Pao-Jen Ann
Taiwan Agricultural Research Institute, Taichung, Taiwan

Tun-Tschu Chang
Taiwan Forestry Research Institute, Taipei, Taiwan

Wen-Hsiung Ko
University of Hawaii at Manoa, Hilo, HI

Phellinus noxius Brown Root Rot of Fruit and Ornamental Trees in Taiwan

In 1985, the third author (W. H. Ko) noticed unusually high mortality of some fruit trees in residential areas in southern Taiwan. Tree death appeared to be very sudden, because all the leaves had turned brown but had remained attached to the branches (Fig. 1). In 1987, numerous dying longan trees (*Dimocarpus longan*) were found in the mountain areas of central and southern Taiwan. Trees in the early stages of decline exhibited a brown discoloration of the wood on large roots (Fig. 2). A fast-growing, basidiomycete-like fungus was subsequently isolated from diseased roots, and inoculation studies verified its pathogenicity. However, it was not possible to identify the pathogen at the time because fruiting bodies were not initially found on diseased trees in the field or in laboratory cultures, nor were clamp connections observed on hyphae.

In 1990, Ko found a young, thin, flat, brown basidiocarp with a white margin on an exposed root of a diseased longan tree. He then realized that what looked like dirty bark on the basal stems of some declining trees was in fact remnants of decomposed fruiting bodies of the pathogen (Fig. 3) and that fungal structures previously thought to be mycelial mats on sawdust medium were actually fruiting bodies (Fig. 4). Subsequently, the fungus was identified as *Phellinus noxius* (Corner) G. H. Cunn.

Soon after the report of brown root rot causing serious decline in longan (2), the *P. noxius* pathogen was found to be widespread and destructive on a number of tree species throughout Taiwan. Due to the seriousness of the problem, the Taiwan government created a *Phellinus noxius* Brown Root Rot Diagnosis and Control Information Center in 2000 to address public concern about the disease.

Dr. Ko's address is: Department of Plant and Environmental Protection Sciences, Beaumont Agricultural Research Center, University of Hawaii at Manoa, Hilo, HI 96720; E-mail: kowh@hawaii.edu

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History and Occurrence of the Disease Worldwide

The fungus causing brown root disease of trees was first described in Singapore by Corner in 1932 as *Fomes noxius* (18) and reclassified by Cunningham in 1965 as *Phellinus noxius* (19). Corner speculated that the fungus was the cause of brown root rot of rubber trees and tea bushes. However, attempts to demonstrate pathogenicity of this fungus were not successful until the realization that it requires a food base for successful infection of the host. Bolland (11) inoculated hoop pine (*Araucaria cunninghamii*) by inserting a severed root into a jar containing 250 g of enriched sawdust medium colonized by *P. noxius*. The fungus killed the inoculated root and began to girdle the tree within 6 months.

P. noxius has a wide host range; it has been reported on more than 200 plant species representing 59 families. Although most hosts are woody plants, some herbaceous plants are also susceptible to the pathogen. *P. noxius* is widespread among tropical countries in Southeast Asia, Africa, Oceania, Central America, and the Caribbean (25). It has also been reported from the tropical Hainan Island of China (29). In Japan, the pathogen was found only on the subtropical island of Okinawa (1). In Taiwan, it has been found in both tropical and subtropical districts (8,17).

Fig. 1. Quick decline of a 6-year-old longan tree (*Dimocarpus longan*) resulting from brown root rot caused by *Phellinus noxius*.

The Pathogen

P. noxius is a fast-growing organism. The linear growth rate can be 35 mm/day on potato dextrose agar (PDA) at 30°C (4,7). The fungus produces a brown colony on PDA with irregular dark brown lines or patches permeating the culture (Fig. 5). Arthrospores (Fig. 6) and trichocysts (Fig. 7), but not clamp connections, are commonly produced in culture. When grown on sawdust medium, *P. noxius* produces thin, hard, uneven basidiocarps (Fig. 4) similar to those found in nature. They are initially yellowish-brown with a white margin and later become brown and then dark gray. In addition to basidiospores,

Fig. 2. A large longan root with brown discoloration caused by *Phellinus noxius*.

there are scant hymenial setae and narrow setal hyphae inside the basidiocarp, which distinguish *P. noxius* from the closely related species of *Phellinus lamaensis* (*Fomes lamaensis*) (25).

P. noxius is a high-temperature organism with optimal growth near 30°C and none at 8°C. This may explain the geographic restriction of this pathogen to tropical and subtropical regions. The fungus prefers acidic conditions and is capable of growth at a pH as low as 3.5. Growth is completely inhibited at a pH of 7.5 (7).

Hosts and Geographic Distribution in Taiwan

Brown root rot caused by *P. noxius* was reported in Taiwan by Sawada as early as 1928 (26). The fungus was identified as *Fomes lamaensis,* which he later considered to be a synonym of *Fomes noxius* (27). Initially, Sawada did not find the fruiting bodies of *P. noxius,* so the identification was based on the symptom of brown rot on roots. The 18 hosts (Table 1) he found were located in northern, central, and southern Taiwan. His report remained essentially unnoticed until 1991, when the fungus became a serious threat to the cultivation of certain fruit trees (2–4). Among the approximately 200 plant species listed as hosts of *P. noxius* in the world, about half of them were reported for the first time from Taiwan (Table 1). Most of the hosts found in Taiwan are woody fruit and ornamental trees. Only seven species are herbaceous plants.

Not all hosts listed in Table 1 have been proven experimentally to be susceptible to *P. noxius*. Prior to 1992, most species of plants were reported as hosts of *P. noxius* without completion of Koch's postulates. We employed a simple inoculation technique developed by Ko et al. (22) to demonstrate pathogenicity. The method consisted of culturing *P. noxius* in a wheat–oat medium and wrapping approximately 5 g of the colonized medium with a sheet of clear plastic around the lightly scraped stem or taproot (4). Successful pathogenicity tests have now been accomplished with this method for most of the hosts of *P. noxius* reported from Taiwan (4,7,9,13).

In Taiwan, *P. noxius* causes brown root rot on a number of popular tropical fruit crops such as longan, litchi, carambola, loquat, avocado, and sugar apple (Table 1). Some persimmon, peach, pear, plum, and grape cultivars were also attacked by the pathogen in subtropical areas. The disease causes considerable losses to growers each year. Due to its wide host range, most of the tree species used in ornamental landscape plantings are susceptible to brown root rot. *P. noxius* causes decline and death of ornamental trees planted on campuses, sightseeing places, and parks, and around private and public buildings (Figs. 8 and 9).

Fig. 3. Basal stem of a longan tree (*Dimocarpus longan*) with remnants of old decomposed fruiting bodies of *Phellinus noxius*.

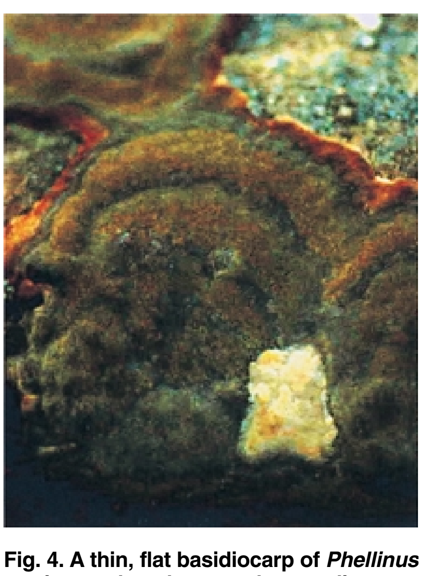

Fig. 4. A thin, flat basidiocarp of *Phellinus noxius* produced on sawdust medium.

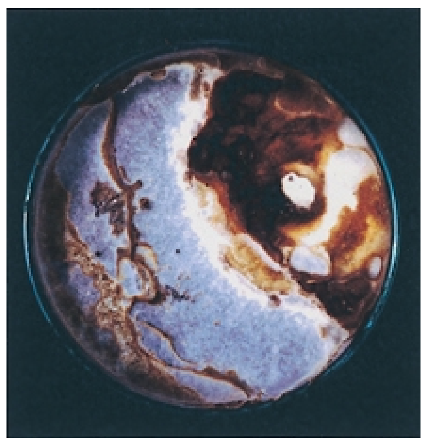

Fig. 5. Colony of *Phellinus noxius* on potato dextrose agar with irregular dark brown lines or patches permeating the culture.

Fig. 6. Arthrospores of *Phellinus noxius* produced on potato dextrose agar.

Fig. 7. Trichocysts of *Phellinus noxius* produced on potato dextrose agar.

Fig. 8. A 5-year-old golden shower tree (*Cassia fistula*) killed by *Phellinus noxius* in a park.

Fig. 9. A camphor tree (*Cinnamomum camphor*) killed by *Phellinus noxius* in front of a residential house.

Brown root rot has been found in every county on the island of Taiwan (Fig. 10) but not in mountainous areas above 1,000-m elevation, even though there are numerous susceptible hosts in those areas (17). Apparently the cold winter in these areas is detrimental to disease development (7).

The distribution of *P. noxius* in Taiwan appears to be limited to areas with human activity. Brown root rot has never been found in undisturbed natural forests, suggesting that the pathogen is not indigenous to Taiwan. Since the late nineteenth century, numerous fruit and ornamental trees originating from Southeast Asia have been introduced into Taiwan for planting in residential areas and in the Kentin Tropical Botanical Garden in southern Taiwan (24). It is probable that *P. noxius* was introduced into Taiwan on diseased roots of these exotic tree species.

Symptoms and Development of the Disease

Brown root rot may occur on trees of all ages. Disease development in most tree species is rapid (8). Foliage on a diseased tree may change from normal color to pale green to brown within 1 or 2 months (Fig. 1). This rapid tree death commonly is referred to as quick decline. Some tree species may bloom luxuriantly the year before the onset of quick decline symptoms. For example, flame trees (*Delonia regia*) nor-

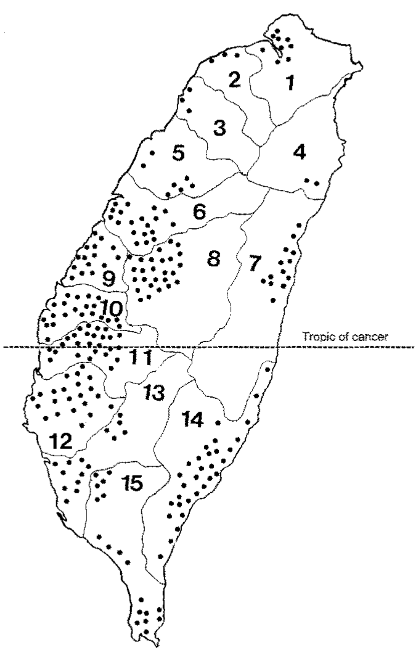

Fig. 10. Geographic distribution of *Phellinus noxius* in Taiwan. Each point represents a combination of host and locality. Each number represents one of the following counties: 1, Taipei; 2, Tao Yuan; 3, Hsin Chu; 4, I Lan; 5, Miao Li; 6, Taichung; 7, Hua Len; 8, Nan Tow; 9, Chang Hua; 10, Yun Lin; 11, Chia Yi; 12, Tainan; 13, Kaohsiung; 14, Taitung; 15, Pingtung.

Table 1. List of host records of *Phellinus noxius* in Taiwan

Scientific name (common name)	Year first reported (or found)	Reported (or found) as new disease	Citation
Fruit trees			
1. *Annona montana* (mountain soursop)	1996	+[a]	6,8
2. *Annona squamosa* (custard apple)	1991	+	3,7,23
3. *Annona squamosa* × *A. cherimola* (atimoya)	(1994)	+	U[b]
4. *Artocarpus heterophyllus* (jack fruit)	1998	+	17
5. *Averrhoa carambola* (carambola)	1991	+	3,7
6. *Dimocarpus longan* (longan)	1928	+	4,26
7. *Diospyros kaki* (persimmon)	1994	+	5,7
8. *Elaeocarpus serratus* (Ceylon olive)	1998	+	17
9. *Eriobotrya japonica* (loquat)	1991	+	3,7
10. *Ficus pumila* var. *awkeotsang* (jellyfig)	1991	+	7,23
11. *Litchi chinensis* (litchi)	1991	+	3,7
12. *Muntingia calabura* (Indian cherry)	(1997)	+	U
13. *Pachira macrocarpa* (malabar chestnut)	1991	+	8,23
14. *Persea americana* (avocado)	(1988)	–	U
15. *Prunus mume* (Japanese apricot, plum)	1991	+	3,7,12
16. *Prunus persica* (peach)	1999	+	8
17. *Pyrus pyrifolia* (pear)	1991	+	7,23
18. *Syzygium samarangense* (wax apple)	1992	+	4,7
19. *Sterculia nobilis* (ping-pong)	1991	+	8,23
20. *Vitis vinifera* (grape)	1996	+	6,7
Ornamental trees			
21. *Acacia confusa* (Taiwan acacia)	1995	–	14
22. *Actinodaphne pedicellata* (litsea)	1928	+	26
23. *Aleurites fordii* (tungoil tree)	1998	+	17
24. *Alstonia scholaris* (blackboard tree)	1998	+	17
25. *Araucaria cunninghamii* (hook pine)	1998	–	17
26. *Araucaria heterophylla (*Norfolk Island pine)	1998	+	17
27. *Bauhinia* × hybrid (butterfly-tree)	1996	+	6,8
28. *Bauhinia purpurea* (purple bauhinia)	1996	+	6,8
29. *Bauhinia variegata* (orchid-tree)	1942	+	17,27
30. *Bischofia javanica* (autumn maple tree)	1928	+	17,26
31. *Bombax ceiba* (silk cotton)	1998	+	17
32. *Broussonetia kazinoki* (small paper mulberry)	(1998)	+	U
33. *Broussonetia papyrifera* (paper mulberry)	(1998)	+	U
34. *Calocedrus formosana* (Taiwan incense cedar)	(1998)	+	U
35. *Calophyllum inophyllum* (Indian poon beauty leaf)	1995	–	17
36. *Camellia japonica* (camellia)	1998	+	17
37. *Cassia fistula* (yellow golden shower tree)	1998	+	17
38. *Casuarina equisetifolia* (ironwood tree)	1995	–	17
39. *Ceiba pentandra*	(1998)	–	U
40. *Cerbera manghas* (odollam cerberus tree)	(1998)	+	U
41. *Chamaecyparis formosensis* (Taiwan red cypress)	(1998)	+	U
42. *Chorisia speciosa* (floss silk tree)	1999	–	8
43. *Chrysalidocarpus lutescens* (yellow areca palm)	(1999)	+	U
44. *Cinnamomum kanehirai* (stout camphor)	1998	+	17
45. *Codiaeum variegatum* (croton)	1928	–	26
46. C*ryptocarya concinnai* (Konishi crytocarya)	(1998)	+	U
47. *Cycas taiwaniana* (Taiwan cycas)	1991	+	12,13
48. *Dalbergia sissoo* (sissoo tree)	1928	+	26
49. *Delonix regia* (flame tree)	1991	–	12,13
50. *Diospyros ferrea* var. *buxifolia* (Philippine ebony persimmon)	(2000)	+	U
51. *Diospyros oldhamii* (oldham persimmon)	(2000)	+	U
52. *Duranta repens* (creeping sky flower)	1928	+	8,26
53. *Eucalyptus camaldulensis* (murray red gum eucalyptus)	1991	+	12,13
54. *Eucalyptus citriodora* (lemon gum eucalyptus)	1991	+	12,13
55. *Eucalyptus grandis* (maiden eucalyptus)	1991	+	12,13
56. *Ficus elastica* (rubber plant)	1998	+	17
57. *Ficus microcarpa* (small-leafed banyan)	1995	+	14
58. *Ficus religiosa* (botree fig)	1996	+	6,8

(*continued on next page*)

[a] +, first reported (or found) worldwide; –, first report was not from Taiwan.
[b] U, unpublished.

Table 1. (*continued from preceding page*)

Scientific name (common name)	Year first reported (or found)	Reported (or found) as new disease	Citation
59. *Firmiana simplex* (Chinese parasol)	1998	+	17
60. *Fraxinus formosana* (island ash)	1998	+	17
61. *Gardenia jasminoides* (cape jasmine)	1928	+	26
62. *Grevillea robusta* (silver oak)	1996	–	6,8
63. *Hibiscus rosa-sinensis* (hibiscus)	1996	–	6,8
64. *Hibiscus schizopetalus* (fringed hibiscus)	1928	+	26
65. *Hibiscus tiliaceus* (linden hibiscus)	1998	–	17
66. *Hydrangea chinensis* (Chinese hydrangea)	1928	+	26
67. *Keteleeria davidiana* var. *formosana* (Taiwan keteleeria)	1998	+	17
68. *Kigelia pinnata* (sausage tree)	1999	+	8
69. *Koelreuteria henryi* (flame gold rain tree)	1995	+	14
70. *Lagerstroemia turbinata* (crape myrtle)	1998	+	17
71. *Lagerstroemia speciosa* (queen's crape myrtle)	1996	+	6,8
72. *Lantana camara* (lantana)	1998	+	17
73. *Leucaena leucocephala* (white popinac)	1998	–	17
74. *Liquidambar formosana* (maple)	1991	+	12,17
75. *Litsea glutinosa*	1998	+	17
76. *Litsea hypophaea*	1928	+	26
77. *Macaranga tanarius* (macaranga)	1998	+	17
78. *Machilus zuihoensis* (incense machilus)	1928	+	26
79. *Maesa tenera* (Taiwan maesa)	1928	+	26
80. *Mallotus paniculatus* (turn in the wind)	(2000)	+	U
81. *Melaleuca leucadendron* (cajuput tree)	1996	+	6,8
82. *Melia azedarach* (China berry)	1928	–	26
83. *Melodinus angustifolius* (narrow leafed melodinus)	(1999)	+	U
84. *Michelia compresa* (Formosan michelia)	1998	+	17
85. *Michelia figo* (banana magnolia)	1996	+	6,8
86. *Muntingia calabura*	(1998)	+	U
87. *Murraya paniculata* (orange jasmine)	1928	+	13,26
88. *Neolitsea parvigemma* (small bud neolitsea)	(2000)	+	U
89. *Nerium oleander* (oleander)	1998	+	17
90. *Palaquium formosanum* (Formosan nato tree)	1998	+	17
91. *Pinus thunbergii* (black pine)	1998	+	17
92. *Pistacia chinensis* (Chinese pistache)	1998	+	17
93. *Podocarpus macrophyllus*	1995	–	14
94. *Pongamia pinnata* (pongamia)	1998	+	17
95. *Pterocarpus indicus* (rose wood)	1998	–	17
96. *Prunus campanulata* (Taiwan cherry)	1999	+	8
97. *Osmanthus fragrans* (sweet osmanthus)	(1998)	+	U
98. *Rhododendron obtusum* (rhododendron)	(1998)	+	U
99. *Roystonea regia* (royal palm)	1996	+	6,8
100. *Salix babylonica* (willow)	1995	+	14
101. *Scheffera octophylla* (scheffera)	(1999)	+	U
102. *Sterculia foetida* (hazel sterculia)	1999	+	8
103. *Swietenia mahagoni* (mahogany)	1995	+	14
104. *Tabebuia chrysantha* (yellow golden bell tree)	(2000)	–	U
105. *Taiwania cryptomerioides* (Taiwania)	1998	+	17
106. *Terminalia catappa* (Indian almond)	1996	+	6,8
107. *Terminalia boivinii*	(1998)	+	U
108. *Ulmus parvifolia* (Chinese elm)	1998	+	7
109. *Zelkova serrata* var. *serrat* (zelkova)	1996	+	6,8
Special crops			
110. *Camellia sinensis* (tea)	1965	–	10
111. *Cinnamomum camphora* (camphor)	1928	–	13,26
112. *Cinnamomum zeylanicum* (Ceylon cinnamon)	1998	+	17
113. *Coffea arabica* (coffee)	1943	+	28
114. *Cordia dichotoma* (cordia)	1998	+	17
Herbaceous plants			
115. *Artemisia capillaris* (wormwood)	1998	+	17
116. *Artemisia princeps* (mugwort)	(1997)	+	U
117. *Ipomoea pescaprae*	1998	+	17
118. *Lactuca indica* (wild lettuce)	1998	+	17
119. *Melicope merrilli* (melicope)	1998	+	17
120. *Sauranja oldhami*	1928	+	26
121. *Urena lobata* (cadillo)	1928	+	26

mally bloom sparingly in central Taiwan. However, flame trees with incipient infections often flower profusely in the year preceding quick decline (Fig. 11A and B). Because infection originates from the roots near the basal stem, a large portion of the trunk may have already been invaded by the pathogen before the appearance of decline symptoms. This may reduce the amount of water passing through the trunk to a level insufficient to support the whole tree, thereby triggering the development of flower buds and then the onset of quick decline (20).

Decline symptoms in other trees may occur over periods of a year or more (8) (Fig. 12). This slow decline may be the result of root infections originating at greater distances from the trunk. This progressive root destruction impairs carbohydrate storage and water uptake and results in a more gradual defoliation (21). Host resistance and vigor, and pathogen isolates that are relatively nonaggressive, may also contribute to the slow process of disease development. When greater destruction of the root system by *P. noxius* occurs on one side of the root system, the affected tree may display yellowing and defoliation only on that side of the crown during the early stages of disease development.

Roots infected with *P. noxius* initially exhibit a brown discoloration of the wood just beneath the bark (Fig. 2). In advanced stages of decay, the wood develops a soft, stringy white rot with a conspicuous network of brown zone lines (Fig. 13). The outer bark surface appears rough because it is covered with a layer of adhering soil particles and brown fungal mycelia (Fig. 14). The inner bark is covered with the white to brownish mycelial mat (Fig. 15).

Occasionally, thin, hard and flat basidiocarps are formed on the basal trunks or exposed roots of diseased trees. The conks are initially white with the context gradually turning yellow to brown (Fig. 16). The conks eventually become brownish-gray or dark gray (Fig. 17).

Dissemination and Survival of the Pathogen

The way by which new infection centers of brown root rot are established is still undetermined. It is likely that *P. noxius* is introduced into new areas on trees infected in the nursery and then planted in the landscape. The fungus may then spread to adjacent trees through root-to-root contact (7,11) (Fig. 18). A brown root rot infection center also may arise following colonization of a freshly cut stump by basidiospores (11) (Fig. 18) and then mycelial movement from the stump to surrounding healthy roots. However, this probably is not a common method by which *P. noxius* initiates new disease centers in Taiwan because the fungus rarely produces basidiocarps on diseased trees in the field (8,13,14). Arthrospores produced by *P.*

Fig. 11. A 30-year-old flame tree (*Delonia regia*) in central Taiwan. A, 3 months before the appearance of quick decline; B, after the appearance of quick decline. (courtesy H. Y. Lu)

Fig. 12. Slow decline of a 20-year-old small-leafed banyan tree (*Ficus microcarpa*) resulting from *Phellinus noxius* brown root rot.

Fig. 13. A longan root (*Dimocarpus longan*) showing advanced white rot symptoms caused by *Phellinus noxius*. Note the conspicuous network of brown lines permeating the white and soft wood tissue.

Fig. 14. Outer surface of diseased longan roots (*Dimocarpus longan*) covered with a layer of adhering mixture of soil particles and brownish fungal mycelia of *Phellinus noxius*.

Fig. 15. Inner surface of bark of diseased longan root (*Dimocarpus longan*) covered with a white to brown mycelial mat of *Phellinus noxius*.

noxius in culture are probably not an important source of inoculum in nature because they have never been observed in the field (11).

After tree removal, *P. noxius* can survive in colonized roots remaining in the soil for more than 10 years (15). It can also remain viable as mycelium in the rhizosphere for several months.

Measures for Disease Control

Replanting of susceptible trees in infested soils is not recommended because they may become infected after contact with mycelium in the rhizosphere or in buried roots (2) (Fig. 18). Many soil treatments have been tested and numerous experiments have been performed to find an effective way of eliminating such inoculum. Currently, the most efficient method of destroying the residual inoculum is by flooding the field (15), and the most practical way is to fumigate the infested soil with ammonia generated from urea amended in soil under alkaline conditions (5,16). Another approach is to replant the infested areas with resistant species (9). The recommended replacement species for fruit trees are mango and citrus. For ornamental trees, the locally popular species of *Alstonia scholaris* is recommended. Although *A. scholaris* is listed in Table 1 as a host, inoculation tests show that it is very resistant to *P. noxius* (9).

Current Status and Future Outlook

Besides Taiwan, *P. noxius* is widespread in other parts of Southeast Asia and the

South Pacific (25). Brown root rot may become a serious problem in these regions if a large number of susceptible fruit and ornamental trees were planted in infested areas, or if tree seedlings from infested nurseries were used for agricultural and landscape plantings. Since *P. noxius* attacks a wide range of plant species, more reports concerning the incidence of brown root rot may be expected in these regions in the future.

More information regarding the use of fungicides is needed to slow down and hopefully stop disease development in infected trees next to a dying or dead tree. In this regard, seven of 45 fungicides have been found to be strongly inhibitory to the growth of *P. noxius* in vitro (5). These fungicides were further evaluated for their ability to control the disease in greenhouse experiments. The systemic fungicides triadimefon, prochloraz, and mepronil were found to be nonphytotoxic and effective in reducing disease incidence.

Recently, each of these fungicides was applied to diseased grapevines in the field as a soil drench once every 3 months in combination with a soil amendment containing lime and urea. The treatments appear to be promising, as no further decline or death of grapevines was recorded in the treated plots, while disease progress remained unchecked in the control plot. Thus, it appears likely that fungicides can be useful in managing disease development. Still to be determined is the recurrent rate of brown root rot after the termination of the treatments and the economic feasibility of the treatments.

There is a wide range of susceptibility to brown root rot among different species of the same genus, and among different varieties of the same species (9). Disease resistance needs to be further identified and

Fig. 16. Young fruiting bodies of *Phellinus noxius* produced on a declining longan tree (*Dimocarpus longan*).

Fig. 17. Mature fruiting bodies of *Phellinus noxius* produced on a declining flame tree (*Delonia regia*). (courtesy J. H. Huang)

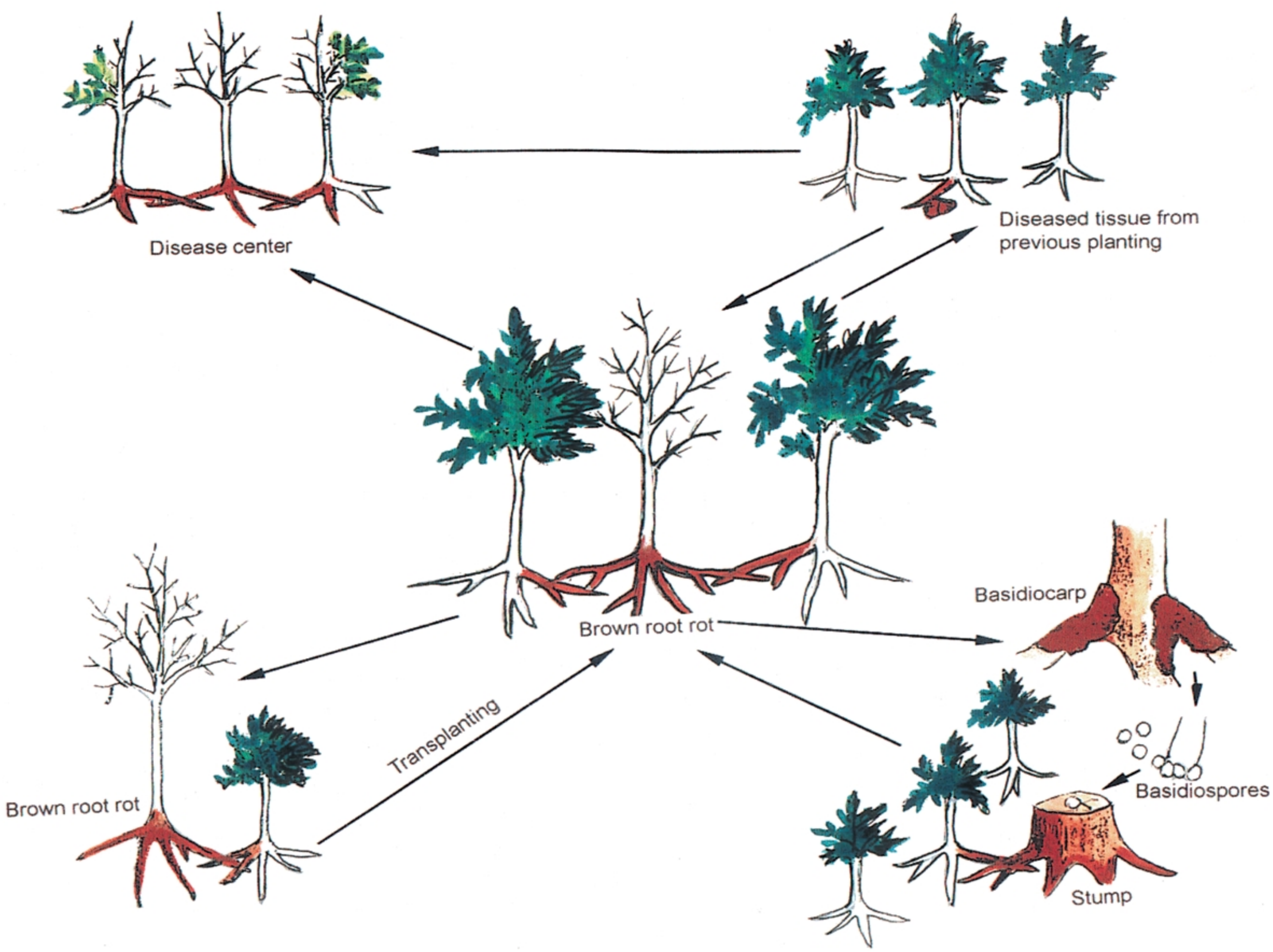

Fig. 18. Diagrammatic illustration of the disease cycle of *Phellinus noxius* brown root rot on susceptible trees.

characterized as a basis for development of commercially acceptable resistant fruit and ornamental trees through conventional breeding and genetic engineering.

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Pao-Jen Ann

Dr. Ann is a senior researcher of the Department of Plant Pathology, Taiwan Agricultural Research Institute, Taichung, Taiwan. She received her B.S. and M.S. degrees from National Taiwan University at Taipei, Taiwan, and her Ph.D. degree from the University of Hawaii. Her current research interests include fungal diseases of fruit trees and etiology and control of diseases caused by species of *Phytophthora*. She received the Agricultural Research and Development Award from the Department of Agriculture and Forestry of Taiwan in 1997.

Tun-Tschu Chang

Dr. Chang is a principal scientist and head of the Forest Protection Division of Taiwan Forestry Research Institute, Taipei, Taiwan. He received B.S. and M.S. degrees from National Taiwan University at Taipei, Taiwan, and his Ph.D. degree from the University of Hawaii. His current research focuses on root diseases of woody trees caused by Basidiomycetes and taxonomy of wood-inhabiting Aphyllophorales. He received the Outstanding Research Award from the National Science Council of Taiwan in 1996.

Wen-Hsiung Ko

Dr. Ko is professor of plant pathology at Beaumont Agricultural Research Center of the University of Hawaii. He received his B.S. degree from National Taiwan University and his Ph.D. degree from Michigan State University. His research interests include ecology and biological control of soilborne diseases of tropical fruit crops and biology of *Phytophthora*. He received the Ruth Allen Award in 1984 from the American Phytopathological Society for his contribution in hormonal regulation of sexual reproduction in *Phytophthora* and is a Fellow of the American Phytopathological Society.