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REVIEW PAPER

Nature of slow and quick decline of macadamia trees

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ABSTRACT. Macadamia which is native to Australia has been grown in commercial scale in many counties after its development into an economic crop in Hawaii in the 1930s. Tree decline is the most serious problem in macadamia plantations. It consists of slow decline resulting from root rot caused by *Kretzschmaria clavus* or *Ganoderma lucidum* and quick decline resulting from trunk decay caused by *Nectria rugulosa*, *Xylaria arbuscula*, *Phellinus gilvus*, *Phytophthora tropicalis*, or *Acremonium recifei.* Inoculum sources and modes of disease development differ due to difference in causal organisms. A diagnostic key for slow and quick decline of macadamia trees is presented.

Keywords: *Acremonium recifei*; *Ganoderma lucidum*; *Kretzschmaria clavus*; *Macadamia integrifolia*; *Nectria rugulosa*; *Phellinus gilvus*; *Phytophthora tropicalis*; *Xylaria arbuscula*; Quick decline; Slow decline.

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INTRODUCTION

Macadamia (*Macadamia integrifolia* Maiden & Betche) is a beautiful, evergreen tree that usually attains a height of 20 m and a crown diameter of 13 m (Figure 1A). Its nuts are renowned as being among world's most delicious. In addition to the popularity of chocolate-covered macadamia nuts, whole kernels of macadamia are sold as oil-roasted or dry-roasted snack nuts while broken kernels are used as an ingredient in ice cream, cookies, bread, cake, pie, muffins, wafers, and fresh vegetable salads.

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Figure 1. Macadamia trees (A), raceme (B), and immature nuts (C).

Macadamia is native to subtropical eastern Australia where many homeowners have planted it around their homes for shade, as a source of nuts, and to enhance the beauty of their properties. The University of Hawaii developed its potential as an economic crop in the 1930s. The number of macadamia farms increased steadily, and macadamia nut has gradually become one of the highest commodities by value in Hawaii. In 1989, a record 22,500 tons of nuts were harvested from approximately 22,300 acres in Hawaii for a record farm value of $44.9 million (Crop Knowledge Master, 2005). The Hawaiian success encouraged other countries to grow macadamia on a commercial scale in the 1950s, and since 1970, the area under cultivation has increased rapidly, with large-scale plantings in many countries including Australia, South Africa, Guatemala, Kenya, Malawi, Costa Rica, Brazil, Mexico, and China (Agroforestry Tree Database, 2006). In 1997, Australia overtook Hawaii to become the world's largest producer of macadamia nuts. The country harvested 34,000 tons of nuts in 1998 /1999 (USDA Foreign Agricultural Service, 2002). Test planting of macadamia trees in Taiwan commenced in the 1970s. Even though conditions for growth and nut production were very favorable, planting acreage has not increased because of the threat of damage by typhoons. The brittle wood and lack of clearly defined taproot make macadamia trees particularly sensitive to damage and blow-down in strong winds (Quinian and Wilk, 2005; Agroforestry Tree Database, 2006).

Grafted seedlings are planted in commercial macadamia orchards, and Hawaiian selections are the most important cultivars planted in all macadamia-producing countries (Allen, 1995). Grafted trees begin bearing in 5 years and take about 10 years to reach maturity and maximum nut yield. In Hawaii some trees over 60-years-old are still producing. Macadamia racemes consist of small, white, tasseled flowers growing on long spikes (Figure 1B). Fruits are globose, consisting of a white edible kernel surrounded by a hard seed coat covered with a thick fibrous pericarp (Figure 1C).

HISTORY OF MACADAMIA DECLINE

Slow decline

Light brown discoloration and chlorosis of leaves on some branches of trees followed by gradual defoliation and development of dieback symptoms (Figure 2A) were noticed in the 1960s in macadamia orchards near Hilo on the island of Hawaii, the major macadamia-nut-producing

Figure 2. Slow decline of macadamia caused by *Kretzschmaria clavus*. A, a macadamia tree showing characteristic symptoms of leaf chlorosis, defoliation, and branch dieback associated with slow decline; B, cross section of a partially decayed root with distinct black zone lines; C, fruiting bodies of *K. clavus* produced on the surface of basal trunk.

area in Hawaii (Ko et al., 1977). The decline was relatively slow, it taking more than 10 years for the affected trees to die. The decline occurred only on trees over 3 years of age. The incidence and severity of macadamia decline were positively correlated with tree age. In an orchard surveyed, the percentage of trees with dieback symptoms was 9% for those 6 years of age, and more than 80% for those 25 years of age (Ko et al., 1977). Slow decline was considered the most serious production problem in Hawaii before the occurrence of quick decline in 1986. In 1988, a slow decline of macadamia trees also was reported from Taiwan (Ann and Ko, 1988).

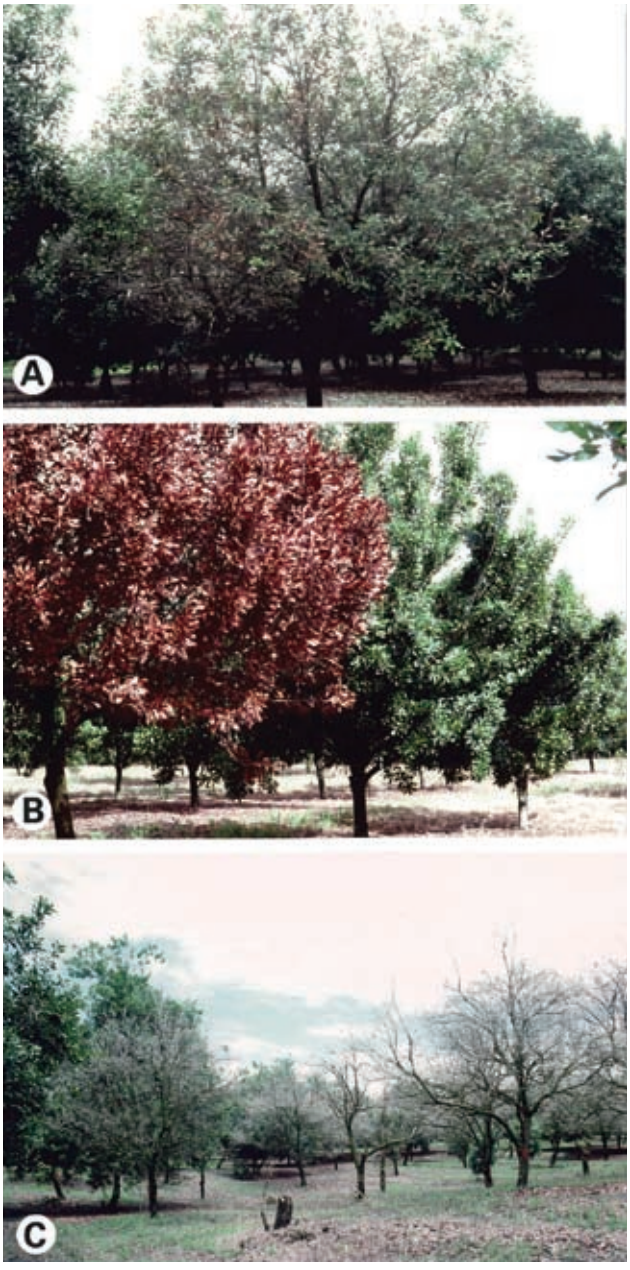

Figure 3. Quick decline of macadamia. A, a macadamia tree showing color fading and browning of leaves before sudden death; B, a macadamia tree that died suddenly as the result quick decline; C, a macadamia orchard devastated by quick decline.

Quick decline

In 1986, the foliage color of the entire canopy of some macadamia trees in a large orchard at Keaau on the island of Hawaii changed subtly from dark green to light green. Within 2 to 3 months, the leaf color started to turn light brown (Figure 3A), and within a month the whole canopy turned brown and the tree died (Figure 3B). Some trees adjacent to the affected ones began to show the same progression of symptoms and the number of dead trees increased rapidly (Figure 3C). Subsequently, quick decline of macadamia trees also occurred in orchards located in the northeastern and western sides of the island, and on the island of Maui. It has become the most serious production problem of macadamia in Hawaii. In 1998, about 5,000 trees were lost to macadamia quick decline. Responding to a desperate need by the macadamia industry, the College of Tropical Agriculture and Human Resources of the University of Hawaii formed a committee consisting of a horticulturist, two entomologists, and a plant pathologist to investigate the cause of the problem.

DETERMINATION OF THE CAUSES OF DECLINE PROBLEMS

Slow decline

The problem of slow decline of macadamia trees was originally considered due to a deficiency of certain essential elements (Shigeura and Bullock, 1973). *Phytophthora cinnamomi* Rand, which is widely distributed on the island of Hawaii, has been reported to cause macadamia trunk canker in Hawaii (Hine, 1961). However, the disease is not of common occurrence and is not associated with macadamia decline (Ko and Kunimoto,

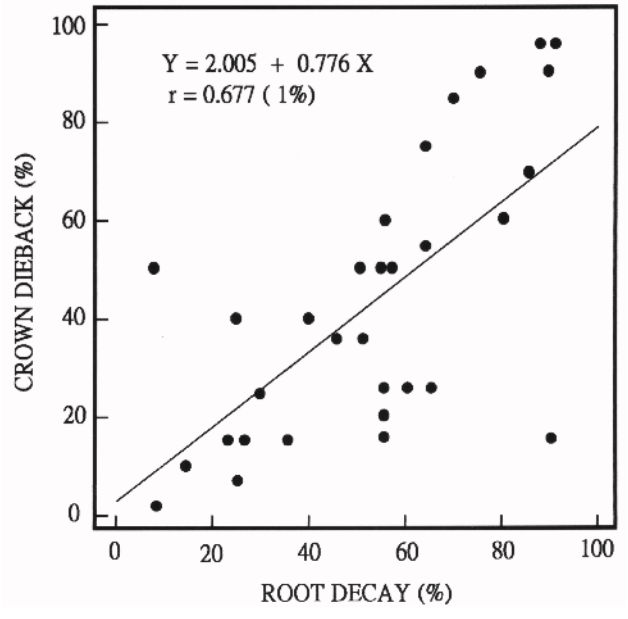

Figure 4. Correlation between severity of macadamia decline and amount of root decayed by *Kretzschmaria clavus*.

1976). At the University of Hawaii Experimental Farm, a declining macadamia tree with a number of healthy branches remaining toppled over, without any evidence of damage from strong winds. Close examination of the tree revealed that most of the large roots were discolored and decayed (Figure 2B). Fruiting bodies of *Kretzschmaria clavus* (Fr.) Sacc. were found on the surface of the diseased trunk (Figure 2C) and roots. The same organism was isolated from decayed tissue and from ascospores obtained from the stromata of *K. clavus*. Pathogenicity tests with this organism demonstrated that the decay was caused by *K. clavus* (Ko et al., 1977) (Table 1). The causal relationship between slow decline and *K. clavus* was further supported by the positive correlation between severity of macadamia decline and the amount of root decayed by *K. clavus* (Ko et al., 1977) (Figure 4). In Taiwan, the majority of macadamia trees showing slow decline symptoms was caused by *Ganoderma lucidum* (W. Curt. Ex Fr.) Karst. Only about 20% of declining trees was caused by *K. clavus* (Ann and Ko, 1988).

Quick decline

Members of the investigation committee conducted a very thorough multidisciplinary field investigation, and as a result, rainfall, temperature, and other possible stress factors such as herbicides, fertilization, and tree crowding and shading were excluded as possible causes of macadamia quick decline because none of them was correlated with the incidence of decline (Oi et al., 1991).

Table 1. Causal organisms of slow and quick decline of macadamia trees.

Causal organism	Year first reported (citation)	Reported as new host record
Slow decline		
Ascomycetes		
Kretzschmaria clavus	1977 (Ko et al.)	+[b]
Basidiomycetes		
Ganoderma lucidum	1988 (Ann and Ko)	+
Quick decline		
Oomycetes		
Phytophthora tropicalis[a]	1994 (Ko and Kunimoto)	−
Ascomycetes		
Nectria rugulosa	1991 (Ko and Kunimoto)	+
Xylaria arbuscula	1991 (Ko and Kunimoto)	+
Basidiomycetes		
Phellinus gilvus	1996 (Ko and Kunimoto)	+
Hyphomycetes		
Acremonium recifei	1999 (Ko and Kunimoto)	+

[a]Originally reported as *Phytophthora capsici*.
[b]+ = yes; − = no.

Although a number of trees with quick recline symptoms were infested with ambrosia beetles, they were regarded as secondary pests attacking weakened trees (Oi et al., 1991). Exposure of the whole root system of affected trees also failed to reveal any abnormality of roots like those observed on trees with slow decline symptoms. Upon examination of trees at the original site of the quick decline problem, fruiting bodies of *Phellinus gilvus* (Schw.) Pat. (Figure 5A) and *Xylaria arbuscula* Sacc. (Figure 6A) were observed on trunks of several trees showing various stages of decline. These fungi were considered saprobes and had been ignored previously. Saprobes, by definition, cannot invade living trees. These trees were still alive. The presence of fruiting bodies on living trees indicated that these fungi had potentially established themselves inside the trunks for a considerable length of time. When the trunk area with *P. gilvus* fruiting bodies was cut with a chainsaw, more than 90% of the cross section surface was decayed and non-functional (Ko and Kunimoto, 1996) (Figure 5B), suggesting that *P. gilvus* was associated with the decline and impending death of this tree. Ability of *P. gilvus* to cause quick decline on macadamia trees was

Figure 5. A, fruiting bodies of *Phellinus gilvus* produced on the trunk of a macadamia tree showing quick decline symptoms; B, cross section of diseased trunk showing white rot caused by the pathogen.

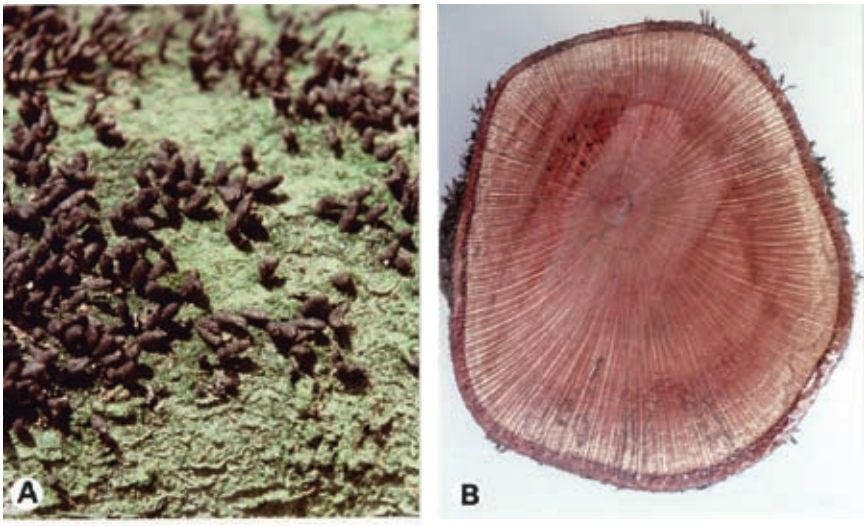

Figure 6. A, fruiting bodies of *Xylaria arbuscula* produced on trunk of a macadamia tree showing quick decline symptoms. B, cross section of a diseased trunk showing characteristic black lines.

subsequently confirmed by fulfilling Koch's postulates in pathogenicity tests (Ko and Kunimoto, 1996) (Table 1). When the trunk of another declining tree with *X. arbuscula* fruiting bodies was cut, it was observed that about 60% of wood tissue and 100% of bark on the cross section surface were decayed and non-functional (Ko and Kunimoto, 1991b) (Figure 6B), suggesting that *X. arbuscula* may be the cause of decline of this tree. Ability of *X. arbuscula* to cause quick decline was later confirmed by completing Koch's postulates in subsequent pathogenicity tests (Ko and Kunimoto, 1991b).

During the subsequent visits to various affected orchards, fruiting bodies of *Nectria rugulosa* Pat. were observed on trunks of many declining macadamia trees (Figure 7) at several locations on the island of Hawaii and at one location on the island of Maui (Ko and Kunimoto, 1991a). No visible fungal fruiting bodies were found on some macadamia trees with quick decline symptoms. A cross section of the trunk from these declining trees showed the change of appearance on part of the cut surface of bark tissue from moist, reddish brown to dry, grayish brown, and wood tissue from whitish yellow to grayish (Ko and Kunimoto, 1994; 1999). Isolation of tissues revealed that the invasion by *Acremonium recifei* (Leao & Lobo) Gams or *Phytophthora capsici* Leonian, which was subsequently reclassified as *Phytophthora tropicalis* Aragaki et Uchida (Aragaki and Uchida, 2001), had already reached or was about to reach the trunk center (Ko and Kunimoto, 1999) (Table 2). Pathogenicity tests also confirmed the ability of each organism to cause quick decline of macadamia trees (Ko and Kunimoto, 1994; 1999) (Table 1).

Figure 7. Fruiting bodies of *Nectria rugulosa* produced on trunk of a macadamia tree showing quick decline symptoms.

Figure 8. Bleeding on the trunk of a macadamia tree showing quick decline symptoms caused by *Phytophthora tropicalis*.

Phytoplasmas were once associated with a quick decline of macadamia trees (Borth et al., 1994a; 1994b). However, phytoplasma infection has never been reported to cause zonal lesions in the wood tissue of trunks (Agrios, 2005) like those observed on declining macadamia trees (Table 3). Using direct-PCR and ultrasensitive nested-PCR assays, phytoplasmas were not detected in either symptomless trees or trees with quick decline symptoms (Lee and Ko, 1998), thus refuting the suggestion that phytoplasmas may play a role in macadamia quick decline. Subsequent tests by others also failed to detect phytoplasmas in declining macadamia trees (Borth et al., 1999).

SYMPTOMS AND SIGNS OF SLOW AND QUICK DECLINE

Refer to Table 3 for a diagnostic key to identify slow and quick decline and causal organisms.

Slow decline

Slow decline of macadamia trees may be recognized at a distance by defoliated branches in the canopy of lighter color (Figure 2A). When affected branches appear on one side of the canopy, it is an indication of the position where root decay occurs. The disease progresses very slowly. More than 10 years after the appearance of initial symptoms of leaf yellowing on a single branch, a declining tree will remain alive with only one or two twigs with green leaves on the lower part of the trunk. *K. clavus* produces small, black, mushroom shaped stromata on large exposed roots and the basal trunk of the affected tree (Figure 2B). The wood of the diseased roots (Figure 2C) and trunk turns brown, shows distinct black lines consisting of pigmented hyphae, and remains firm and hard (Table 3). *Ganoderma lucidum* produces large brown basidiocarps with stipe on the lower trunk or on the ground above decaying roots. It is readily isolated from diseased trees (Ann and Ko, 1988). The wood near fruiting bodies turns soft and white (Table 3).

Quick decline

During the early stages of disease development, quick decline of macadamia trees may be recognized by the subtle loss of the dark green canopy color and a slight browning of the whole tree (Figure 3A). The most striking feature of quick decline is a dark brown tree among normal green trees during the final stage of disease development (Figure 3B).

Nectria rugulosa produces small reddish perithecia in aggregates on the trunk of the affected tree (Figure 7). The

Table 2. Isolation of *Nectria rugulosa* and *Phytophthora tropicalis* from wood at various horizontal distances from the bark (0 mm) in cross-section of trunks of declining macadamia trees

Distance from bark (mm)[a]	Tissues with pathogen (%)[b]	
	N. rugulosa	*P. tropicalis*
0	63	47
20	73	87
40	56	47
60	54	27
80	37	27
100	37	0

[a]Three to ten pieces of wood tissues taken at each distance from a diseased tree were tested (Ko and Kunimoto, 1991a; 1994).
[b]Data were average of three trees for each pathogen.

Table 3. Diagnostic key for slow and quick decline of macadamia trees and the causal organisms.

Symptom and Sign	Type of Decline and Causal Organism
A. Yellowing and browning of leaves on some branches; death of trees takes more than 10 years…….....	Slow Decline
1. Small mushroom-shaped carbonaceous stromata (2-5 mm in diameter) on exposed roots and lower trunk; diseased woody tissue firm with distinct black line…….…….....	*Kretzschmaria clavus*
2. Large brown basidiocarps (4-10 cm in diameter) with stipe on lower trunk and ground above decaying roots, wood near fruiting bodies soft and white…….……...	*Ganoderma lucidum*
B. Color of leaves in whole canopy changes from dark green, to light green, to yellow and finally brown; trees die within 2 to 3 months after leaves turn dark brown……..……...	Quick Decline
1. Aggregates of small reddish perithecial (0.2-0.4 mm in diameter) on trunk; infected bark dry and dead, infected wood grayish……..……	*Nectria rugulosa*
2. Small club-shaped black perithecial stromata (5-8 × 2-3 mm) on trunk; infected bark dry and dead, infected wood with distinct black lines……..……..	*Xylaria arbuscula*
3. Large dark yellowish brown basidiocarps (2-15 cm in diameter) on trunk; bark and wood near fruiting bodies extensively decayed, whitish and soft……..……....	*Phellinus gilvus*
4. Bleeding on trunk; under bleeding area bark blackish brown, wood grayish brown……	*Phytophthora tropicalis*
5. Neither fruiting bodies nor bleeding on trunk; infected area bark dry and dead, wood light brown…....	*Acremonium recifei*

bark of the diseased trunk is dry and dead, and the wood becomes grayish (Table 3). Pathogenicity tests confirmed this as a pathogen. Small club-shaped black perithecial stromata are produced on the trunks of declining trees infected with *X. arbuscula* (Figure 6). The bark of the diseased trunk is dry and dead, and the wood turns brown and shows distinct black lines like those caused by *K. clavus* (Table 3). Both *X. arbuscula* and *K. clavus* belong to the black-line producing Xylariaceae (Rogers, 1979). *Phellinus gilvus* produces large, dark yellowish-brown basidiocarps on the trunks of affected trees (Figure 5). The diseased wood tissue turns brown, and eventually become white and soft like wood affected by *G. lucidum* (Table 3). Both fungi belong to white-rot producing Polyporaceae, and both have bean confirmed as pathogens. *P. tropicalis* causes bleeding on the trunk of a declining tree (Figure 8). The bark of the diseased trunk becomes blackish brown, and the wood tissue turns grayish brown (Table 3). Quick decline caused by *A. recifei* shows no abnormality on the trunk surface of affected tree. However, cross-sections of the diseased trunk display dead dry black to light brown wood tissue (Table 3). Pathogenicity tests of both *P. tropicalis* and *A. recifei* reproduce these symptoms.

INOCULUM SOURCES AND INITIAL INFECTION

Slow decline

Most macadamia orchards on the island of Hawaii are located near forests, and also were originally covered with forest trees. The predominant tree species prior to macadamia production were ohia (*Metrosideros collina* subsp. *polymorpha*), melochia (*Melochia indica*), trumpet tree (*Cecropia peltata*) and Hawaiian tree fern (*Cibotium glaucum*). A survey conducted in the forest near macadamia orchards revealed the presence of *K. clavus* fruiting bodies on dead or diseased trunks of melochia and trumpet tree. Isolates of *K. clavus* obtained from these two tree species were capable of infecting macadamia trees (Ko et al., 1986). Therefore, diseased tissues and fruiting bodies incorporated into the soil during the ground preparation for planting of macadamia trees were considered the main source of primary inoculum for initial infection in the new orchard. After establishment of an infection site on root, the pathogen will begin to colonize the root system and provide secondary inoculum for initial infection of roots of adjacent healthy trees through root-to-root contact (Ann et al., 2002). In the vicinity of Hilo on the island of Hawaii, ascospores discharged from fruiting bodies produced on exposed roots and trunk may be carried by rainwater through the rocky and porous volcanic soil to reach macadamia roots underground (Ko, 1982) and serve as another source of secondary inoculum for an initial infection of roots.

Quick decline

Quick decline of macadamia trees results from trunk infection by various pathogens (Table 3). Infection of tree trunks by wood-decay organisms is usually through wounds (Adaskaveg and Ogawa, 1990). On the island of Hawaii, trunk infection of macadamia trees originates about 60 cm above the ground (Ko and Kunimoto, 1991a, 1991b, 1996) (Figure 9). The infection site correlates to injury caused by the mechanical shakers used by larger growers to remove nuts from the trees, and/or by flying small, sharp broken lava rocks during the clearing of leaf debris with leaf blowers. The known inocula for initial infection include basidiospores of *P. gilvus*, ascospores, marconidia and microconidia of *N. rugulosa* and *X. arbuscula*, conidia of *A. recifei,* and sporangia and zoospores of *P. tropicalis.* Oospore production by *P. tropicalis* rarely occurs in nature because the organism is heterothallic (Ko, 1998; 2007). *Phellinus gilvus* has a wide host range (Farr et al., 1989; Adaskaveg and Ogawa, 1990). Therefore, fruiting bodies produced on diseased forest trees or cultivated trees may serve as the source of basidiospores for initial infection by this pathogen. The fruiting bodies produced on diseased trunks of macadamia (Figure 5) may then become the secondary inoculum source for infection of other macadamia trees. *P. tropicalis* also causes raceme blight (Kunimoto et al., 1976) and foliar blight (Aragaki and Uchida, 1980) in macadamia. Sporangia produced on diseased racemes and leaves, therefore, may serve as the main source of primary inoculum for initial infection. It is not known if the organism also produces sporangia on diseased trunks. The sources of primary inoculum of *X. arbuscula*, *N. rugulosa*, and *A. recifei* are still unknown. The fruiting bodies of *X. arbuscula* (Figure 8) and *N. rugulosa* (Figure 7) produced on diseased trunks may serve as the sources of inoculum for infection of other macadamia trees. Whether secondary inoculum of *A. recifei* is produced on the surface of diseased trunks remains to be investigated.

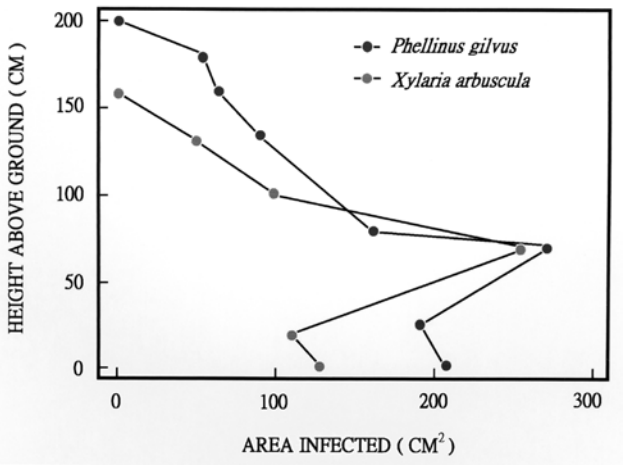

Figure 9. Area of trunk showing symptoms of infection by *Phellinus gilvus* (red dot) or *Xylaria arbuscula* (green dot) on cross sections of macadamia trunks cut every 30-40 cm starting from the soil line.

MODES OF DISEASE DEVELOPMENT RESULTING IN SLOW AND QUICK DECLINE

Slow decline

The root system of macadamia trees appear to be slightly resistant to *K. clavus* as destruction of root by this pathogen progresses very slowly. When *K. clavus* infects the macadamia root system, the affected trees with the diseased roots appear healthy for several years. It usually takes more than 5 years to cause approximately 10% root decay and initiate foliar symptoms on a few branches (Ko et al., 1977). Root decay reduces the amount of water and mineral nutrients translocated from soil to leaves. As a result, affected trees shed many leaves, and as the quantity of roots decayed increases, the amount of leaves lost also increases (Figure 4). Because the decay of macadamia roots caused by *K. clavus* is relatively slow, usually more than 10 years are required for the amount of root decay to reach more than 80%, leading to severe crown dieback and eventual death of the tree (Ko et al., 1977).

Quick decline

As the pathogen colonizes the woody tissues of the trunk from the point of infection, the area of decay expands vertically in both directions and horizontally across the trunk. Apparently, the diseased trunk continues to transport water and nutrients, providing an adequate supply to the entire canopy before the final stage of the disease development. By the time the first foliar symptoms of slight browning of the entire canopy of quick decline are visible, 90 to 100% of the bark and 58 to 97% of the wood have been killed by the pathogens (Ko and Kunimito, 1991a; 1991b; 1994; 1996; 1999). Therefore, before the appearance of visible canopy symptoms, the pathogen has already been in the bark and wood for an undetermined period of time without causing a significant adverse effect on transportation of water and nutrients. When the majority of the vascular system is blocked by infection of the pathogen, the onset of the decline resulting in death of the tree will occur within a relatively short period of time because a large amount of water is needed to sustain the whole tree.

Decline caused by multiple infections

Although a single pathogen can cause a slow or quick decline, depending on the position of initial infection, infection of a macadamia tree in nature by two different pathogens has also been observed. Our field survey revealed the concurrent presence of fruiting bodies of both *N. rugulosa* and *X. arbuscula* on some macadamia trees with quick decline symptoms (Lee and Ko, 1998). Isolation from diseased tissues of quick-declining macadamia trees without visible fungal fruiting bodies also showed the existence of *P. tropicalis* and *A. recifei* on the same trees at one of the four locations surveyed (Ko and Kunimoto, 1999). The mode of interaction between two different pathogens on the same tree remains to be investigated. If the infections do not occur on the same side of the trunk, complete girdling and death of affected trees may occur faster.

DISEASE MANAGEMENT

Because of the severity of the problem, various fungicides and application methods have been tested for controlling quick decline of macadamia trees in the field. However, the results have not been satisfactory. Ridomil 2E was used as a trunk spray and soil drench, and Alliette was used as a trunk spray. Trees were treated at 3-month intervals. Although certain treatments appeared to be effective in slowing the disease progress during the 24-month test period, browning of leaves and eventual death of trees inevitably followed. Similar results were obtained when Kocide and a systemic experimental fungicide, WECO-42894, were applied as a trunk spray. Injection of macadamia trees with Alliette also slowed the death of trees for about 6 months, but by the 7th month there was no difference in tree death between injected and control trees (Wayne Nishijima, personal communication).

Currently, no resistant cultivars are available for control of slow or quick decline of macadamia. Recommended measures for disease management include removal of diseased plants and orchard cultivation practices that minimize tree wounding. Because of the presence of *K. clavus* fruiting bodies on the dead and diseased trunks of trees in the forest (Ko and Kunimoto, 1986), the stem tissue of forest trees should be removed during the land preparation for new plantings of macadamia. Macadamia trees in the orchards infected with *K. clavu*s should be removed along with major roots. The surrounding area of macadamia orchards should be free of dead tree branches to avoid their colonization by *K. clavus* and production of fruiting bodies on colonized branches (Ko, 1979) that may serve as an inoculum source.

Racemes and leaves infected with *P. tropicalis* should be cut and removed to reduce the primary inoculum of this pathogen. Trunks of trees with quick decline symptoms should be destroyed by burning to prevent spread of the disease in the orchards by secondary inocula. Cultural practices, including mechanical harvesting and leaf dearing and chemical and mechanical methods of weed control, which may cause wounds on trees, should be performed with great caution to minimize injury to trunks.

CURRENT STATUS AND FUTURE OUTLOOK

Besides Hawaii, slow decline of macadamia trees also has been reported from Taiwan (Ann and Ko, 1988). More reports concerning the incidence of macadamia slow decline induced by fungal root rot may come from other countries in the future. Quick decline of macadamia is not expected to be severe in other macadamia-growing countries, unless a significant amount of trunk damage

occurs as the result of inappropriate cultural practices.

A rapid method for screening macadamia seedlings for resistance to *K. clavus* was developed in 1986 (Ko and Kunimoto, 1986). However, a selective breeding and screening program has not been implemented since then due to lack of funds. In the future with funds available cultivars resistant to *K. clavus* may be obtained through a selection program and used as the root stock for control of slow decline. Commercial cultivars of macadamia have been shown to differ in susceptibility to *A. recifei* (Ko and Kunimoto, 1999). All commercial cultivars of macadamia should be tested for susceptibility to all known pathogens associated with quick decline and trees with quick decline symptoms should be diagnosed to determine the causal agent. Extension agents can use this information to advise growers on selection of cultivars for replanting in affected orchards.

Fungicides should also be tested for ability to prevent wounded trunks from infection by the known quick decline pathogens. Effective fungicides can then be tested in the field to determine the feasibility of applying these chemicals to a vulnerable area of the trunk following each harmful cultural practice. Development of soil drenches or soil fumigation prior to replanting to reduce the decline incidence is also urgently needed.

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澳洲胡桃樹之慢速與急速枯萎之特性

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澳洲胡桃樹雖然原產於澳洲，卻是經過夏威夷大學的育種與開發後，其核果才成為高價值的產品，並引起許多國家大面積的種植。樹的枯萎是種植澳洲胡桃所面臨的最嚴重問題。此問題包括由 *Kretzschmaria clavus* 或 *Ganoderma lucidum* 造成根腐所引起的慢速枯萎，及由 *Nectria rugulosa*、*Xylaria arbuscula*、*Phellinus gilvus*、*Phytophthora tropicalis* 或 *Acremonium recifei* 造成主幹腐朽所引起的急速枯萎。接種原的來源及病害發展模式皆因病原菌的不同而有所差異。慢速同急速枯萎的病害診斷所以特別在這篇報告裡提出。

關鍵詞： *Acremonium recifei*; *Ganoderma lucidum*; *Kretzschmaria clavus*; *Macadamia integrifolia*; *Nectria rugulosa*; *Phellinus gilvus*; *Phytophthora tropicalis*; *Xylaria arbuscula*； 急速枯萎 ； 慢速枯萎。