence, what may have been a disease-free orchard becomes infested. Once established, pathogens like *Phytophthora* are practically impossible to eradicate. In established durian-growing countries, such as Thailand, nursery operators have developed considerable expertise in propagating selected cultivars for distribution to orchards. However, even here, soil-borne disease can be a problem if nursery hygiene is not carefully

implemented and monitored. The impacts of diseases like phytophthora on nurseries include the direct costs due to plant deaths, and the difficulties and extra costs associated with managing diseases, poor-plant quality and damage to the nursery's reputation among customers.

### Propagation Techniques

Nurseries use a range of propagation techniques to service the rapidly expanding durian industries in Vietnam. The particular technique favoured depends on the availability of selected genotype stock and scion material, the quantity of planting material required, the price paid by purchasers, and labour costs and skills.

Cho Lach District in Ben Tre Province in the Mekong Delta of Vietnam is well known for its production of fruit tree saplings. The Cho Lach people learnt grafting techniques from the French around 100 years ago and now produce more than 20 million citrus, durian, mango, longan, mangosteen and rambutan saplings annually. A hard-working family in this area can produce 30,000 to 40,000 durian plants each year. In general, the quality of the nursery stock is good, as the nurserymen and women are skilled and experienced.

In Australia, durian planting material is provided by a small number of nurseries where the proprietors are usually also durian growers. The Australian durian industry is relatively small and still in its infancy, hence clonal production is based on a range of cultivars as part of longer-term, regional cultivar

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testing. In the past, seed supply was limited, and imported seed, mainly of Indonesian and Malaysian origin, was the main source of seedling stock. Australian-grown fruit not suitable for fresh fruit sales were also keenly sought as a source of seed. The genetic base of rootstock is extremely variable and may explain some of the differences in tree performance and survival seen in the field. Seeds were sown either in bulk or into individual pots (2–5 L plastic bags; Figure 8.4.1). Potting mix varies between nurseries, but generally consists of a mixture of sand, soil and composted organic matter (pine bark, peanut shells or similar). In some cases, vermiculite or perlite is used in place of organic compost. Some growers have found that a more open (aerated) mixture results in improved root growth and seedling vigour (Figure 8.4.2). One major producer of durian planting material has moved to a soil-less mix consisting of 80% composted pine bark and 20% sand (Zappala et al. 2002). Potting mix is rarely pasteurised at present, but is being considered against a background of improved understanding of how disease is transferred.

A major innovation has been the introduction of raised nursery benches, which allow pots to be placed above the ground, hence minimising contamination of new pots and plants by water movement on the nursery floor.

Propagation techniques are evolving as nurseries learn and develop new and more reliable techniques. Nurseries have used approach grafting, marcotting, budding and wedge-graft techniques. Bud grafting utilising the Fokert technique was initially the preferred method of propagation. In the

Northern Territory, Lim (1997) reported that cleft-grafting techniques were as successful as Fokert budding, but the time of year was crucial to maximal success. Zappala et al. (2002) also presented data that confirm that propagation during the warm, wet season resulted in higher success (generally greater than 60%) than propagation carried out under cool, dry conditions.

Australian nurseries, like their Vietnamese counterparts, now predominately use a wedge-grafting technique rather than Fokert budding. Actively growing, 6–12-month-old seedling material is preferred as rootstock. Scion material with one to two active buds is selected from healthy trees (Figure 8.4.3). One-third to one-half a leaf is left on the bud stick and the lower part of the stick is trimmed to a wedge shape. The stock stem is cut cleanly and split, and the bud stick is inserted and held together with plastic clothes pegs. The newly prepared graft is covered with a semi-opaque plastic bag and the pot placed in a warm, plastic house. The pegs are removed after a callus has formed 3–4 weeks after grafting (Figure 8.4.3). Some durian growers who produce planting material for their own use prefer to use an approach-graft technique (Figure 8.4.4).

In Vietnam, the traditional wedge-graft or budding technique was largely replaced by the U-grafting (side-graft) technique about six years ago. U-grafting allows four to five times the number of saplings to be produced per budwood (Figure 8.4.5). The U-grafting technique is also much easier to carry out than is traditional budding.



**Figure 8.4.1** Durian seed germination



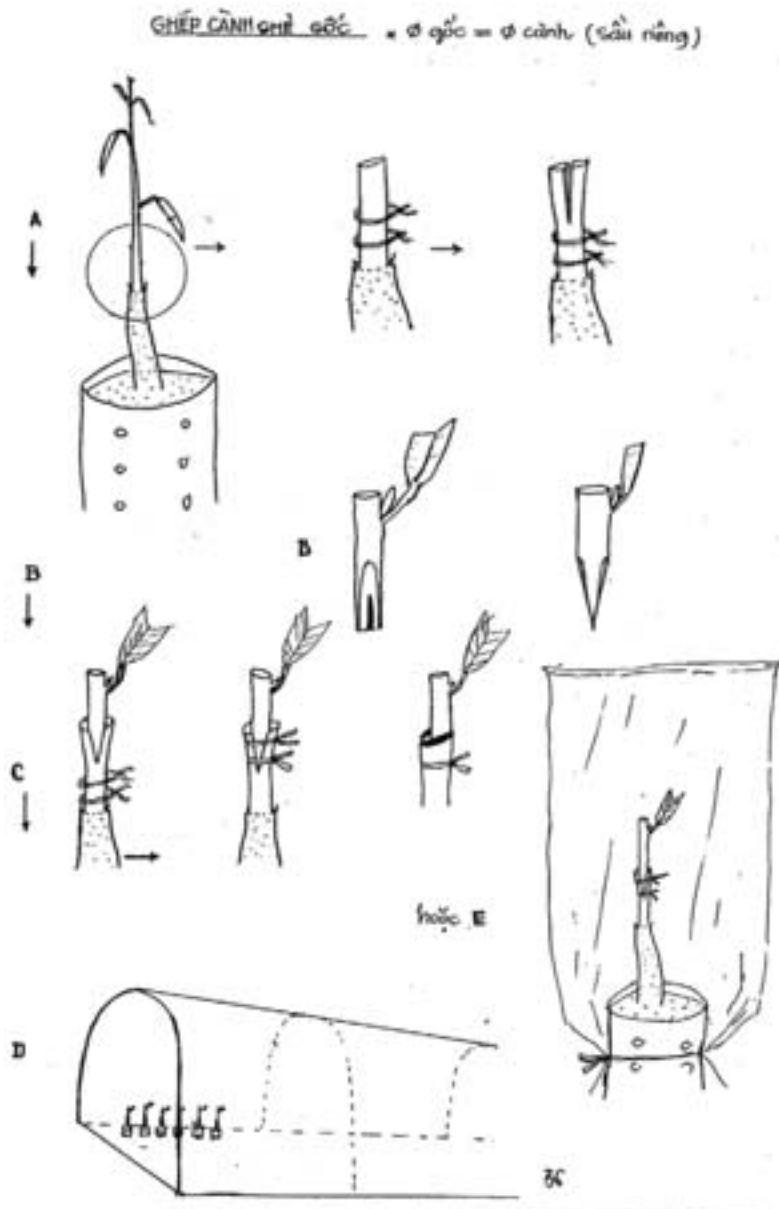
**Figure 8.4.2** Well-aerated potting mix (80% composted pine bark:20% sand) results in greater root vigour (plant on right) relative to a plant grown in a soil mix.



**Figure 8.4.3a** (above) Scion material with one to two active buds is selected from healthy trees.



**Figure 8.4.3c** (right) New buds emerging from a wedge graft 3-4 weeks after grafting. Plastic clothes pegs are used to bind the grafts



**Figure 8.4.3b** Wedge-grafting technique

Durian nurseries produce two types of durian saplings – one rootstock or two rootstocks. Saplings with two rootstocks establish and grow faster than single rootstock saplings. The wedge graft is used for two rootstock saplings, while U-grafts are used for single rootstock saplings. The time needed from sowing the seed to selling the plants is approximately 12 months.

As in Vietnam, double versus single rootstocks have been tested in Australia (Figure 8.4.4). Australian nurseries prefer to produce single rootstock material. Shortage of seedling stock, lower labour requirements and better long-term field survival of single-stock plants are the main reasons for preferring single rootstock material. Australian experience suggests that field survival of trees is

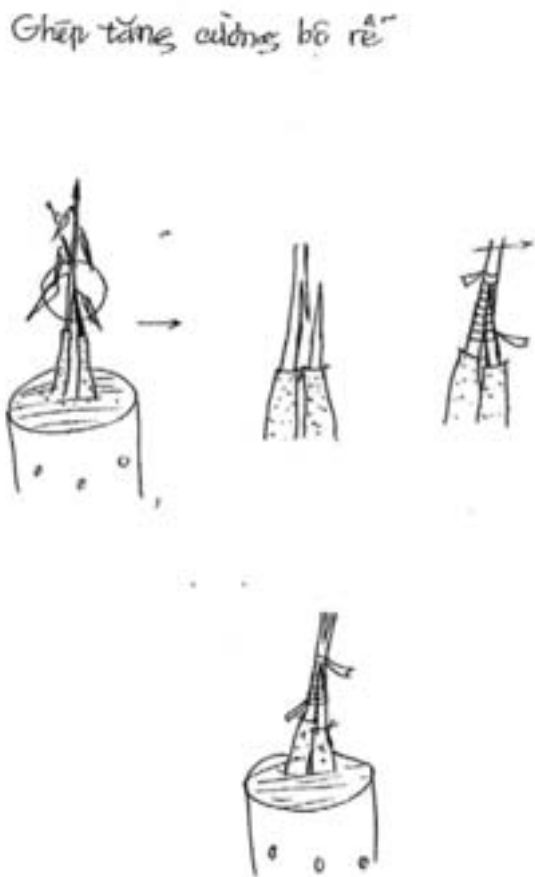


Figure 8.4.4b (above) Vietnamese durian approach-grafting technique.

Figure 8.4.4a (left) Approach graft used to create multiple rootstocks.



Figure 8.4.4c Approach grafting using plastic clothes pegs for graft clamping.



Figure 8.4.4d Advanced double rootstocks ready for planting (SOFRI, Vietnam).

enhanced if grafted trees are kept in the nursery until they have a trunk diameter of more than 12 mm and are approximately 1 m in height (Zappala et al. 2002). Australian nurseries have made little use of the side-graft technique, known in Vietnam as the U-graft. This method uses 12–24-month-old rootstocks, which in Vietnam are direct seeded into nursery beds and then uprooted and potted a month before grafting.

A few durian growers avoid using grafted planting material, preferring to use seedlings. Anecdotal evidence suggests that stock/scion incompatibility may affect the vigour and productivity of grafted durian. There are very few hard data on the

performance and disease susceptibility of durian stock/scion combinations, and this is an area in high need of further research.

### Nursery Hygiene

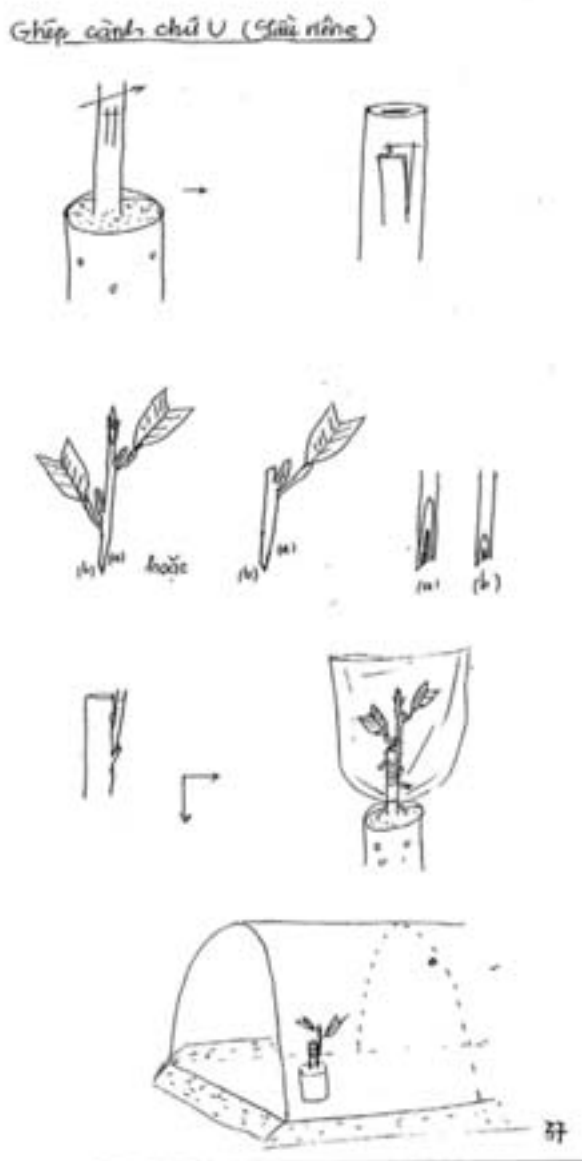
It is important that more attention be paid to producing disease-free planting stock in the future, to prevent the spread of pests and pathogens. To achieve this, durian nursery operators need to follow best-practice methods, such as those established in the citrus and avocado industries and discussed in Chapter 7.2 (NGIA 2003). They also require access to reliable diagnostic services. Furthermore, it is advisable to accurately record and



**Figure 8.4.5a** Uprooted 18-month-old seedling being prepared for side or U-grafting (Vietnam)



**Figure 8.4.5c** Side-grafted durian seedling ready for planting



**Figure 8.4.5b** Side-grafting technique

regularly audit nursery procedures to ensure that recommended practices are being followed, and to identify difficulties. Ultimately, these procedures form the basis of a nursery accreditation scheme, guaranteeing high-quality, certified, disease-free planting material for growers.

The following best practices are recommended for durian nurseries:

- Nurseries should be established away from mature orchards on sites that are properly drained to avoid water entry or run-off.
- Only seed from disease-free fruit that has not been lying on the ground should be used to establish rootstocks.
- Only budwood from disease-free trees, taken from branches above the soil-splash level, should be used as scion material.
- Plant material from other nurseries should be quarantined in a separate facility and monitored for pests and diseases for at least four weeks.
- Potting media should be porous and free-draining. Soil, river sand or coconut fibre, should be avoided, as these substrates frequently contain *Phytophthora*, *Pythium*, *Rhizoctonia* and nematodes. Composts should be anaerobically fermented and matured for at least 10 weeks before use.
- All potting media should be thoroughly mixed on surfaces that are drained to exclude both water run-off and entry, and are free from soil and other sources of contamination.
- Potting media should be pasteurised by steam-air treatment.
- Pasteurised potting media should be stored in closed, disinfected containers, and must be regularly baited for *Phytophthora* before use.
- Potting media can be recycled, but must be steam-air pasteurised and stored hygienically.
- Nursery floors and paths should be sealed with concrete, or covered with coarse gravel at least 75 mm deep, and kept free of plant material and weeds.
- All pots, utensils, tools, containers and trolleys must be cleaned of soil or potting mix after use. Used pots and containers should be sterilised in 1% hypochlorite solution, and tools regularly disinfected with quaternary ammonium detergents (2000 ppm is recommended) or 70% methylated spirit. Hands must be washed with soap and water or an approved hand-washing biocide.
- Only pathogen-free irrigation water, preferably from deep bores, should be used. Irrigation water must be regularly monitored for pathogens, especially *Phytophthora*.
- Pots should be placed on raised, slatted benches and spaced to allow free air movement. Larger pots may be placed on raised beds of coarse gravel at least 75 mm deep, with adequate drainage to ensure that water does not accumulate or pond. In these cases, the gravel should be tested regularly and be certified pathogen-free.
- Watering hoses should be kept off the ground.
- Nursery areas should be fenced and secured to restrict access and prevent the entry of animals.
- Wind and dust should be suppressed.
- Plants should be grown in appropriate levels of light. Durian seedlings tolerate direct sunlight and overshadowing can cause disease problems.
- Appropriate fertiliser applications, preferably composted chicken manure, should be timed to ensure optimal nutrition and growth.
- Anyone entering the nursery area should wash their hands before entry, walk through a footbath containing copper fungicide, and not smoke or eat.
- Plants should be regularly inspected for pests and diseases and culled as required.
- Plants should be sold or distributed for planting before the roots become bound.
- Discarded plants and potting mix should be stored in designated closed containers and removed frequently. Discarded material may be anaerobically fermented and composted, or buried away from the nursery and drainage lines. Diseased plants should be burnt.
- Weeds in the pots and around the nursery beds must be rigorously controlled.
- Insect pests such as mealy bugs, aphids, thrips, white-fly, scale, mites and borers, should be managed, preferably using integrated pest management.
- Use of fungicides in the nursery should be avoided (especially phosphonates) as these may mask disease symptoms without eradicating the pathogen.

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## 8.5 Durian Tree Phenology and the Control of Phytophthora Diseases of Durian Using Phosphonate Trunk Injection

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### Abstract

We have identified phenological patterns of mature durian trees grown in the north of Queensland, Australia, and monitored the distribution of phosphonate following trunk injection at three distinct phenological periods, to identify the injection period which results in maximum uptake in all tree organs. Durian cultivars Gumpun, Parung and Gob Yaow were injected with 16 g a.i. phosphonate at each of three injection periods (early flowering fruit/fruit-set, mid-fruit-set, and immediately after harvest). In northern Queensland, durian shoot and root development appears to be active throughout the year despite the relatively cool conditions that occur during winter. Shoot-flushing activity often occurs in parts of the tree rather than uniformly over the canopy. Phosphonate was detected within two days of injection in all organs sampled and reached a peak between four and eight days after injection. The highest levels of phosphonate were recorded in leaves and flowers (mean value of 60 and 40 µg/g dry weight). Phosphonate levels either declined or increased with sampling date, depending on organ and injection time, but persisted in all tissues for at least 128 days. Phosphonate trunk injection trials were also carried out on local durian varieties in Vietnam. Under moderate disease pressure, annual injections of 16 g a.i. per tree gave superior control of canker compared with recommended sprays of metalaxyl or Aliette. Under high disease pressure, 48 g a.i., injected at 3 three-monthly intervals, gave the best disease control. Results presented in this paper demonstrate the efficacy of phosphonate in controlling phytophthora diseases in durian when applied as a trunk injection.

### Introduction

In all regions where durian is grown, it is seriously threatened by diseases caused by *Phytophthora palmivora* Butl. This disease generally occurs on

mature fruit-producing trees. Symptoms include initial leaf-yellowing and leaf loss from the top of the canopy, with further loss of leaves occurring through the canopy at varying rates. New shoots may appear following initial severe defoliation, but further development and growth is unusual. Tree death generally occurs in 4–12 months from the initial onset of symptoms.

Attempts at controlling phytophthora diseases in durian have included repeated foliar sprays, or painting the cankered trunk with metalaxyl and phosphonate (salts or esters of phosphonic acid). These methods of application are expensive and the results highly variable under monsoonal conditions. Phosphonate is systemic and mobile in both xylem and phloem, and injection of the

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compound directly into the tree trunk has proved highly effective in controlling phytophthora diseases in a range of other tropical crops, including avocado, cocoa and coconut (Guest et al. 1995; Whiley et al. 1988).

Work in avocado has shown that, during periods of high vegetative flush and low root activity, phosphonate is carried up into the leaves rather than into the roots where it is required for the amelioration of *P. cinnamomi* (Whiley et al. 1995). Hence, the timing of injections in relation to tree phenology may be crucial to determining the distribution of the phosphonate within the durian tree and hence control of *P. palmivora*.

The experiments described in this chapter had three major objectives:

- to identify tree phenological activity under north Queensland environmental conditions with particular reference to the possibility of *P. palmivora* disease control using phosphonate injections;
- to monitor the distribution of phosphonate following trunk injection at three distinct phenological periods
- to identify the injection period which results in maximum uptake in all tree organs.

Finally, phosphonate was injected at a range of rates during different seasons into durian trees growing under a range of disease pressures in commercial orchards in Vietnam, to determine optimal application rates and timing.

## Materials and Methods

### Phenology monitoring

Three commercial farms and the Queensland Department of Primary Industries' (QDPI) South Johnstone research station, on the wet tropical coast of north Queensland, Australia, were selected as phenology recording sites. The sites were located within a region that extends from Bellenden Ker (16.5°S) in the north to an area south of Tully (18°S) a

distance of approximately 100 km. Five groups of mature trees (i.e. had flowered previously), each consisting of three trees of each of two cultivars (Luang and Montong), were chosen for monitoring depending on availability at each site. Tree phenology (shoot, root, flowering and fruiting activity) was monitored monthly for 30 months from January 2000 until June 2002. The monitoring sites and the sampling schedule are listed in Table 8.5.1.

Shoot activity was rated on a whole tree basis as a percentage of new, hardening or mature shoot (Figure 8.5.1). Flowering was rated on a scale of 0 to 3, with 0 = no flowers present, 1 = 1–20 flowers, 2 = 20–60 flowers and 3 = > 60 flowers present. Fruiting was also rated on a scale of 0–3 with 0 = no fruits, 1 = 1–10 fruits, 2 = 11–20 fruits and 3 = more than 20 fruits present. Harvest dates were recorded where applicable.



Figure 8.5.1 Durian flush standards, from left to right (new, maturing, mature).

Surface root activity was monitored through the use of 'root windows' (Figure 8.5.2a). The root windows consisted of a Perspex sheet (600 mm × 400 mm × 6 mm) installed on the SE side of each tree at a distance from the trunk equal to half the radius of the canopy. The perspex sheet was placed on a slope (5–35°) dependent on site topography, following soil removal and associated drainage. This process removed existing surface roots in the area. Before placing the

Table 8.5.1 Phenology monitoring sites, root window installation dates and sampling schedule

Farm	Variety	Install date	Sampling period during which monthly observations were made
CWTA	Luang	4/11/99	Jan 2000–June 2002
CWTA	Montong	14/12/99	Jan 2000–June 2002
Kuradui	Montong	23/11/99	Jan 2000–June 2002
Jensen	Montong	14/12/99	Jan 2000–June 2002
Zappala	Luang	11/11/99	Jan 2000–June 2002

perspex sheet, the face of the slope was covered in a fine layer of sterilised potting mix. The perspex sheet was held in place using steel pegs affixed to each corner. Each sheet was etched with corner markers to allow the placement of two A4 overhead projector acetate sheets. At each sampling, if unsuberised roots were present the overhead sheets were placed on the perspex sheet and root growth traced using a permanent marking pen. Between recording periods the perspex sheets were covered with newspaper, shade cloth and bags filled with hay to stop light penetration and insulate the roots from incident solar radiation. Root activity was assessed qualitatively. The qualitative method consisted of an activity rating of 0–2, where 0 = dormant roots, 1 = slight new growth and 2 = active new growth.



**Figure 8.5.2** Root window installed under durian tree.

Phenology rating data were compiled and mean ratings were calculated per site and variety combination as well as across all varieties and sites. Variation is described by standard error. Climate data were collected at all four sites. Because of the similarity between climate data sets, only data collected at the South Johnstone research station are shown.

### Phosphonate injection (Queensland)

An injection trial was carried out at the South Johnstone research station on the durian variety block. The block of 14-year-old trees consists of 14 cultivars, each cultivar replicated three times. The block is one of the few in north Queensland that has not been treated (injected or sprayed) with phosphonate. Although *P. palmivora* had been recorded on the trial site, trees showed no symptoms of the disease.

Injection times selected included:

- EFF – early flowering/fruit-set (7 October 2000), with the aim of getting phosphonate into

developing fruit, particularly fruit rind. Shoots and roots are also targeted

- MFS – mid-fruit-set (8 January 2001), with the aim of protecting all parts of the tree (shoot, root and possibly some protection to fruit)
- PH – immediately after harvest (26 March 2001), with the aim of avoiding direct flow of phosphonate to fruit, and distributing phosphonate to tops and possibly to roots during the last active phase of root development before root dormancy.

Three replicate trees were used per injection time, comprising three cultivars, Gumpun, Parung and Gob Yaow (all replicates of these varieties flowered and fruited during the 1998–99 season). Tree phenology was similar, and replicate trees of the same three varieties were used at each of the above injection times. The injection rate utilised was four 20 mL Chemjet® syringes of Foli-R-Phos® 200, which is equivalent to 16 g a.i. of phosphonate. Injections were administered in the early morning.

### Sampling regime

All trees were sampled pre-injection on 21 September 2000. Post injection samples were obtained at 2, 4, 8, 16, 32, 64, 96, 128, 192, and 256 days. At each sampling date the following tree material was sampled:

- leaves (from lower, mid and upper canopy)
- composite bark and wood sample (lower, mid and upper trunk)
- flower/fruit samples (lower, mid and upper trunk) – where and when available
- root samples (0–15 cm depth) – eight per tree were subsampled and then bulked.

The leaf, bark/wood and flower/fruit samples were oven-dried at 40°C. Root samples were washed to remove all traces of soil before oven-drying at the above temperature. Following drying (2–3 days), samples were ground in a plant mill. A minimum of 5.0 g of dried ground material of each sample was packaged in labelled perspex containers and the collective samples were then air freighted to the University of Melbourne for analysis. Injection times and sampling dates are shown in Table 8.5.2.

### Analysis

Phosphonate residues were measured by gas chromatography with a detection limit of 0.5 µg/g dry weight (dw).

#### *Effect of phosphonate injection on disease in Vietnam*

Phosphonate field trials were established on commercial orchards in the Mekong Delta and the Ba Ria-Vung Tau regions of Vietnam. In the Mekong



Delta, the efficacy of potassium phosphonate at different concentrations was compared with Aliette (aluminium tris-*O*-ethyl phosphonate) and Metalaxyl in 1–12 year-old durian cv. Kho qua xanh. Trunk injection was compared with foliar spray. Canker severity was measured on a scale of 0 (no canker) to 3 (trunk girdling more than 70%, or tree dead).

In Ba Ria–Vung Tau, the results of trunk injection with different concentrations of potassium phosphonate were compared with canker painting with Aliette in 4 or 7-year-old durian cv. Sua Hat Lep Ben Tre. Canker severity was measured on a scale of 0 (no canker) to 5 (canker more than 50 cm<sup>2</sup> or tree dead).

## Results

### Climate monitoring (Queensland)

Monthly maximum and minimum temperature, rainfall and evaporation totals and average shortwave solar radiation inputs are shown in Figure 8.5.3.

Over the 973-day period recorded there were 179 days where the maximum temperature was less than 25°C and 134 days where the minimum temperature was less than or equal to 15°C, with 26 days on which the recorded temperature was 10°C or less. The lowest temperature recorded was 7°C. The range in average temperature was from 14.5 to 31°C. These conditions are substantially cooler than durian trees experience in their native environment where the average temperature ranges from 24 to 30°C (Nanthachai 1994).

Total rainfall was 10,173 mm over 545 wet days, of which 53 days had rainfall equal to or above 50 mm. The corresponding total evaporation for the same period was 4889 mm. The driest months (monthly totals less than 50 mm) were July and September 2000 and May, July, August and December 2001 and

June 2002, when the respective rainfall recordings were 42, 24 and 36 and 37, 36, 43 and 16 mm. The wettest months (monthly totals greater than 500 mm) were December 1999, February, March, April and November 2000 and February 2001 when 505, 1121, 612, 948, 804 and 858 mm were recorded. These conditions, particularly during the first 24 months, are wetter than that experienced by the crop in its native environment where average rainfall ranges from 1600 to 4000 mm per year (Nanthachai 1994).

Energy inputs as measured by short wave solar radiation (SWSR) indicate that energy inputs varied across seasons. The average daily SWSR during the 973-day monitoring period was 18.6 MJ/m<sup>2</sup>/day, with a maximum daily influx of 29 MJ/m<sup>2</sup>/day and a minimum 6 MJ/m<sup>2</sup>/day. Monthly averages ranged from 12 to 24 MJ/m<sup>2</sup>/day. These variations are in part due to seasonal variation in day length and to a greater degree due to rainfall and associated cloud cover which occurs during the wet season. In general, clear days during the months September to October result in the highest incident SWSR.

In summary, the climate in the major north Queensland durian-growing areas is cooler and wetter than the climate in the natural growing environment of the fruit.

### Phenology monitoring

Shoot activity was high throughout the monitoring period (Figure 8.5.4). The means, for all trees, show that during the 30-month monitoring period there were 10 months in which new shoot flush occurred on 40% or more shoots. Shoot growth occurred throughout the year, but the highest activity was generally recorded in the months leading up to summer (September–December). Flush activity during the winter months was generally below 40% and occurred in discrete patches within the canopy.

**Table 8.5.2** Phosphonate injection and sampling schedule.

Days (pre/post injection)	1 <sup>st</sup> injection	2 <sup>nd</sup> injection	3 <sup>rd</sup> injection
Pre injection sample	21/9/00	21/9/00	21/9/00
Injection date	7/10/00	8/01/01	26/3/01
2	9/10/00	10/1/01	28/03/01
4	11/10/00	12/01/01	30/03/01
8	15/10/00	16/01/01	3/04/01
16	23/10/00	24/01/01	11/04/01
32	8/11/00	9/02/01	27/04/01
64	10/12/00	13/03/01	29/05/01
96	11/01/01	14/04/01	30/06/01
128	12/02/01	16/05/01	1/08/01
192	17/04/01	19/07/01	4/10/01
256	20/06/01	21/09/01	7/12/01

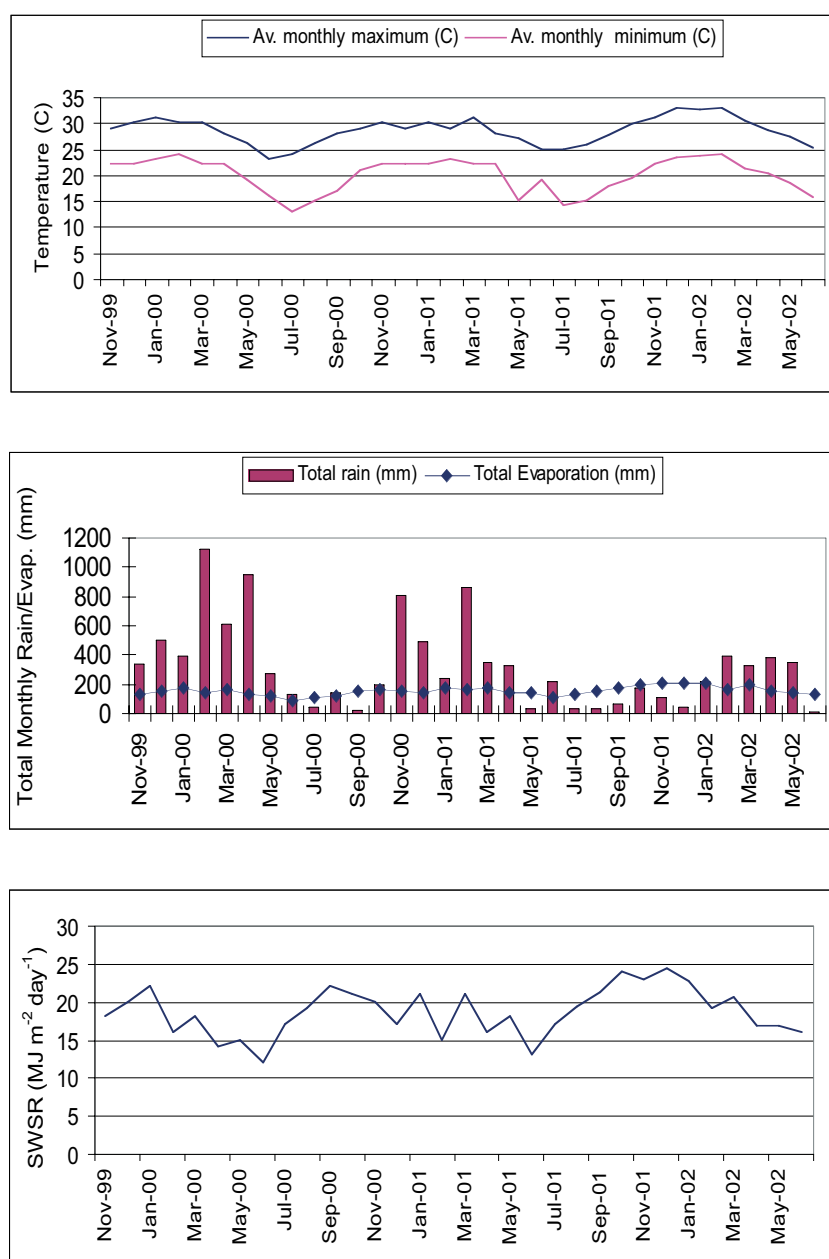
Trees at individual sites exhibited similar flushing patterns.

Flower and fruiting activity varied between seasons (Figure 8.5.5). In the 2000 season, the spread of flowering was relatively short and intense, with a peak from September to October.

In the 2001 season, flowering at three of the five sites occurred over a longer period (May 2001–January 2002), continuing until May 2002 at one of the sites. The longer flowering period in 2001 may have been

due to the drier conditions (Figure 8.5.3), which occurred from July 2001 to December 2001. fruit-set and growth closely followed flowering, with fruit harvest occurring from January 2001 to March 2001 in the 2000–2001 season and from January 2002 to May 2002 in the 2001–2002 season. fruit-set at one site (SJ-Monthong) was particularly poor in the 2001–2002 season.

In trees monitored in north Queensland root activity varied greatly between sites (Figure 8.5.6). Peaks in activity tended to occur during summer, but some



**Figure 8.5.3** Mean monthly maximum and minimum temperature (°C), total monthly rain (mm) and evaporation (mm) and mean monthly shortwave solar radiation (MJ m<sup>2</sup>/day) recorded at South Johnstone, northern Queensland, during the phenology monitoring period.

activity was noted throughout the year. The one period noted for a lack in activity in four of the five sites (May 2000–August 2000) corresponded with consistent cool conditions.

### Translocation of phosphonate

Phosphonate concentration data from three injection periods have been analysed (early flowering/fruit-set, mid-fruit-set and postharvest). Phosphonate was not detected in any of the pre-injection samples of tissue, but was detected in all tissues within 2 days of injection (Figure 8.5.7). The concentration of phosphonate in organs was highest between 4 and 16 days after injection and generally fell below 10  $\mu\text{g/g}$  dry weight 65 days after injection.

Phosphonate concentrations increased in bark/wood samples from 96 to 256 days after the early flowering/fruit-set injection, whereas they remained relatively high following the mid-fruit-set injection.

The highest concentrations of phosphonate were recorded in leaves and bark wood (mean values of 134 and 105  $\mu\text{g/g}$ , respectively) within 8 days of injection at the postharvest injection. However, there were little differences in the concentration between organs as the variability within the leaf samples was very high (Figure 8.5.7), with no detectable residue in some samples and more than 200  $\mu\text{g/g}$  dw in others. In trees injected during mid-fruit-set, mean phosphonate concentrations never exceeded 30  $\mu\text{g/g}$  dw. Variability within organs was lower, but a peak in phosphonate concentrations (8 days after injection) was discernible only in the leaf samples. Mean phosphonate concentration in roots was generally low ( $\leq 10$   $\mu\text{g/g}$  dw), but in the postharvest injection treatment, concentrations in roots ranged from 21 to 44  $\mu\text{g/g}$  dw from 4 to 32 days after injection.

### Effect of phosphonate injection on disease in Vietnam

At sites of moderate disease pressure in the Mekong Delta Region, canker healing was observed within 4 months of injecting trees with 16 g a.i. phosphonate (applied as a single injection in April). Cankers continued to heal over the following 8 months until they had a canker rating of less than 1. Canker healing was achieved in other sites in the Mekong Delta Region with 32 g a.i. phosphonate (applied in two injections of 16 g a.i. with a 5-month interval). Under heavy disease pressure, 48 g a.i. per tree, along with pruning, improved drainage and orchard hygiene, gave the best disease control.

Phosphonate (0.2 or 0.4 g a.i./L), Aliette (1.6 g a.i./L) or metalaxyl (1.6 g a.i./L) significantly reduced

preharvest fruit rot when applied as foliar/fruit sprays 1 month before harvest in the Mekong Delta. However, sprays of phosphonate applied at 0.4 g a.i./L or Aliette at 1.6 g a.i./L gave significantly superior control (Table 8.5.3).

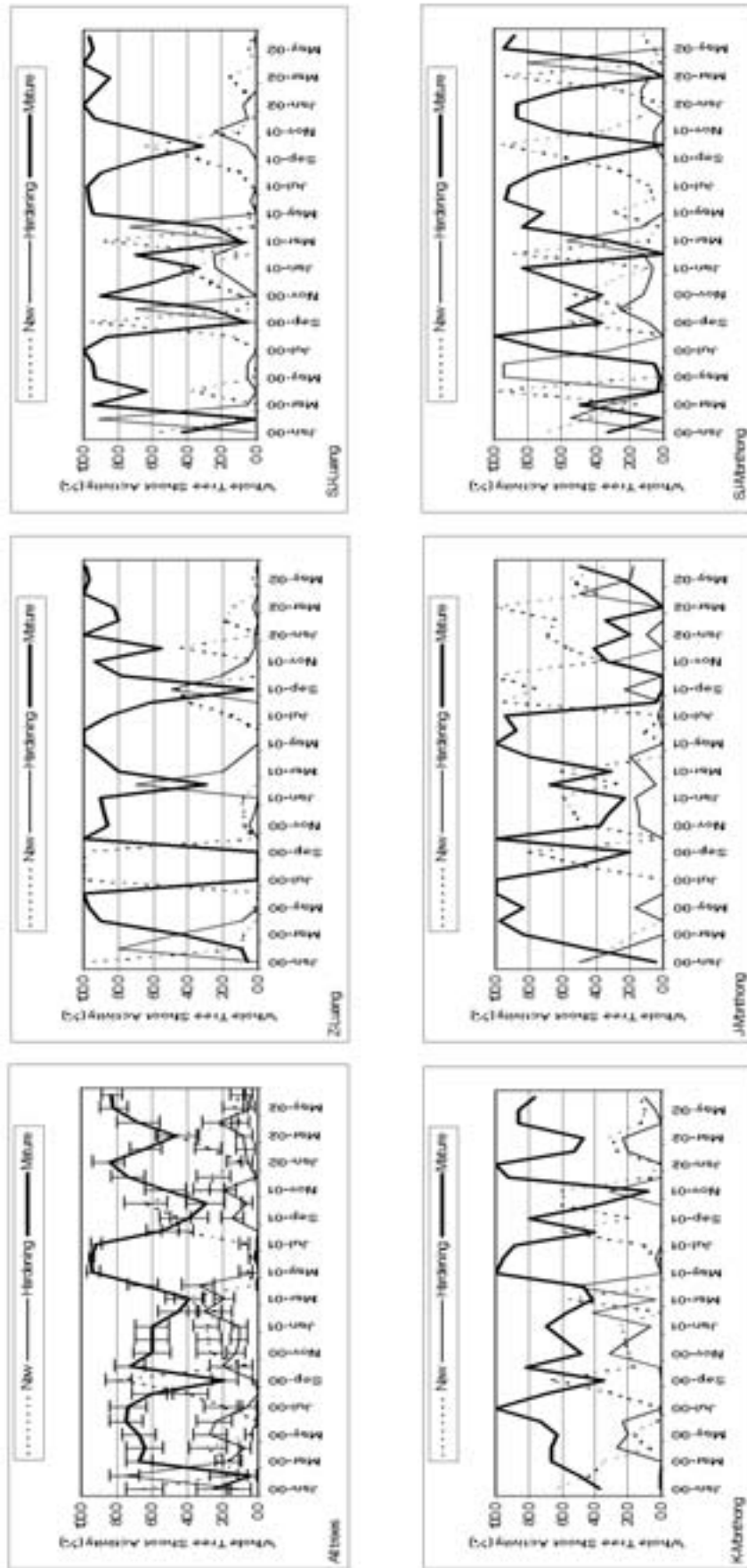
**Table 8.5.3** Average fruit yield and preharvest rot from 6-year-old durian trees in Vung Tai–Ba Ria, Vietnam, one year after treatment;  $n = 20$ . Values within columns are shown to be significantly different by ANOVA,  $P = 0.05$

Treatment	Average yield (kg/tree)	Percentage fruit rot
Water injection	11.4a	43.7a
Phosphonate injection 12 g	25.5b	10.5c
Phosphonate injection 18 g	26.7b	13.5b
Phosphonate injection 24 g	27.3b	12.0bc

In Vung Tau–Ba Ria, canker healing was achieved in 4-year-old trees with either one or two applications of 8 g a.i. phosphonate per tree per year, while canker painting did not significantly reduce cankers (Figure 8.5.8). In 6-year-old trees 3 injections at 3-month intervals with 8 g a.i. or 2 injections (6-month interval) of 8 g a.i., gave superior control to a single injection of 12 g a.i. All of the above treatments resulted in a significantly higher yield of healthy fruit. Excellent control was also achieved in 7-year-old trees with 3 injections totalling 16, 24, 32 g a.i. of phosphonate per tree per year, compared with Aliette 80 WP 1% paint, with 32 g a.i. treatment the most effective.

## Discussion

Flushing, flowering and fruiting patterns of durian recorded in north Queensland are similar to patterns observed in Malaysia and Thailand. Higher rates of leaf flushing occur during the wet season, while flowering normally occurs during or near the end of the dry spring months, and fruit development and harvest during the wet summer months (Subhadrabandhu and Ketsa 2001). Thai researchers report that the ideal temperature range for durian production is from 24°C to 30°C (Nanthachai 1994, Subhadrabandhu and Ketsa 2001). This study has revealed that active vegetative growth can occur under relatively cool conditions (three months where mean temperatures range from 18.5°C to 20°C and seven months where mean temperatures were >20°C and less than 24°C) as experienced in north Queensland. Surprisingly, root growth also continues during this period. In north Queensland, observations on durian root distribution agree with data presented by Masri (1991) showing that the durian root length density decreased horizontally



**Figure 8.5.4** Whole tree shoot phenology (%) for individual farm sites (Z-Luang, S-Luang, J-Monhong, K-Monhong, S-Monhong) and all trees plus standard error bars.

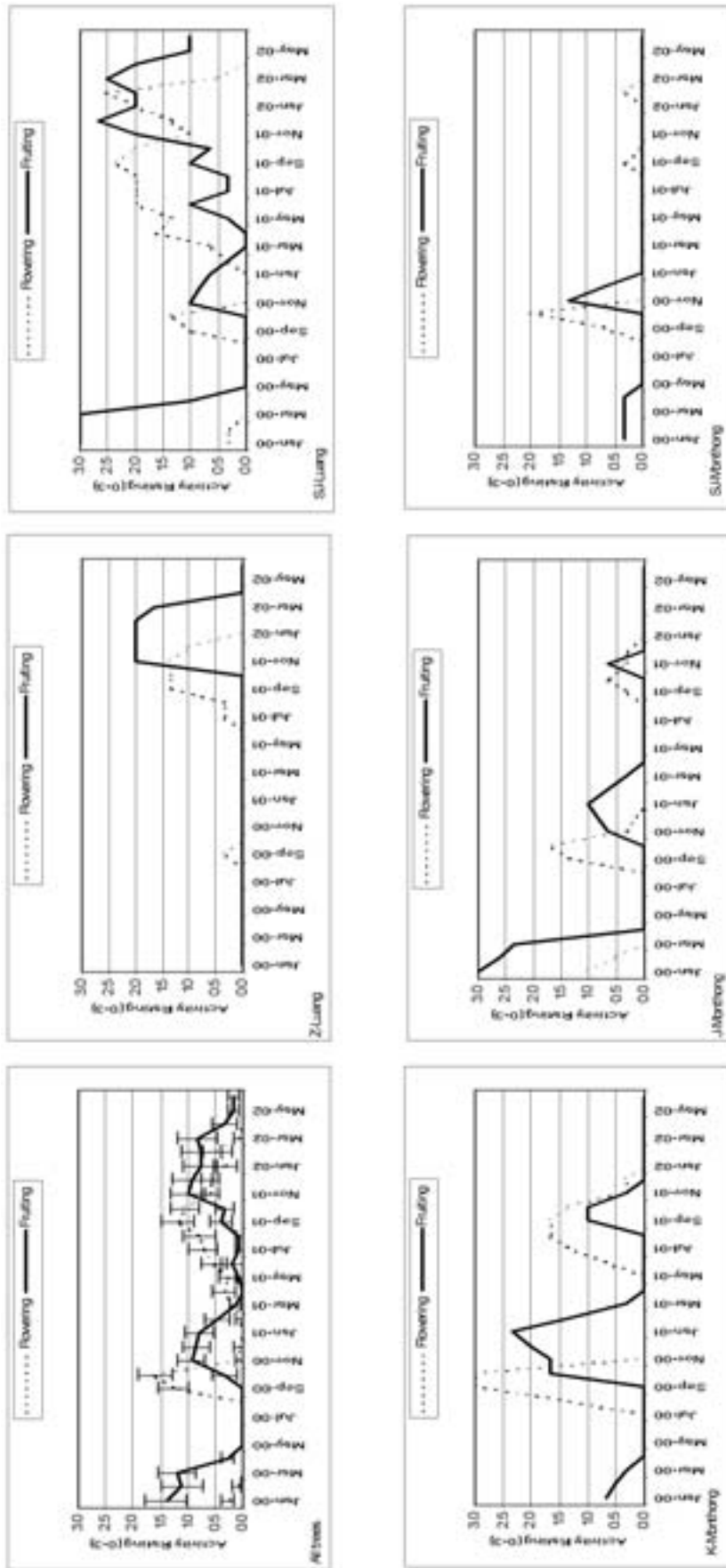


Figure 8.5.5 Flowering and fruit-set activity rating for individual farm sites (Z-Luang, SJ-Luang, K-Monthon, J-Monthon, SJ Monthon) and all trees plus SE bars.

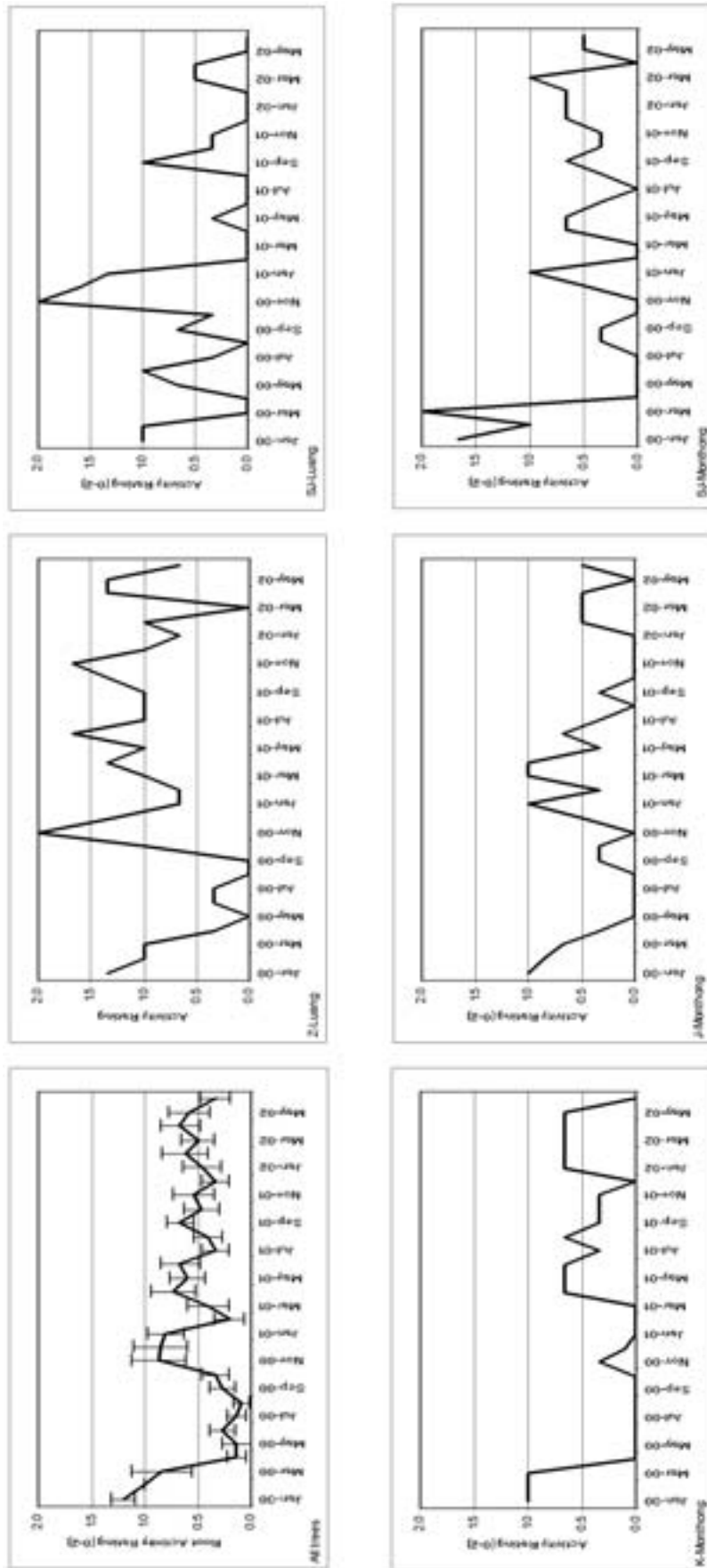


Figure 8.5.6 Root growth activity rating for individual farm sites (Z-Luang, S1-Luang, K-Monthon, J-Monthon, S2-Luang) and all trees plus SE bars.

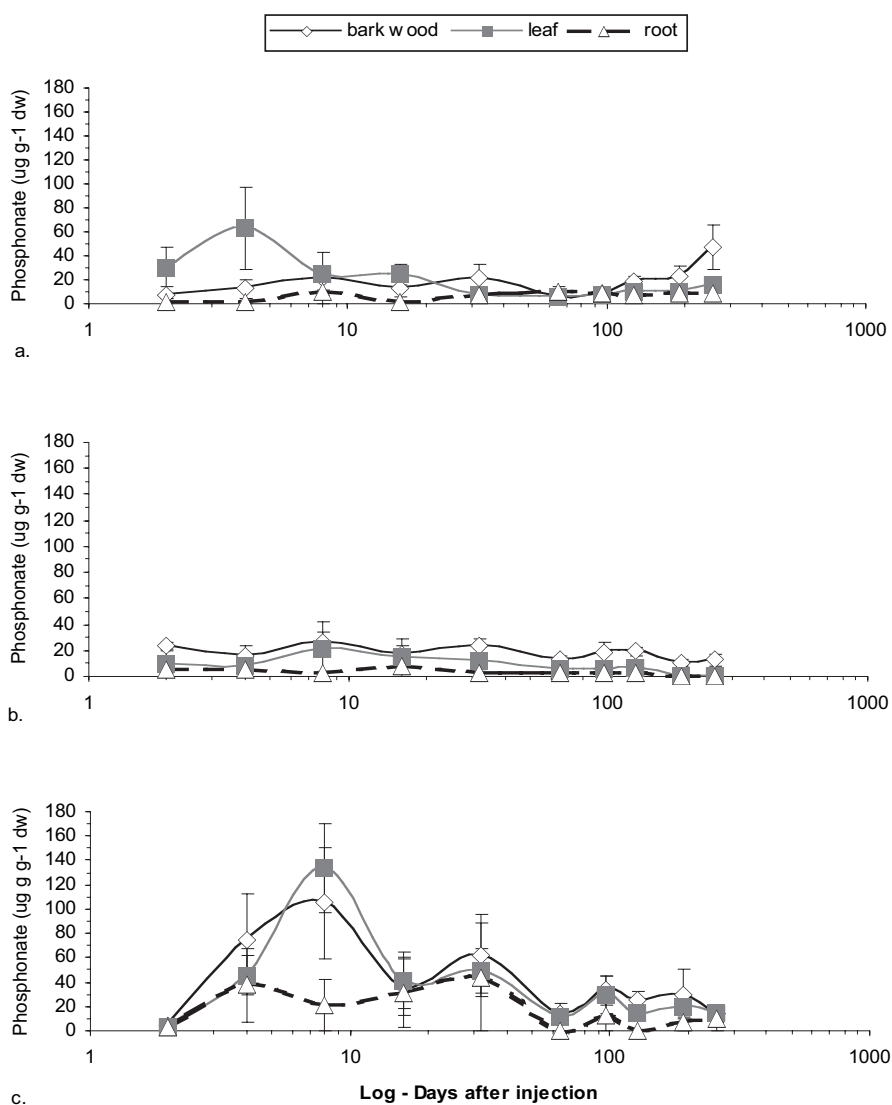
from the crown and vertically with soil depth but no data have been found that document root flushing activity.

The continuous growth of shoots and roots observed in durian differs from avocado where shoot and root activities have two distinct growth stages with the root growth following shoot growth (Whiley et al. 1988). Our data suggest that new shoot and root activity in durian occur simultaneously or are only slightly offset.

Phosphonate concentrations recorded in durian in this trial are lower than those observed in similar studies conducted in avocado (Whiley et al. 1995). In avocado, concentrations of phosphonate were as high as 80 µg/g fresh weight (fw) and 25 µg/g fw in

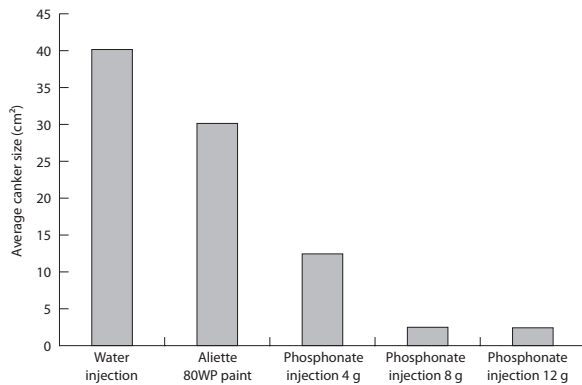
shoots and roots, respectively. Equivalent fresh weight maximum concentrations in durian were 24 µg/g and 2.3 µg/g for shoots and roots.

The phenological patterns observed suggest that shoot and root growth occurs throughout the year, albeit at higher levels during the summer months. This suggests that translocation of phosphonate to all developing meristems is possible regardless of the time of injection, unlike the situation in avocado where maximal levels in roots could be achieved only if injections followed the maturity of the spring shoot growth (Whiley et al. 1995). Surprisingly, phosphonate levels in durian generally remained low in roots (less than 10 µg/g dw). This suggests that either the root sink strength is low or the



**Figure 8.5.7** Phosphonate concentrations in durian tissue following injection after a) early flower and fruit-set, b) mid fruit-set and c) immediately post harvest with 16 g a.i. phosphonate.

concentration of phosphonate injected is inadequate to supply all organs simultaneously. Concurrent work in Vietnam has shown that the concentrations used in this experiment are sufficient to halt the development of stem canker. In this study, the phosphate concentrations were highest in the bark/wood samples following the mid-fruit-set injection. There were, however, no symptoms of bark canker observed in the trees before or during the sample period in north Queensland.



**Figure 8.5.8** Severity of canker symptoms on 4-year-old trees in Vung Tau-Ba Ria, Vietnam, 1 year after treatment;  $n = 20$ .

Phosphonate trunk injections effectively and consistently control durian trunk canker in trials conducted under high disease pressure in Vietnam, and lead to increased healthy fruit yield, as they do in cocoa and coconut. When they are used in conjunction with improved orchard hygiene, canopy management, drainage and preharvest foliar sprays of either phosphonate or Aliette, one could expect greater control of fruit rot. The optimal rate of application depends on disease severity and disease pressure. Trials conducted over 5 years on cocoa in Papua New Guinea using trunk injections of potassium phosphonate increased healthy pod yield and decreased the incidence of *Phytophthora* pod rot when compared with untreated trees or trees sprayed with recommended doses of Ridomil 250 EC or trunk injected with Aliette CA (Guest et al. 1994). A single annual injection of 15 g a.i. per tree controlled *Phytophthora* disease on mature cocoa trees, with the optimal dose depending on tree size, initial disease severity and disease pressure.

In conclusion, durian shoot and root growth remains relatively active throughout the year. This may be beneficial in terms of *Phytophthora* disease control via the mechanism of phosphonate trunk injection because sink strength remains active in all growing organs throughout the year. However, because of the absence of disease in north Queensland where we monitored the effect of phenology on tissue concentrations of phosphonate, we can only infer that these concentrations are adequate to explain the excellent level of disease control achieved in the trials conducted in Vietnam.

## Acknowledgments

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## 8.6 Control of Postharvest Diseases in Durian

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### Abstract

Disease incidence and disease severity associated with *Phytophthora palmivora* and other fungi was greater in fruit that had contact with soil during harvest, and when postharvest storage conditions were 15°C and 90% relative humidity. Other fungi isolated from symptomatic fruit stored under ambient conditions included *Fusarium* sp., *Mucor* sp. and *Botryodiplodia* sp. Preharvest sprays of durian fruit with 2 g/L fosetyl-al significantly reduced postharvest disease incidence and symptom severity compared with water-treated controls. A combination of preharvest spray and postharvest fruit dip of 1 g/L a.i. fosetyl-Al gave the best disease control. A postharvest dip of fruit in 1 g/L a.i. fosetyl-Al did not reduce postharvest rot.

### Introduction

Much of the literature on phytophthora disease control in durian concentrates on the treatment of patch or trunk canker. However, the development of distant and international markets has also made consideration of postharvest fruit health a priority. While *Phytophthora palmivora* is the most serious pre- and postharvest pathogen of durian, *Sclerotium rolfsii*, *Lasiodiplodia theobromae*, *Colletotrichum gloeosporioides* and *Fusarium solani* also reduce the shelf life and value of the fruit (Lim 1990; Nanthachai 1994).

Harvesting indices developed for Thai varieties enable early harvesting, which gives time for transport of the fruit to distant markets before ripening. Harvesting indices are not relevant to the Vietnamese durian industry, as there is currently a high level of variability in the planting material.

The most recent survey of durian diseases in Vietnam puts postharvest losses of durian due to

phytophthora diseases at up to 15%, but they may be as high as 30%, and locally can be devastating when whole consignments are lost through transit rot (Lim 1990; Lee 1994). Vietnam’s durian industry is small and currently caters mainly to the local market and durian-growing areas in the south-east of Vietnam are close to major population centres (Dr Nguyen Minh Chau, Director, Southern Fruit Research Institute (SOFRI), pers. comm.). Both farmers and the government aim to develop the export potential of this high-value crop to meet increasing international demand for the fruit. Consequently, the area under durian cultivation is expanding rapidly in Vietnam, in some cases into marginal lands, and recommendations for phytophthora disease control are urgently needed. The research presented in this chapter examines methods of postharvest disease control using pre- and postharvest treatments of phosphonate, which have proven highly effective in controlling phytophthora trunk canker in durian (Chapter 8.5), and associated diseases in other crops (Guest et al. 1995; Konam 1999)

### Materials and Methods

#### Effect of harvest method on postharvest disease development

Two harvesting methods were compared on durian cv. Kho Qua Xanh at two times during the fruiting

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season of 2000; early in the season (February) and at the peak of the season (May–June). The two harvesting methods compared were:

- fruit fall, simulated by cutting the fruit from the branch and dropping it to the ground from a height of 3 m
- cut and collect, where ripe fruit was cut from the branch and carefully packed into boxes with no soil contact.

Harvested fruit was transported to the laboratory, where it was stored for 3 weeks either under ambient conditions ( $n = 5$ ), or in controlled-environment chambers at 15°C and 90% relative humidity (RH) ( $n = 10$ ).

To determine disease incidence, symptomatic tissue was excised, surface sterilised and plated onto potato dextrose agar, and the causal agent identified through morphological characteristics. Symptom severity was rated on a scale of 0–4: 0 = no symptoms, 1 = lesions covering 1–5% of the fruit, 2 = lesions covering 6–10% of the fruit, 3 = lesions covering 11–20% of the fruit, and 4 = lesions covering more than 20% of the fruit. The severity for each treatment was calculated using the following formula:

$$\text{Severity} = \sum(\text{severity rating} \times \text{rating frequency})/n$$

#### Effect of preharvest fungicide spray on postharvest disease development

These experiments were carried out between March and June 2000 at Cai Lay District, Tien Giang Province in Vietnam, on durian cv. Kho Qua Xanh. The three preharvest fruit spray treatments were:

- 1) 1 g/L a.i. fosetyl-al (Aliette 80 WP, Bayer CropScience)
- 2) 2 g/L a.i. fosetyl-al
- 3) water (control).

Treatments were applied directly to the fruit 30 days after fruit set, and again after a 30-day interval. There were 5 trees per treatment and 10 fruit harvested from each tree, followed by transport to SOFRI and storage in a controlled-environment chamber at 15°C and 90% RH for 3 weeks. Disease incidence and symptom severity were calculated as described above.

#### Effect of postharvest fungicide dip on postharvest disease development

Experiments were conducted between May and July 2000, on mature fruits of durian cv. Kho Qua Xanh harvested from durian orchards in Tien Giang Province and transported to SOFRI. The five postharvest fruit dip treatments were:

- 1) 1 g/L a.i. fosetyl-al
- 2) 2 g/L a.i. fosetyl-al
- 3) 3 g/L a.i. fosetyl-al
- 4) 4 g/L a.i. fosetyl-al
- 5) water (control).

There were 5 fruit per treatment. Fruit was immersed in the treatment solution for 5 minutes, dried at ambient temperature and stored for 3 weeks in a controlled-environment chamber at 15°C and 90% RH, and a further 2 days under ambient conditions. Disease incidence and symptom severity were calculated as described above.

#### Effect of combining pre- and postharvest fungicide treatments on postharvest disease development

This experiment was also carried out between March and June 2000 at Cai Lay District, Tien Giang Province, on durian cv. Kho Qua Xanh. Six treatments were applied as described above, in the following combinations:

- 1) preharvest spray with 2 g/L a.i. fosetyl-al
- 2) preharvest spray with water
- 3) postharvest dip in 1 g/L a.i. fosetyl-al
- 4) postharvest dip in water
- 5) preharvest spray with 2 g/L a.i. fosetyl-al and postharvest dip in 1 g/L a.i. fosetyl-al
- 6) preharvest spray with water and postharvest dip in water.

Treated fruit were stored in a controlled-environment chamber at 15°C and 90% RH for 15 days, and a further 4 days under ambient conditions. Disease incidence and symptom severity were calculated as described above.

#### Data analysis

Data were analysed by analysis of variance (ANOVA) and least significant differences (LSD) computed at 5% and 1% levels of significance, in order to test differences between means. Results are presented as the LSD between means that would be significant under the conditions of the test.

## Results

#### Effect of harvest method on postharvest disease development

When fruit were harvested to avoid contact with orchard soil, no disease symptoms developed within 21 days of fruit being stored at ambient temperature. When soil contact was allowed during harvest, there was a greater disease incidence in fruit harvested at peak season than fruit harvested early in the season. *P. palmivora* was not isolated from any fruit stored at

ambient conditions, regardless of harvest date or method of harvest (Table 8.6.1).

Disease incidence and disease severity associated with *P. palmivora* and other fungi was greater in fruit that had contact with soil during harvest, when postharvest storage conditions were 15°C and 90% RH (Table 8.6.2). Other fungi isolated from fruit with disease symptoms stored under ambient conditions included *Fusarium* sp., *Mucor* sp. and *Botryodiplodia* sp.

### Effect of preharvest fungicide spray on postharvest disease development

Preharvest sprays of durian fruit with fosetyl-al significantly reduced postharvest disease incidence and symptom severity compared with water-treated controls. There was no significant difference in disease incidence or symptom severity between the two rates of fosetyl-al used (Table 8.6.3), although the cause of disease symptoms was not identified.

**Table 8.6.1** The percentage of durian cv. Kho Qua Xanh fruit exhibiting disease symptoms from infections by *Phytophthora palmivora* or other fungi after harvest in February 2000 (early season) or May–June 2000 (peak season) by one of two harvesting methods: (a) fruit fall – where fruit came into contact with orchard soil and (b) cut and collect – where no soil contact was allowed, followed by storage under ambient conditions.  $n = 5$ .

Harvest method	Number of diseased fruit after 21 days			
	Early season		Peak season	
	<i>Phytophthora</i>	Other fungi	<i>Phytophthora</i>	Other fungi
Fruit fall	0	1	0	3
Cut and collect	0	0	0	0

**Table 8.6.2** The percentage of Kho Qua Xanh variety of durian fruit exhibiting disease symptoms, and mean symptom severity resulting from infections by *Phytophthora palmivora* or other fungi after peak season harvest (May–June 2000) by one of two harvesting methods: (a) fruit fall – where fruit came into contact with orchard soil, and (b) cut and collect – where no soil contact occurred, followed by storage at 15°C and 90% RH for 3 weeks.  $n = 10$ .

Harvest method	Disease incidence (%)		Severity <sup>1</sup>	
	<i>Phytophthora</i>	Other	<i>Phytophthora</i>	Other
Fruit fall	16.7a	27.1a	1.96A	1.72A
Cut and collect	4.0a	15.0b	0.82B	0.72B
LSD <sub>0.05</sub>	16.0	9.7	–	–
LSD <sub>0.01</sub>	–	12.7	0.63	0.92

<sup>1</sup> Severity rated on scale 0–4 according to percentage of fruit surface with lesions: 0 = no lesions, 1 = 1–5%, 2 = 6–10%, 3 = 11–20% and 4 = >20%.

Means followed by the same lower case letter are not significantly different according to LSD (0.05).

Means followed by the same upper case letter are not significantly different according to LSD (0.01).

**Table 8.6.3** The percentage of durian cv. Kho Qua Xanh fruit exhibiting disease symptoms, and mean symptom severity after two preharvest fruit sprays (30-day interval) with fosetyl-al (Aliette 80 WP) followed by manual harvest and storage for 3 weeks at 15°C and 90% RH.  $n = 50$ .

Treatment	Disease incidence (%)	Severity <sup>1</sup>
Water (control)	40.0A	1.20a
fosetyl-Al g/L	12.0B	0.32b
fosetyl-Al 2 g/L	8.0B	0.12b
LSD <sub>0.05</sub>	–	0.68
LSD <sub>0.01</sub>	23.2	–

<sup>1</sup> Severity rated on scale 0–4 according to percentage of fruit surface with lesions: 0 = no lesions, 1 = 1–5%, 2 = 6–10%, 3 = 11–20% and 4 = >20%.

Means followed by the same lower case letter are not significantly different according to LSD (0.05).

Means followed by the same upper case letter are not significantly different according to LSD (0.01).

### Effect of postharvest fungicide dip on postharvest disease development

Although postharvest dipping of durian fruit into fosetyl-al solutions of up to 4 g/L a.i. significantly reduced disease symptom severity compared with the water control, it did not significantly reduce the incidence of disease. There was no significant difference in symptom severity between the different concentrations of fosetyl-al tested (Table 8.6.4). Again, the cause of disease symptoms was not identified.

### Effect of combining pre- and postharvest fungicide treatments on postharvest disease development

Preharvest spray with 2 g/L a.i. fosetyl-Al reduced the postharvest disease incidence and symptom severity in durian, while postharvest dip of fruit in 1 g/L a.i. fosetyl-Al did not. A combination of these pre- and postharvest treatments gave the best disease control (Table 8.6.5), although the cause of fruit rot was not identified.

## Discussion

The results of this study demonstrate the importance of minimising contact between fruit and soil during harvesting, not only in controlling postharvest phytophthora diseases but also those caused by other fungi. An added advantage of harvesting the fruit from the tree is the prevention of impact damage as the ripe fruit hits the ground on abscission. Durian that is allowed to separate naturally is believed to have a better flavour than harvested fruit, so farmers in Malaysia, Indonesia and the Philippines tie the fruit to the branches so that it can separate without the associated problems of natural drop (Figure 8.1.7; Nanthachai 1994). In recent years, farmers in Vietnam have also adopted this practice. In Thailand, harvesting of mature but unripe fruit is commonly undertaken by a skilled team; one person climbs into the tree and cuts the stalk, allowing the fruit to drop to a second person on the ground, who catches it in a jute sack (Figure 8.1.7).

**Table 8.6.4** The percentage of durian cv. Kho Qua Xanh fruit exhibiting disease symptoms, and mean symptom severity after postharvest dip for 5 minutes in 1, 2, 3, or 4 g/L a.i. fosetyl-Al (Aliette 80 WP, or water (control), followed by storage for 3 weeks at 15°C and 90% RH, and a further 2 days under ambient conditions.  $n = 5$ .

Treatment	Disease incidence (%)	Severity <sup>1</sup>
Water (control)	15a	0.85a
fosetyl-Al 1 g/L	15a	0.40b
fosetyl-Al 2 g/L	10a	0.25c
fosetyl-Al 3 g/L	5a	0.15c
fosetyl-Al 4 g/L	10a	0.25c
LSD <sub>0.05</sub>	-	0.15

<sup>1</sup> Severity rated on scale 0–4 according to percentage of fruit surface with lesions: 0 = no lesions, 1 = 1–5%, 2 = 6–10%, 3 = 11–20% and 4 = >20%.

Means followed by the same lower case letter are not significantly different according to LSD (0.05).

**Table 8.6.5** The percentage of durian cv. Kho Qua Xanh fruit exhibiting disease symptoms, and mean symptom severity after preharvest spray with 2 g/L a.i. fosetyl-Al (Aliette 80 WP), postharvest dip in 1 g/L a.i. fosetyl-Al, or a combination of the two. Control fruits were similarly treated with water. After treatment fruit was stored for 15 days at 15°C and 90% RH, and a further 4 days under ambient conditions.  $n = 5$ .

Preharvest spray	Postharvest dip	Disease incidence (%)	Severity <sup>1</sup>
Water	Water	84.4d	1.81a
Water	-	50.0c	0.97b
-	Water	53.1ac	1.09b
2 g/L fosetyl-Al	-	28.1a	0.41c
-	1 g/L fosetyl-Al	37.5a	0.59c
2 g/L fosetyl-Al	1 g/L fosetyl-Al	12.5b	0.25c
LSD <sub>0.01</sub>		27.56	0.39
LSD <sub>0.05</sub>		19.93	0.55

<sup>1</sup> Severity rated on scale 0–4 according to percentage of fruit surface with lesions: 0 = no lesions, 1 = 1–5%, 2 = 6–10%, 3 = 11–20% and 4 = >20%.

Means followed by the same lower case letter are not significantly different according to LSD (0.05).

The current study shows that disease incidence was greater at peak season (May–June) than at the start of the season (February). This is a not unexpected finding, as February in southern Vietnam is hot and dry and fruit is in the early stages of development, while May–June is during the monsoon with high levels of humidity coupled with an ample energy source for pathogens in the ripening fruit.

*Phytophthora* symptoms did not develop on fruit that was stored under ambient conditions, regardless of time or method of harvest, but did develop when fruit was stored at 15°C and 90% RH for 3 weeks. Prolonged periods of high humidity seem to be the key here, as 98% RH had to be maintained for at least 72 h for disease development to occur in non-wounded, artificially inoculated durian fruit (Chapter 3.2).

In the Ba Ria–Vung Tau region of Vietnam, Mr Mai Van Tri and colleagues clearly demonstrated that trunk injection with phosphonate not only ameliorates phytophthora trunk canker but also reduces the incidence of preharvest diseases, with a consequent increase in the yield of healthy fruit (Chapter 8.5). Phosphonate also reduces the incidence and severity of postharvest diseases in durian when applied as a preharvest spray during the fruit development period, with a follow-up postharvest dip. A preharvest spray with phosphonate without any postharvest treatment will afford some protection. Although a postharvest dip on its own may reduce symptom severity, it is not effective in reducing the incidence of disease. Nanthachai (1994) cites unpublished work from Thailand that confirms the effectiveness of combining pre- and postharvest treatments of phosphonate for the control of postharvest diseases.

Nanthachai (1994) expressed some concern about the use of phosphonate in fruit disease control due to limited knowledge about the effect of residues. However, the Australian Pesticides and Veterinary Medicines Authority (formerly the National Registration Authority), which is the national registration authority for agricultural and veterinary chemicals, recently declared that residue data are not required for the registration of phosphonate in Australia, due to the biologically benign nature of the formulas to non-target organisms (Guest and Grant 1991; NRA 2001). Taste-tests revealed that injected phosphonate had no adverse effects on fruit palatability.

Recommendations for the control of postharvest diseases in durian have been formulated through this study. The following control measures should be included into a broader, integrated regime of management for the crop:

- minimisation of inoculum levels in the orchard through the regular removal and destruction of diseased branches and fruit
- minimisation of inoculum levels in the orchard by control of patch canker with phosphonate trunk injections according to recommendations in Chapter 8.5
- control of insects that may carry inoculum into the tree canopy
- reduction humidity in the orchard through pruning to improve airflow
- phosphonate treatment: fruit spray with 2 g/L a.i. fosetyl-Al during fruit development and again 30 days later, followed by a postharvest dip in 1 g/L a.i. solution of fosetyl-Al
- manual harvesting of fruit that prevents fruit coming in contact with the soil
- careful postharvest handling of fruit to prevent injury and development of pathogen infection courts.

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# 8.7 Integrated Management of Phytophthora Diseases of Durian: Recommendations and Benefit–Cost Analysis

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## Abstract

Durian is a favourite fruit throughout Southeast Asia. Increasing areas have been planted to durian orchards in recent years, especially in the Mekong Delta and southeastern provinces of Vietnam, in marginal areas of Thailand and in northern Australia. Durian growers face significant losses due to phytophthora diseases, and there is an urgent need for recommendations to control these diseases. Integrated disease management recommendations, based on an understanding of the biology of the pathogen, optimal growing conditions and soil health, promise sustainable durian production with minimal environmental impact. We have developed integrated orchard management recommendations based on an appreciation of the natural rainforest conditions in which durians co-evolved with the pathogen.

## Introduction

*Phytophthora* is a serious pathogen of durian that has the ability to attack the plant at various stages of its life cycle. Roots, stems and leaves of seedlings, young trees and mature trees are affected, as well as flowers and fruit. *Phytophthora palmivora* is a pathogen on a wide range of host plants grown throughout Southeast Asia. Major epidemics occurred in 1994 in Thailand, and in 2001 in Vietnam. Hence, it is easy to understand that to

control *P. palmivora* in durian, we need an integrated approach that takes the disease cycle, host range and cultivation practices for durians into account.

Integrated disease management (IDM) is the long-term reduction of disease losses to economically acceptable levels through a holistic approach that combines the use of resistant varieties, cultural control methods, biological control methods, and the judicious application of appropriate chemicals. The principle of integrated management of phytophthora diseases in durian has been promoted since the early 1990s (Lim 1990; Bong 1993; Lee 1994), but detailed recommendations appropriate for all regions have been lacking, and subsequent implementation patchy. A systematic approach to developing recommendations was undertaken as part of an ACIAR-funded project, 'Management of *Phytophthora* diseases in durian' (Project no. PHT/1995/134), which commenced in 1998. As part of the project, practical disease-control options were investigated, regionally optimised and disseminated to durian farmers in Thailand, Vietnam and Australia. The project culminated in a

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workshop in Chiang Mai, Thailand in November 2002, discussions at which formed the nucleus for the production of this monograph.

The recent and rapid expansion of the durian industries in Thailand and Vietnam has seen the establishment of orchards on increasingly marginal sites, including rice paddy in Vietnam (Figure 6.7.9), where phytophthora diseases can be exacerbated. Sources of disease resistance in durian and the development of tolerant rootstocks have yet to be identified, although the screening techniques described in Chapter 8.3 should facilitate the search. Nursery standards have to be improved to ensure that infected planting material is not released to growers (Chapter 8.4).

In the past, gaps in our understanding of the epidemiology of *P. palmivora* in durian have hampered effective management, and have resulted in the application of inappropriate and ineffective management practices. Although effective against phytophthora diseases of avocado and cocoa, the lack of specific recommendations for the rate and timing of phosphonate trunk-injection of durian have so far limited efficient application and effective disease control using this technique.

Integrated disease management of durians aims to minimise infection at various points in the disease cycle. Initially, this includes using clean, disease-free planting material and properly prepared planting sites. After establishment of an orchard, management priorities include improving and maintaining soil health through the use of organic matter and green manure, manipulation of soil moisture and drainage, and correct nutrient management. Care must be taken to prevent the spread of soil-borne inoculum into the canopy.

Disease development can also be slowed down through the removal of infected fruit from the canopy and by general orchard hygiene. If stem cankers are active, they may be treated with phosphonate injections to cure them. Details of the various components of the IDM practice developed are given below.

## Planting and Pruning

Farmers should select disease-free planting stock from a reputable nursery. Grafted seedlings can be useful if disease-resistant rootstocks are available, or if the farmer wants to multiply an elite, selected scion cultivar. Avoid planting directly on old rubber, cocoa or pawpaw land, as these plants are susceptible hosts for *Phytophthora palmivora*, and high levels of soil inoculum may have built up. If this

is not possible, grow a legume groundcover for at least one year before transplanting durian, slash the green vegetation and use as a green manure to build-up soil organic matter and microbial activity.

If the green manure is fermented or composted it may also suppress existing *Phytophthora* infestations of the planting hole. One technique is to excavate a 2 m diameter by 50 cm deep planting hole, fill it with green manure, add fresh chicken manure and a microbial starter culture such as EM (Effective Microorganisms, <<http://www.emtrading.com/index.html>>), trample to remove air, and cover with compacted soil. Leave the material to ferment for 8–10 weeks, before forming into a mound at least 50 cm high, into which the durian is transplanted. Anaerobic fermentation of green manure, particularly using fresh chicken manure, will eradicate *Phytophthora* and other pathogens, while leaving an active population of beneficial soil microbes and a rich source of nutrients for the young seedling.

The watertable should be at least 80 cm below ground level. This can be achieved by planting on a mound 50–60 cm above ground level in lowlands such as the Mekong Delta, or 30–40 cm above ground level elsewhere. Mix pelleted or composted chicken manure and lime into the soil before planting. Select strong and healthy saplings grafted onto disease-resistant rootstocks, like the Vietnamese cv. La queo. Do not plant the saplings too deep and ensure the graft is well above the soil line. Drench the transplanted saplings with phosphonate solution around the base of the plant (10 mL of 400 g/L a.i./10 L water).

When establishing an orchard, space trees widely enough (no more than 80–100 trees/ha for most cultivars), and regularly prune to remove branches within 80–100 cm of the ground to provide adequate ventilation, to reduce canopy humidity, and to minimise soil splash into the canopy. Avoid susceptible clonal monocultures and close interplanting, especially with susceptible plants, as uniformly susceptible monocultures provide ideal conditions for epidemic development. Durian interplanted densely with papaya, coconut, or cocoa which act as alternative hosts, may increase the risk of high levels of disease.

An alternative approach to orchard establishment is to establish a diverse community of plants that mimics the rainforest habitat in which durian evolved. This approach, a type of garden agroforestry, aims to create a biologically diverse, sustainable and highly profitable farming system (Leakey 1998). As a large tree normally forming the

upper canopy of rainforests, durian is ideally suited to this type of planting as a shade tree for understorey fruit trees, vegetables and medicinal plants. The genetic diversity of these mixed plantings significantly retards the development of explosive epidemics, even if some of the intercrops are susceptible to *Phytophthora*.

## Mulching

Durian evolved as a rainforest tree. In rainforests, ectomycorrhizal roots absorb mineral nutrients and water from the organic-matter-rich leaf litter layer in the top 50 cm of the soil. Cultivating durian in orchards with bare soil exposes the surface roots to direct sunlight, kills the mycorrhizal fungi, and depletes the biological activity, nutrient availability and health of the topsoil. Irrigation of bare soils under direct sunlight creates a baked crust that inhibits water absorption, forms temporary ponds of water that stimulate sporangial development and zoospore release, and facilitates rainsplash dissemination of *Phytophthora* inoculum.

To recreate the litter layer, especially during orchard establishment, mulch the soil surface under the drip zone of the tree with straw and manure. Mulching encourages mycorrhizal root development, improves soil microbial activity and soil health, suppresses *Phytophthora* and other pathogens and weeds, and improves soil moisture retention in the dry season (Chapter 7.3).

Fresh straw may need to be applied regularly, depending on the local conditions. In the humid wet tropics, such as in north Queensland, the straw decomposes within a few weeks and should be reapplied frequently. In the monsoonal tropics, straw applied toward the end of the rainy season will persist well into the dry season, providing adequate protection for the mycorrhizal roots. Irrigation, whether by spray, drip or flood, can be applied without disturbing the mulch layer, which will also reduce evaporative water loss. During the wet season, it may be wise to clear the mulch from immediately around the base of the trunk to prevent excess moisture persisting directly around the trunk, as this may encourage canker development.

## Water and Nutrient Management

Irrigation may be required in environments with a protracted dry season. Spray or drip irrigation is preferred to flood irrigation, with any spray nozzles directed away from the trunk, so that the drip zone, but not the trunk, is wetted. Water that might come from a source at risk of contamination with

*Phytophthora* should not be used for irrigation. Apply a straw or leaf mulch to cover the ground around the durian tree in the dry season, to reduce water loss from the topsoil.

Organic fertilisers, especially composted chicken manure, are preferred to inorganic fertilisers, as there is evidence that excess inorganic nitrogen increases the risk of phytophthora canker and root rot (Chapter 7.2). Potash fertilisers (supplying potassium) added one month before fruit harvest will prevent the development of 'wet core' and improve fruit quality.

Paclobutrazol, or manipulation of soil water deficits during the rainy season using plastic mulch (Figure 8.1.6) to induce flowering, should be used carefully and not every year. This will avoid stressing the trees.

## Harvesting

Once a fruit becomes infected, it takes only about 4 days for it to become completely colonised by *Phytophthora* and then forms an abundant source of inoculum. Regular harvesting and removal of infected fruit reduces the amount of inoculum when fruits are ripening, usually in the rainy season. Remove and bury infected fruit (see below). Fruit should ideally be harvested only when they are still on the tree, and not from the ground. Avoid contact with soil and damage to ripe fruit, as this causes postharvest rot (Chapter 8.6).

## Orchard Hygiene and Fruit Disposal

During pruning and harvesting, tools should be disinfected with a quaternary ammonium detergent before they are used on the next tree. Avoid moving soil between orchards on tyres or footwear by washing boots and equipment with a quaternary ammonium detergent.

Infected fruit is a significant source of *Phytophthora* inoculum and should be removed from the orchard. Piles of rotting fruit are also breeding grounds for flying beetles that are potential vectors of the pathogen (Konam and Guest 2004). When composted, fruit also improves soil health and provides a valuable source of nutrients.

If in some years disease pressure is very high and a lot of fruit rot does occur, it is a good practice to anaerobically ferment infected fruit to prevent further spread of the disease, eradicate inoculum and recycle nutrients. This technique is similar to that described for preparing planting holes. Anaerobic fermentation takes approximately 10



weeks, and could be completed in furrows between the rows of trees. Furrows could be constructed every three or four rows, and filled in continuous rotation. Dig a furrow approximately 50 cm deep between rows of trees, and place the diseased fruit into the furrow. Add green manure (such as legume leaves, cut grass and prunings), fresh chicken manure and a starter culture such as EM. When the furrow is almost full, stamp down to exclude as much air as possible, and cover with 5–10 cm of soil.

## Canker Treatment

Stem cankers can cause serious tree decline due to damage to the cambium. Cankers reduce tree vigour and yield. They must be diagnosed promptly and accurately for IDM to be successful, and to prevent tree deaths. Once diagnosed, the bark on the surface of cankers should be scraped back and painted with a copper fungicide such as Bordeaux mixture. Ridomil Plus may be used as an alternative, but it is more expensive. The most effective long-term control of canker is achieved through trunk injection of phosphonate.

## Trunk Injection of Phosphonate

Potassium salts of phosphorous acid, neutralised to pH 6.5–7.0, and injected into the trunks of trees, give outstanding control of canker and fruit rot (Chapters 8.5 and 8.6). Potassium phosphonate is available under many brand names including Fosject, Foli-R-Fos, Agri-Fos Supa and Phos-Acid. Concentrations of 200 g/L, 400 g/L and 600 g/L a.i. are available. All these concentrations may be injected. The optimal dose for mature durian trees is two or three injections of 16 g a.i. potassium phosphonate annually (depending on the size of the tree and the disease pressure), applied during leaf flush. In mature Vietnamese orchards, trees should be trunk-injected with phosphonate (40 mL of phosphonate 400 g/L a.i.) twice in the first year. As the disease pressure decreases with improved orchard management and the adoption of IDM, injections may be reduced to once a year.

Trunk injection involves drilling a hole 6.5 mm in diameter and 40 mm deep with a sharp drill, about 50 cm from the base of the trunk. Modified veterinary syringes do not work as well on durians as on avocado. Chemjet® injectors (<<http://www.chemjet.com.au/>>) hold 20 mL of phosphonate solution, requiring three or four holes drilled evenly spaced around the trunk, preferably directly under each main branch. Fill an injector and screw into the hole, without pushing, until a clicking sound is heard. Release the spring to allow the

injection to proceed. Under normal conditions injection should take 10–20 minutes. After all the solution has been taken up by the tree, unscrew the injector, rinse first in a quaternary ammonium detergent solution, then in water and refill, and use to inject the next tree. Injectors should be dismantled and thoroughly washed in clean, soapy water at the end of each day.

The Sidewinder® (<<http://www.treeinjectors.com/>>) drills and injects the trunk in one operation, and although it is more expensive, may be practical in large orchards where labour costs are relatively high. Inject trees in the morning, as uptake slows significantly in the afternoon. Care must be taken with high-pressure, trunk-injection systems, as durian trees are prone to splitting of their bark.

## Benefit–Cost Analysis

The total cost of phosphonate trunk injection includes the cost of injectors, phosphonate and labour. Chemjet® injectors retail for approximately USD5 each, but last for several years if properly maintained. An average-size, mature durian tree requires 80 mL (four 20 mL injectors) of 200 g/L a.i. formulation, taking up to 30 minutes for complete uptake. A farmer will need at least 20 injectors and one drill for continuous operation, although the cost may be shared by a group of farmers, as each farmer uses them only once or twice a year and they last for several years.

The cost of 32 g a.i. phosphonate required per tree is about USD1 per year (assuming a 400 g/L a.i. formulation costs USD12 per litre). Labour costs vary but, on average, each worker could inject 10 trees per hour. Therefore, the total annual cost of injecting would be about USD2 per tree. If a good-quality durian fruit sells for USD2–5, this means that the cost of injecting a mature tree would be repaid by one extra fruit per tree each year. However, it takes up to 9 years for a tree to become profitable, so the overall cost for the lifetime of an orchard, including the cost of injecting immature trees, might require an extra fruit per tree once the trees are mature.

Assuming an average loss of 20% due to *Phytophthora* and a typical yield of 80 kg, disease control would raise the yield to 100 kg per tree, an increase of 20 kg. At USD2 a fruit, disease control through trunk injection yields a net benefit of USD40 for a cost of USD2. This is a conservative estimate that does not include the savings of not having to replace trees that would otherwise have been killed by canker. The cost of other inputs also varies, and should include the cost of chicken manure, straw mulch and orchard hygiene.

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# 9 Conclusions and a Vision for Future Research Priorities

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## Abstract

This chapter provides a brief overview of some of the constraints and challenges of trying to develop and implement plant disease-management strategies in short-term international agricultural research projects. General issues relating to focusing on the problem at the local level, developing effective collaborations, finding solutions, overcoming hurdles to adoption, project planning and management, and the interface between funding bodies and research providers are canvassed.

## Introduction

Phytophthora diseases cause significant reductions in the yield and quality of food, medicinal and cash crops. In this monograph, some of the common diseases have been discussed in detail and options suggested for sustainable disease management. Although there are solutions for many phytophthora problems, the main challenge is not further basic research, but the adaptation, delivery, implementation, and adoption throughout the region of disease-management strategies that are already available.

Millions of smallholders throughout Southeast Asia could benefit from an enhanced capability to recognise disease problems and implement effective disease-management practices. However, the extremely large numbers of individual growers with diverse personal goals and motivations and a wide range of cultures and languages, together with poorly resourced extension services, make filling this gap a very challenging task.

## The Phytophthora Problem

It is clear that *Phytophthora* pathogens can cause many different diseases in many Southeast Asian crops. Phytophthora diseases are difficult to control in the tropics because of the presence of susceptible plant tissues of many different host-plant species and environmental conditions that are conducive to disease development virtually all year round. Although symptoms may abate in the dry season, there is no real break in the disease cycle and inoculum is present all year round. The presence of pronounced wet seasons also significantly aids *Phytophthora* pathogens in their spread and ability to infect susceptible host tissue. The control of these diseases is therefore difficult and an ongoing concern, and there are very few, if any, so-called 'silver bullets' that will solve all the disease problems in a sustainable way. Plant pathologists have long realised that they should use a combination of tools, such as disease-free planting material, orchard management, fertiliser application, disease resistance, fungicides and phosphonate, in an integrated manner if they are to make any significant progress in phytophthora disease management in the tropics. Most smallholders have limited capital or access to credit, further constraining their ability to implement the proposed disease-control methods.

Phytophthora diseases are common and widespread in temperate regions, and have typically been investigated in great detail over long

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periods. This has led to the development of tried-and-tested disease-management options that are implemented and maintained. Unfortunately, this is not the case for phytophthora diseases in the tropics. In tropical areas, a lot less is known about the species involved, the disease cycle and the availability of resistant plant material, and there have been few systematic studies to test and evaluate different disease-management practices. Therefore, the first hurdle to overcome is a technology gap of practical and cost-effective disease-control methods developed and implemented in the tropics.

Working in the tropics, one is continually exposed to comments such as 'we tried this and it did not work' and 'this treatment is very effective'. Further investigation all too often reveals that the statements are not based on statistically rigorous field data. Without knowing exact yield, quality and disease losses it is hard to accurately quantify the effect of different disease-management practices. Therefore, the second hurdle encountered is a shortage of comparative field data, which seriously hampers making choices between different disease-control methods.

The third hurdle is linked to this; it is the lack of baseline data against which the effectiveness of newly introduced disease-management strategies can be compared.

## Phytophthora in Southeast Asia

As part of the ACIAR projects that contributed results for this monograph, a workshop was held in Chiang Mai in November 2002, supported by the Thailand Department of Agriculture, ACIAR and the ATSE Crawford Fund. This workshop was the first ever regional meeting on phytophthora in Southeast Asia and provided an excellent networking opportunity for all involved. The aims of the meeting were:

- to review information on the occurrence, impact, species diversity and management of *Phytophthora* pathogens in Southeast Asia and make recommendations for future research
- to review the aetiology and management of fruit rot, patch canker and dieback of durian (*Durio* spp.) caused by *Phytophthora*
- to provide recommendations for the integrated management of phytophthora disease, using durian as a case study.

Based on the field visits, research, field experiments, discussion and the outcomes of the aforementioned workshop towards the end of the project, a number of overall conclusions were reached (Table 9.1).

Table 9.2 lists, in the left-hand column, the needs identified in the original project documentation and

**Table 9.1** *Phytophthora* in Southeast Asia: critical issues and solutions identified by two ACIAR projects.

<i>Phytophthora</i> is widespread in Southeast Asia.
Numerous <i>Phytophthora</i> species are involved.
Economic damage is high and needs to be quantified.
<i>Phytophthora</i> epidemics are explosive in favourable weather conditions.
<i>Phytophthora palmivora</i> is the most commonly recorded species and occurs on many hosts.
<i>Phytophthora nicotianae</i> is an important pathogen on many hosts.
<i>Phytophthora cinnamomi</i> is important only in tropical highlands.
<i>Phytophthora infestans</i> is important on potatoes and tomatoes in tropical highlands.
Early detection of symptoms is important for disease control.
The epidemiology of only a few species is understood.
The role of insects as vectors in spread and infection is poorly understood.
Host specificity of <i>Phytophthora palmivora</i> towards the various crops is poorly understood.
The effect of intercropping of hosts susceptible to <i>P. palmivora</i> is poorly understood.
The diversity within <i>Phytophthora palmivora</i> and its centre of origin is unknown.
Some serious pathogens, such as <i>Phytophthora megakarya</i> and <i>P. ramorum</i> , have not been detected in Southeast Asia.
There are numerous disease problems in Southeast Asia on a wide range of minor crops which may be caused by <i>Phytophthora</i> and are in need of further investigation.
There is a need for development and implementation of integrated disease-control methods for a wide range of disease problems in the region.

during the course of both ACIAR projects. Activities to provide a solution to those needs are listed in the right-hand column.

### Future Research Priorities Concerning *Phytophthora*

Although both projects addressed some of the needs outlined in Table 9.2, there is clearly an enormous need to tackle some of the most devastating diseases in a wide range of crops in the tropics. In this monograph, durian has been used as an example of how to develop and implement effective integrated disease management practices. While each crop has its own specific problems and needs, the following general advice should aid the setting of research priorities that apply to a wide range of crops:

- encourage regional and international collaboration to detect and identify sources of resistance towards phytophthora diseases

- focus on screening and selection programs to identify germplasm of crops suitable for the each growing region
- critically evaluate the aims of breeding programs that too often focus strongly on yield, ignoring the reality that yield potential is hardly ever a constraint for the smallholder, whose yields are much more likely to be constrained by the lack of inputs and high levels of diseases and pests
- need to identify good source of resistance and protection of wild germplasm of crop plant species and their relatives
- need for robust tests for disease-resistance screening of local materials and breeding lines
- more research is needed on disease complexes such as yield declines and replanting diseases
- need to collect and disseminate comparative field data of food crops and identify constraints to profitability by smallholders.
- attention to nursery hygiene for tree crops

**Table 9.2** Needs concerning *Phytophthora* in Southeast Asia and solutions provided by ACIAR projects PHT/1995/134 and PHT/1996/193.

Needs	Solutions
Training in all aspects of <i>Phytophthora</i> biology and disease control	Start-up workshop Hands-on training Field trips Field experiments Workshop in Chiang Mai Practical guide to detection and identification of <i>Phytophthora</i>
Training in development and implementation of disease management practices	Through nursery and field visits, field experiments, extension activities and uptake of recommendations by farmers, a significant improvement of disease control in durians has been achieved.
Focus on integrated disease management	Through discussions, farmer field visits, workshops and extension activities both projects had a strong practical focus on implementation of disease-control strategies.
Improve accessibility of information	This monograph reviews a large proportion of the information from the collaborating countries and makes it available to all project collaborators and others. Lists of recent theses on <i>Phytophthora</i> submitted in Thailand have been collated.
Accurate species identification	Close to 500 species identifications were performed in the survey project.
Occurrence of <i>Phytophthora</i> species in Southeast Asia	Tabulation of <i>Phytophthora</i> records in the country reports in this monograph.
Disease records, reference strains and collections	Disease records published as part of this monograph and strains lodged in BRIP Brisbane and information made available to relevant country.
Coordination of government and international research institute programs	Both ACIAR projects involved a large number of collaborators from many different organisations working on the same problems. This unique networking opportunity forms the basis for further collaboration in the future.
Networking	A website established at the University of Melbourne for the durian project. Regular contact by email between the participants in the various countries.
<i>Phytophthora</i> management in forests	Solutions are needed but they were not covered in these projects.

- projects on the development of integrated disease and pest management
- focus on development and adoption of appropriate technologies based on sound principles of integrated disease management
- follow up on reports of emerging phytophthora diseases in crops including longan, mango, mangosteen and coffee.

### Thoughts on the Challenges of International Research Projects

In order to improve the uptake of research findings and make the outcomes of international collaborative projects available as widely as possible a clear focus is needed. Projects should:

- clearly define practical problems at the local level
- foster partnerships and establish an effective and experienced project team committed to finding solutions to the problem
- take into account the profitability and risk exposure of local growers
- find effective and realistic solutions which address the real need and the real problem
- involve all players in the chain of production, processing, transport and marketing in the form of a stakeholder platform
- focus on implementation and adoption of the research findings and solutions to the target group
- ensure the collection of comparative field data to form a foundation to build upon
- establish benchmarks for performance comparisons
- include long-term training that enables the formation of enduring partnerships
- deliver long-term benefits.

The success of any project is highly dependent on how well the problem is defined at the start of the work. Funding agencies, policy makers and governments need to make difficult choices about resource allocation to priorities and problems they want to address. With a plethora of problems in agricultural production it would make sense to focus on the problems that cause most significant losses. This immediately leads to the question of who decides what is significant and how they define it. Defining priorities can further complicate decision-making. Priorities can be defined in economic terms, food-security terms, impacts on smallholders, or long-term development goals for the country, among others.

An important question to consider is: What difference will it make if the team successfully conducts the project, implements the findings and

gets good adoption by the local growers? In such an analysis one needs to assess positives and negatives. Hence, stakeholders should evaluate projects on the basis of the potential positive impacts they may bring, and carefully weigh these up against negative impacts.

Finding solutions to problems within the constraint of available resources and time is essential. It is important that projects be set up and planned in such a way that they are realistic, achievable and provide a foundation for future improvement. It is also important to consider if the solution can be widely applied to other crops and regions. There is always a temptation to conduct projects in a number of regions simultaneously, but it may be wiser and more efficient to show that the solution works in one region before attempting to implement it elsewhere.

Once the problem is defined, the search for an effective project team with a track record of delivery of outcomes is needed to implement the solutions. There has to be a reappraisal of the value of spending scarce research dollars on fashionable, highly advanced and expensive research that is typically never implemented due to its high cost and marginal benefit. Priority should be given to implementing practical solutions based on existing technology. Researchers do not need to pursue glamorous technological solutions if simple and low-key technological solutions are effective. The delivery of the research outcomes that benefit large numbers of smallholders should be a high priority.

It is important to obtain field data on an ongoing basis. Without field data – simply defined here as yield, quality, disease loss, price, price of inputs and farmer income and farming profitability – project teams cannot measure long-term improvements in production, quality and profitability. Hence, it is important to work as colleagues to capture this information on an ongoing basis to provide a benchmark against which to measure gains. Experimental scientists working in tropical countries need to have the ability and confidence to conceptualise, design, execute and interpret field experiments.

There has to be a significant improvement in agricultural income and profitability to bridge the gap between the countryside and the city in many developing countries. Donors and project teams have to be careful not to burden people in developing countries through overly optimistic expectations of biotechnology or notions of farming with no inputs, sometimes confused with organic farming. In order to stop land degradation and the

ever-increasing land areas needed to feed the world's population, a rapid and sustainable increase in productivity and profitability is needed from the agricultural land already under cultivation.

Any organisation commissioning international agricultural research projects involving developing countries should have a strong focus on fostering implementation of the findings. Without implementation and adoption of the outcomes, research into disease management is futile. However, donors have to be extremely careful that they support initiatives that lead to implementation of the right solution, and in order to find the best solutions they must foster partnerships that can deliver what the country and industry need.

The training through partnership with scientists from developing countries was an important aspect of our projects. All-round training in science coupled with hands-on field experience is needed now more than ever. In an effort to make a significant contribution to one of the main challenges of the 21st century — food supply and food security — this

generation needs to train the next generation of scientists and provide them with hands-on experience in complex technical or biological areas.

In order for young scientists from developing countries to become an asset to their own country, they often need a mentor with accumulated practical experience in science and field experimentation, and a capability to implement effective solutions. Ideally, agricultural research training should include hands-on training in the form of internships with experienced researchers or mentors, over a long period. In order to facilitate and support such an endeavour, a partnership program may be needed whereby research organisations involved in the same research field form a bilateral link and exchange staff and students to form effective and long-term partnerships. It is important that project leaders have hands-on experience of working in the facilities and with the extension staff of organisations in developing countries, so as to fully understand the challenges of working in a resource-limited environment.

# Appendix

## Table of *Phytophthora* pathogens and hosts in Southeast Asia



Table of *Phytophthora* pathogens and hosts in Southeast Asia

<i>Phytophthora</i> species	Host	Disease <sup>a</sup>	Country	Pages referred to in this monograph
<i>P. arecae</i> (Coleman) Pethybridge	Coconut ( <i>Cocos nucifera</i> L.)	Bud rot and nut fall Bud rot and fruit rot	Indonesia Philippines	78 117
<i>P. botryosa</i> Chee	Rubber ( <i>Hevea brasiliensis</i> Meull. Arg.)	Leaf fall and pod rot Black stripe Leaf fall and black stripe	Malaysia Thailand Vietnam	61, 62 79 88
<i>P. cactorum</i> (Lebert and Cohn) Schröeter (= <i>P. omnitrova</i> de Bary)	Apple ( <i>Malus pumila</i> Mill.) Avocado ( <i>Persea americana</i> Mill.) Cocoa ( <i>Theobroma cacao</i> L.) Plum ( <i>Prunus salicina</i> Lindl.)	Collar rot Root rot and stem canker Oriental cocoa pod disease Black spot and fruit rot	Indonesia Indonesia Philippines Vietnam	71 71 91 84, 87, 88
<i>P. capsici</i> Leonian (= <i>P. palmivora</i> MF4)	Black pepper ( <i>Piper nigrum</i> L.)	Foot rot Foot rot Foot rot Root and stem rot Fruit rot Crown and root rot –	Malaysia Indonesia Vietnam Thailand Indonesia Philippines Thailand	60, 66 70, 132–134, 171–173 84 77, 78 71 91 138
<i>P. cinnamomi</i> Rands	Rubber ( <i>Hevea brasiliensis</i> Meull. Arg.) Cinchona ( <i>Cinchona ledgeriana</i> Moens and <i>C. succirubra</i> Pav. Ex. Klotzsch Cinnamon ( <i>Cinnamomum burmannii</i> (Nees) Blume) Pineapple ( <i>Ananas comosus</i> (L.) Cinchona ( <i>Cinchona calisaya</i> Wedd.)	Root rot and dieback Bark canker Bark canker Heart rot Seedling dieback	Malaysia Indonesia Indonesia Vietnam Indonesia	61, 62 70, 71 70, 71 84–86 71
<i>P. citricola</i> Sawada	Citrus ( <i>Citrus</i> spp.)	Foot rot, gummosis and brown rot Gummosis and fruit rot Crown and root rot Crown and root rot	Philippines Vietnam Philippines Philippines	91 86 91 91
<i>P. colocasiae</i> Raciborski	Betel vine ( <i>Piper betle</i> L.) Yam/taro ( <i>Colocasia esculenta</i> (L.) Schott.)	– – Leaf blight – –	Malaysia Malaysia Indonesia Vietnam Philippines	61–62 61–62 71 84–85 91
<i>P. heveae</i> Thompson	Cocoa ( <i>Theobroma cacao</i> L.) Rubber ( <i>Hevea brasiliensis</i> Meull. Arg.) Santol ( <i>Sandoricum koetjape</i> Merr.)	Pod disease – Crown and root rot	Malaysia Malaysia Philippines	61–62 61–62 91
<i>P. infestans</i> (Mont.) de Bary	Potato ( <i>Solanum tuberosum</i> L.)  Tomato ( <i>Lycopersicon esculentum</i> Mill.)	Late blight Late blight – Late blight Late blight – Late blight	Malaysia Indonesia Thailand Philippines Vietnam Malaysia Indonesia	61–62 71 78 91 83–84 61–62 71

(Cont'd) Table of *Phytophthora* pathogens and hosts in Southeast Asia

<i>Phytophthora</i> species	Host	Disease <sup>a</sup>	Country	Pages referred to in this monograph
<i>P. meadii</i> McRae	Betel ( <i>Piper betle</i> L.) Cocoa ( <i>Theobroma cacao</i> L.) Rubber ( <i>Hevea brasiliensis</i> Meull. Arg.)	- Pods Black thread - -	Malaysia Malaysia Philippines Malaysia Thailand	61 63 91 61, 137-139 78
<i>P. nicotianae</i> Breda de Haan = <i>P. parasitica</i> Dastur = <i>P. nicotianae</i> var. <i>nicotianae</i> = <i>P. nicotianae</i> Breda de Haan var. <i>parasitica</i> (Dastur) G.M. Waterhouse = <i>P. melongenae</i> Sawada	Betel ( <i>Piper betle</i> L.) Brinjal ( <i>Solanum melongena</i> L.) Citrus ( <i>Citrus</i> spp.)  Coconut ( <i>Cocos nucifera</i> L.) Durian ( <i>Durio zibethinus</i> Murr.)  Eggplant ( <i>Solanum melongena</i> L.) Guava ( <i>Psidium guajava</i> L.)  Longan ( <i>Euphoria longana</i> Lam.) Orchid ( <i>Vanda</i> spp.) Papaya ( <i>Carica papaya</i> L.)  Passionfruit ( <i>Passiflora edulis</i> Sims.) Pepper ( <i>Piper nigrum</i> L.)  Periwinkle ( <i>Vinca rosea</i> L.) Pineapple ( <i>Ananas comosus</i> (L.)	- - Foot and root rot Root and fruit rot Stem canker Root rot and gummosis Bud rot and nut fall Root rot and canker Fruit rot Fruit rot Leaf blight Root rot - Blight and fruit rot Fruit, collar and root diseases - Root and stem rot Crown and root rot - - - - Heart rot and wilt Heart rot and root rot Heart rot Wilt Black foot rot - - Black shank Black shank Pod rot Rot	Malaysia Malaysia Thailand Vietnam Philippines Indonesia Thailand Malaysia Philippines Indonesia Malaysia Thailand Malaysia Philippines Malaysia Thailand Philippines Malaysia Thailand Philippines Indonesia Vietnam Malaysia Indonesia Malaysia Malaysia Indonesia Vietnam Indonesia Philippines	61-62 61-62 61, 62 77-78 84, 86 91 73 78 143 91-92 71 61 78 61 91 61 61 77-78 91 66 132 61 78 91-92 71 84-86 61-62 71 61-62 61 71 71 84 84 71 91
	Rosella ( <i>Hibiscus sabdarifra</i> L.)  Scarlet sage ( <i>Salvia splendens</i> Sellow ex Roemer & J.A. Schultes) Strawberry ( <i>Fragaria</i> sp.) Tobacco ( <i>Nicotiana tabacum</i> L.)  Vanilla ( <i>Vanilla planifolia</i> Andrews) Watermelon ( <i>Citrullus lanatus</i> Schrad.)			

(Cont'd) Table of *Phytophthora* pathogens and hosts in Southeast Asia

<i>Phytophthora</i> species	Host	Disease <sup>a</sup>	Country	Pages referred to in this monograph
<i>Phytophthora palmivora</i> Butler (syn. <i>P. fiberei</i> Maubl.)	Avocado ( <i>Persa americana</i> Mill.)	Crown and root rot	Philippines	91
	Citrus ( <i>Citrus</i> spp.)	Blight	Philippines	91
Cocoa ( <i>Theobroma cacao</i> L.)		Gummosis	Indonesia	71
		Black pod	Malaysia	61, 62
Coconut ( <i>Cocos nucifera</i> L.)		Pod rot, stem and cushion cankers, leaf, chupon and seedling blights and sudden death	Indonesia	11, 71, 72
		Black rot and stem canker	Philippines	91
		Pod rot	Thailand	77, 78
		Fruit rot	Vietnam	84
		Bud rot and premature nut fall	Indonesia	73
		Bud rot and premature nut fall	Philippines	91, 116, 124
		Nut drop	Thailand	78
		Stem canker	Vietnam	84
		Trunk and root rot, patch canker	Malaysia	60-62
		Patch canker	Indonesia	71
Durian ( <i>Durio zibethinus</i> Murr.)		Trunk canker, root, stem and fruit rot	Thailand	53, 77
		Crown and root rot	Philippines	91
		Root and fruit rot, stem canker and leaf blight	Vietnam	84
		Crown and root rot		84, 87
		Crown and root rot	Philippines	91
		Crown and root rot	Philippines	91
		Crown and root rot	Philippines	91
		Crown and root rot	Philippines	91
		Root rot	Thailand	78
		-	Thailand	78
Jackfruit ( <i>Artocarpus</i> spp.)		Crown and root rot	Philippines	91
		Crown and root rot	Philippines	91
		Crown and root rot	Philippines	91
		Crown and root rot	Philippines	91
		Crown and root rot	Philippines	91
		Root rot	Thailand	78
		-	Thailand	78
		Crown and root rot	Philippines	91
		Crown and root rot	Philippines	91
		Black rot	Philippines	91
Mango ( <i>Mangifera indica</i> L.)		-	Malaysia	61, 62
		Crown and root rot	Indonesia	71
		Crown and root rot	Indonesia	71
		Black rot	Malaysia	61, 62
		Black rot	Malaysia	61, 62
		Root, collar and fruit rot	Philippines	91
		Fruit rot	Philippines	91
		Root and fruit rot	Indonesia	71
		Sudden death	Malaysia	61
		Root rot	Thailand	77, 78
-	Thailand	78		
Kamansi ( <i>Artocarpus camansi</i> Blanco)		Jackfruit ( <i>Artocarpus</i> spp.)		
		Kamansi ( <i>Artocarpus camansi</i> Blanco)		
		Lanzones ( <i>Lansium domesticum</i> Corréa)		
		Longan ( <i>Euphoria longana</i> Lam.)		
		Mango ( <i>Mangifera indica</i> L.)		
		Mangosteen ( <i>Garcinia mangostana</i> L.)		
		Neem ( <i>Azadirachta indica</i> A. Juss.)		
		Orchid ( <i>Phalaenopsis</i> spp.)		
		Orchid ( <i>Vanida</i> spp.)		
		Papaya ( <i>Carica papaya</i> L.)		
Pepper ( <i>Piper nigrum</i> L.)		Pepper ( <i>Piper nigrum</i> L.)		
		Pineapple ( <i>Ananas comosus</i> (L.)		

(Cont'd) Table of *Phytophthora* pathogens and hosts in Southeast Asia

<i>Phytophthora</i> species	Host	Disease <sup>a</sup>	Country	Pages referred to in this monograph
<i>Phytophthora palmivora</i> Butler (syn. <i>P. faberi</i> Maubl.) - cont'd	Cinchona ( <i>Cinchona calisaya</i> Wedd.)	Seedling blight	Philippines	91, 92
	Rubber ( <i>Hevea brasiliensis</i> Meull. Arg.)	Leaf fall and black stripe	Thailand	78
		Leaf fall and black stripe	Vietnam	88
		Canker and black rot of fruit	Philippines	91
		Black stripe and patch canker	Malaysia	60, 62
		Black stripe and leaf fall	Indonesia	71
	Soursop ( <i>Annona muricata</i> L.)	Crown and root rot	Philippines	91
	Tamarind ( <i>Tamarindus indica</i> L.)	Crown and root rot	Philippines	91
	Vanilla ( <i>Vanilla</i> spp.)	Black rot	Thailand	78
	<i>P. phaseoli</i> Thaxt.	Santol ( <i>Sandoricum koejape</i> Merr.)	Leaf blight	Philippines
<i>Phytophthora</i> sp.	Avocado ( <i>Persea americana</i> Mill.)	-	Malaysia	61
	Citrus ( <i>Citrus</i> spp.)	Gummosis and fruit rot	Vietnam	84
	Longan ( <i>Euphoria longana</i> Lam.)	Fruit rot and leaf blight	Vietnam	84
	Pepper ( <i>Piper nigrum</i> L.)	-	Malaysia	62
	Rubber ( <i>Hevea brasiliensis</i> Meull. Arg.)	-	Malaysia	62
		Stem canker	Vietnam	84
	Ziziphus ( <i>Zizyphus mauritania</i> )	Fruit rot	Vietnam	84

<sup>a</sup> - = no specific disease identified.