

**Pest Management Strategic Plan
for
Macadamia Nut Production
in Hawai'i**



Macadamia Nut PMSP May, 2006
Workshop Summary
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Cover Photograph courtesy of Island Princess Macadamia Nut Company

Executive Summary

The macadamia nut is the principal orchard crop cultivated in Hawai'i and has attained a reputation as one of the world's finest nuts. Hawai'i remains virtually the sole producer of macadamias in the U.S. Hawai'i was the world's largest producer of macadamia nuts (dried, in-shell) until 1997 when Australia took the lead. For nine years, macadamia nut was the third highest commodity by value in the state. In 2003, macadamia was the fourth highest commodity by value in the state. Macadamia nuts are grown on 18,000 acres in Hawai'i, 17,800 of which are harvested. For the 2004-2005 production season, the net yield was 3,200 pounds per bearing acre, resulting in a net production of 56.5 million pounds and a net farm value of over \$40 million.

Over 90% of the orchards are 10 acres or less. However, a few large farms account for most of the acreage in production. Almost all of the orchards are located on the Big Island (Hawai'i), at the southeast end of the Hawaiian Island chain. The macadamia industry is the major employer in the South Kona District of the Big Island.

This Pest Management Strategic Plan is created with the following conclusions about macadamia nut production in Hawai'i:

- Hawai'i is relatively free of pests in macadamia nut compared to the rest of the world and we need to try to keep it that way.
- Pesticide use in macadamia nut orchards in Hawai'i is also relatively low.
- We have maximum yields because we don't have to hedge the trees for pesticide application.
- In Hawaii it is common to observe flowering, nut maturation and vegetative flushing occurring simultaneously within a single orchard or even within a single tree.

Commercial orchards are planted almost exclusively with *Macadamia integrifolia*, the smooth-shell macadamia, which produces a higher quality kernel than the rough-shell *Macadamia tetraphylla*. Since flowering of macadamia trees occurs over several months, nuts will mature over an extended period and multiple harvests are required to gather the entire season's crop. Most trees are propagated by grafted seedlings. Macadamia nut trees can start bearing a small crop in the fifth year after planting. Under ideal conditions, full production may be reached in 12 to 15 years. However, trees exposed to severe conditions such as droughts, disease or windstorms may take more than 21 years to reach full production. Trees which receive proper care may produce for 40 to 60 years or more in suitable environments.

The most important insect pests of macadamia are the southern green stinkbug (*Nezara viridula*), tropical nut borer (*Hypothenemus obscurus*) and two species of *Cryptophlebia*, the koa seedworm moth (*C. illepida*) and litchi fruit moth (*C. ombrodelta*). The southern green stinkbug cannot survive on macadamia nuts alone and requires another host. There are differences in stinkbug infestations between orchard locations, but these differences can vary with environmental conditions. In the normally wetter growing areas, stinkbug

damage has become serious in the last three years. Also, rains in late 2001 and early 2002 were followed by a return to drought-like conditions in the normally dry Kona growing areas and increased insect infestations. In 2002-2003, the Hawai'i Agricultural Statistics Service reported unusually high levels of stinkbug damage in Kona, Ka'u and Kohala, with some orchards experiencing severe losses.

Diseases do not present threats as serious as those caused by insects for Hawai'i's macadamia nut production. The most serious diseases are raceme and blossom blights caused by *Phytophthora capsici*. The diseases are more common in growing areas where there is lots of moisture, either rainy or foggy environments. This disease also tends to develop under warmer conditions at lower elevations.

Weed management is an important component in macadamia nut production because weeds compete for water and nutrients. They also provide shelter for insect pests and their predators, and can enhance or reduce insect damage. Weeds can make rodent management more difficult. Weeds can also interfere with harvesting.

The impacts of nematodes on macadamia production are unknown. No treatments are made for them. Nematodes are not yet a problem in macadamia anywhere in Hawai'i.

Integrated Pest Management

An Integrated Pest Management (IPM) program has been designed and implemented for macadamia nut production in Hawai'i. Fields are surveyed for insects, diseases, and weeds as part of the program. Classical biocontrol has played an important role in the management of macadamia pests, notably the southern green stinkbug.

Macadamia producers tend to restrict pesticide applications even though there are pests that cause significant yield loss. A primary factor is the small profit margins associated with macadamia nut production in Hawai'i. While the prices realized for nuts were high in past decades, in 1990, prices began dropping considerably. In the last two years, prices have increased, but they have not returned to levels reached in some years in the 1990's, and remain unpredictable. This, coupled with the high cost of labor in Hawai'i, makes dependence on pesticides undesirable. The costs of pesticide application equipment, chemical products and labor are prohibitive for many of the growers in the islands.

Another significant factor is that a large number of macadamia growers in Hawai'i are environmentally conscious, and prefer to avoid large inputs of pesticides. Some of the largest producers are participants in the IPM verification program, administered by the University of Hawai'i, and a significant component of obtaining verification is demonstrating that chemical applications are made only when absolutely necessary. In addition, there are a number of significant pests for which there are no effective chemical treatments. In fact, the most important insect pests (tropical nut borer, southern green stinkbug and koa seedworm / litchi fruit moth) are extremely difficult to control with insecticides, owing to their biology. All the currently available and more effective chemicals for the control of these pests result in perturbations of natural enemy complexes in orchards that growers prefer to avoid.

Trade Issue

Australia completed Free Trade Agreement (FTA) negotiations with the U.S. in early 2004, with the agreement taking effect on January 1, 2005. Under the FTA, the U.S. tariff on macadamia nuts-in-shell was eliminated immediately and the tariff on macadamia products will be phased out over five years.

Overall Critical Needs for Macadamia Nut Production

Research

- Biology, control and monitoring of insect pests (stinkbug; *Cryptophlebia* spp.: koa seedworm moth and litchi fruit moth; and tropical nut borer).
- Improve rootstock for macadamia nut disease resistance.
- Evaluate biocontrol agents to control stinkbug and *Cryptophlebia*.
- Assess economic impact and thresholds of Hawaiian flower thrips and red-banded thrips and mites.
- Screen pesticide and application methods (including baiting).
- Market assessment for promotion of local biocontrol businesses.
- Evaluate organic foliar sprays and compost teas on insect and disease pests.

Regulatory

- “Strict quarantine regulations” on all macadamia plants and plant parts, including kernels.
- Ban importation of raw kernels into Hawai‘i.

Education

- Prepare educational materials or diagnostic materials for HDOA and APHIS to recognize serious pests
- Educate growers, purchasers of kernels, retailers, etc., about the risks of importing pests.

Background

Economic Importance

The macadamia nut is the principal orchard crop cultivated in Hawai'i and has attained a reputation as one of the world's finest nuts. Hawai'i remains virtually the sole producer of macadamias in the U.S. Hawai'i was the world's largest producer of macadamia nuts (dried, in-shell) until 1997 when Australia took over the lead. In 1999, Hawai'i produced 45% of the world's macadamia nuts. In 2003, Hawai'i's share of the world's macadamia production was 24%. Approximately 40% of the world's macadamia nuts come from Australia, which remains the world's largest producer. Forecasted acreage and yield increases in Australia and Africa (the world's third largest producer) are expected to continue to increase world supplies.

For nine years, macadamia nut was the third highest commodity by value in the state. In 2003, macadamia was the fourth highest commodity by value in the state. Macadamia nuts are grown on 18,000 acres in Hawai'i, 17,800 of which are harvested. For the 2004-2005 production season, the net yield was 3,200 pounds per bearing acre, resulting in a net production of 56.5 million pounds and a net farm value of over \$40 million.

Over 90% of the orchards are 10 acres or less. However, a few large farms account for most of the acreage in production. Almost all of the orchards are located on the Big Island (Hawai'i), at the southeast end of the Hawaiian Island chain. The macadamia industry is the major employer in the South Kona District of the Big Island.

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General Cropping Guidelines

In Hawai'i, commercial orchards are planted almost exclusively with *Macadamia integrifolia*, the smooth-shell macadamia, which produces a higher quality kernel than the rough-shell *Macadamia tetraphylla*.

Most trees are propagated by grafted seedlings. Macadamia seeds are planted in a seed bed and will germinate in 4 to 6 weeks. The seedlings are then transplanted into pots and allowed to grow until the tree diameter at 18 inches above the pot surface is approximately 1cm. Ten to twelve months of growth is needed to reach this stage before the seedling can be grafted with a scion from a preferred cultivar. During the first six months when growth is normally slow, seedling height will be 10-12 inches tall. Growth thereafter is relatively fast when seedlings can reach heights of 4-6 feet in the remaining 4 to 6 months. After the trees are grafted, the growth from the scion must be protected from

red-banded thrips infestation. The total propagation time to develop a grafted tree that is ready for field planting takes approximately two years.

Macadamia nut trees can start bearing a small crop in the fifth year after planting. Under ideal conditions, full production may be reached in 12 to 15 years. However, trees exposed to severe conditions such as droughts, disease or windstorms may take more than 21 years to reach full production. Trees which receive proper care may produce for 40 to 60 years or more in suitable environments.

Macadamia nut trees are grown on deep, well-drained soils with a pH of 5.5-6.5 or on well-drained 'a'a lava land that is sufficiently weathered to support natural vegetation. Optimum yields occur where maximum temperatures are below 90°F and minimum temperatures are above 55°F. The trees require 60-120 inches of rainfall per year (80 inches or more on lava) and can be grown from sea level to an elevation of 2,500 feet. In drier locations, supplemental irrigation is needed. Therefore, manual labor is needed to monitor and maintain the irrigation systems.

Typically, to facilitate harvesting, tree rows are treated with herbicide, leaves are blown into the drive row and the drive rows are mowed. Macadamia nuts are harvested after the mature nuts have been allowed to fall from the trees. Most growers harvest at 6-12 week intervals. Statewide, on average, approximately 35% of the crop is harvested by hand. Where the terrain allows, larger growers may use mechanical shakers to shake and collect the nuts from the trees or mechanical harvesters to pick fallen nuts off the ground.

In general, fields are surveyed for insects, diseases, and weeds as part of an integrated pest management program. Leaf and soil samples are collected several times per year to determine tree and soil nutrient status for subsequent fertilizer or soil amendments application as needed.



Figure 1. Fallen nuts on 'a'a lava

Stages of Growth, Flowering and Nut Development

In Hawai'i it is common to observe flowering, nut maturation and vegetative flushing occurring simultaneously within a single macadamia tree. The rhythmic growth observed on individual branches indicates that branches cycle between an active growth phase and a dormant or resting phase, but the entire tree is not in synchrony with

regard to vegetative flushing. A characteristic of macadamia trees is the presence of young vegetative flushes on sections of the canopy throughout the year; however major flushing peaks can be observed during the early spring and late summer.

Flowering generally occurs from November to May, with as many as three flowering peaks observed within a cultivar during the flowering season, but it is not unusual to encounter orchards and trees that produce heavily or even flower during off-season periods. This is due to the wide range of environments in which orchards can be found on the Island of Hawai‘i. Macadamia flowering is best induced when warm temperatures are followed by cool night temperatures below 64°F. When trees are grown in warmer locations, flowering is both delayed and reduced. Rainfall may also play a role in altering the flowering season. Vegetative flushing is reduced during drought and is stimulated after sufficient rainfall, and a similar response with flowering is sometimes observed. If trees encounter a drought period during the normal flowering season, late season flowering can occur when trees are subsequently irrigated or encounter heavy rainfall.

Nuts increase in diameter until 15 weeks after anthesis and reach their full weight at 20 weeks after anthesis. Nuts then mature on the trees for another 2-3 months. During this time, their oil content doubles until they attain full oil content of 75-79%. The abscission layer in the stem then matures and the nuts fall from the trees.

Since flowering of macadamia trees occurs over several months, nuts will mature over an extended period and multiple harvests are required to gather the entire season’s crop. The harvesting pattern for each cultivar can also vary since some cultivars have an earlier and more defined flowering period with a short harvesting season, while others may tend to flower later, have a broad, more diffuse flowering pattern and possess a more extended harvest. The main period of harvest is from August through January but in some areas, nuts mature throughout the year.

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- Pesticide use in macadamia nut orchards in Hawai‘i is also relatively low.
- We have maximum yields because we don’t have to hedge the trees for pesticide application.
- In Hawaii it is common to observe flowering, nut maturation and vegetative flushing occurring simultaneously within a single macadamia tree.

Major Pests of Macadamia Nuts

The most important insect pests of macadamia are the southern green stinkbug (*Nezara viridula*), tropical nut borer (*Hypothenemus obscurus*) and two species of *Cryptophlebia*, the koa seedworm moth (*C. illepida*) and litchi fruit moth (*C. ombrodelta*). The southern green stinkbug cannot survive on macadamia nuts alone and requires another host. There

are differences in stinkbug infestations between orchard locations, but these differences can vary with environmental conditions. In the normally wetter growing areas, stinkbug damage has become serious in the last three years. Also, rains in late 2001 and early 2002 were followed by a return to drought-like conditions in the normally dry Kona growing areas and increased insect infestations. In 2002-2003, the Hawai'i Agricultural Statistics Service reported unusually high levels of stinkbug damage in Kona, Ka'u and Kohala, with some orchards experiencing severe losses.

The discussion and research which contributed to the production of this document, identified seven insect pest groups which are economically or potentially economically important to macadamia nut production in Hawai'i. In South Africa, the world's third largest producer of macadamia nuts, there are some 60 insect and two mite species identified which are known to attack trees and fruit. Of these, stink bugs are the most important and in addition to the green stinkbug, *Nezara viridula* (L.) which is also a serious problem in Hawai'i, there are more than 30 other stinkbug species that attack the flowers and developing nuts. In Australia, more than 150 species that damage macadamia have been reported. Australia also has numerous parasites and predators which affect some control of insect pests. The parasites and predators may not be present in Hawai'i or may not perform the population control function that they do in Australia.

Emerging Pest

An emerging and possibly critical new pest is the macadamia felted coccid (*Eriococcus ironsidei*/Williams) (Hemiptera: Eriococcidae). This insect was first collected from macadamia trees in the South Kona area in March 2005 and later was positively identified. This insect is originally from Australia, where it can become a severe problem on macadamia nut trees. Dense infestations in Australia are known to cause leaf die-back, and floret drop, with subsequent reductions in nut-set.

A note on the current situation with macadamia felted coccid: Recent surveys (August 2005) of macadamia felted coccid infestations in South Kona showed that very few previously heavily infested trees still bear live scales, and the infestation has not spread throughout the surveyed areas. This suggests that the extensive oil applications that were made were effective, and it seems that predatory insects are having a positive impact on continuing to suppress scale populations.

Integrated Pest Management

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Macadamia producers tend to restrict pesticide applications even though there are pests that cause significant yield loss. A primary factor is the profit margins associated with macadamia nut production in Hawai'i. While the prices realized for nuts were high in past decades, in 1990, prices began dropping considerably. Beginning in 2003 and con-

tinuing through 2005, prices have increased, but they have not returned even to levels reached in some years in the 1990's, and remain unpredictable. This, coupled with high costs of labor in Hawai'i, makes dependence on pesticides undesirable. The costs of pesticide application equipment, chemical products and labor are prohibitive for many of the growers in the islands.

Another significant factor is that a large number of macadamia growers in Hawai'i are environmentally conscious, and prefer to avoid large inputs of pesticides. Some of the largest producers are participants in the IPM verification program, administered by the University of Hawai'i, and a significant component of obtaining verification is demonstrating that chemical applications are made only when absolutely necessary. In addition, there are a number of significant pests for which there are no effective chemical treatments. In fact, the most important insect pests (tropical nut borer, southern green stinkbug and koa seedworm / litchi fruit moth) are extremely difficult to control with insecticides, owing to their biology. All the currently available and more effective chemicals for the control of these pests result in perturbations of natural enemy complexes in orchards, that growers prefer to avoid.

The following is a pest by pest analysis of the current pest management practices in macadamia nut production in Hawai'i. Non-chemical, cultural, and biological control measures are also discussed. A critical needs list for research, regulatory, and education is included with each pest analysis. Insect and disease pests are presented in order of economic impact.

Insect and Mite Pests

1. Southern Green Stinkbug (*Nezara viridula*)

Southern green stinkbug (SGS) is one of the three most important pests of macadamia nut. Stinkbug causes premature nut drop and kernel damage. For the 2004-2005 growing season, 3.7% of the delivered crop was rejected by processors because of damage attributed to stinkbug feeding, representing a loss of \$1.6 million, 23.4% of all losses. Additionally, stinkbugs may introduce mold while feeding; in 2002, researcher Vince Jones reported that 25% of nuts rejected as moldy were damaged by stinkbugs.

The stinkbug inserts its hollow needle-like mouthpart into the nut and injects saliva into the kernel. Enzymes in the saliva liquefy the tissue around the tip of the mouthparts and the bug consumes the liquid. This feeding activity causes pitting of the kernel. Nuts infested on the ground may also have white or brown discoloring. SGS feeding on nuts that are not fully sized often results in premature abscission.

Peak damage is observed from July through September but actually took place earlier in the year (damage is cumulative), and damage can be seen year-round.

There are differences in stinkbug infestations between orchard locations, but these differences can vary with environmental conditions. In the normally wetter growing areas, stinkbug damage has become serious in the last four years. The explanation for this is

thought to be because wet winters allow weed proliferation and then, when the weather becomes drier, the preferred weed hosts are lost and stinkbugs move onto the macadamia trees. Also, rains in late 2001 and early 2002 were followed by a return to drought-like conditions in the normally dry Kona growing areas and increased insect infestations. In 2002-2003, the Hawai'i Agricultural Statistics Service reported unusually high levels of stinkbug damage in Kona, Ka'u and Kohala, with some orchards experiencing severe losses. In 2004-2005, immature nuts and damage from stinkbugs accounted for half of the nut losses overall.

Southern green stinkbug cannot survive on macadamia nuts alone and require a primary food plant, or host. Sixty-five percent of weed species found in Hawai'i are recorded as hosts of SGS. Stinkbugs reproduce and develop on the weeds and feed on macadamia when their primary food plants become unavailable.

Chemical Controls

- Endosulfan (Thionex)
 - Efficacy: Fair to Good
 - Disadvantages: 24(c) registration (SLN HI-030001, for Thionex 50WP) expires Mar 11, 2008. It reduces populations of natural enemies and has environmental restrictions. It is toxic to bees and is a known endocrine disrupter.
- Malathion
 - Efficacy: Good
 - Advantages/Disadvantages: 12-hour PHI; familiarity with product; safe for employees to use; and inexpensive/To be effective, should be sprayed in the trees and on the ground. (There was some misunderstanding of this recommendation and growers concentrated sprays on the ground, but this is not as effective.)

Other pest management aids

- Weed control. Reduction of legume populations will lower stinkbug populations.
- Natural enemies. The introduced parasites, *Trissolcus basalus*, an egg parasitoid, and *Trichopoda pilipes*, an adult parasitoid, are present in Hawai'i. Their effectiveness is variable and research is currently being conducted on the potential for implementing augmentative releases of *T. basalus*.

Critical Needs for Southern Green Stinkbug

Research needs

- Development of a monitoring system that is less labor-intensive; that can cover acreage in less time.
- Determination of economic thresholds.
- Evaluate the movement of pest to and from orchards.
- Identification of the stages of nut development in which damage occurs.
- Determination of the efficacy of new pest management alternatives.
- Identify pesticides for use in organic production.

- Research to determine specifically when stinkbug damages the crop to effectively time treatment.
- Determination of parasitoid efficacy and rates of parasitism.

Regulatory needs

- Expedite the registration of organic pesticides once they have been identified.

Education needs

- Educate neighbors of macadamia farms about host vegetation management.

2. Tropical Nut Borer (*Hypothenemus obscurus*)

Tropical nut borer (TNB) is one of the three most important pests of macadamia nut. TNB is found in 75% of orchards in Hawai'i and causes very consistent damage by boring through the shell and feeding on the kernel. TNB is more prevalent during very dry years. It is widespread, but orchards in dryer areas are more susceptible, as are those at lower elevations. TNB affects fallen nuts and sticktight (nuts which fail to abscise after maturation). In the 2004-2005 crop season, the estimated percentage of crop loss due to TNB was 11.1%, representing 1.8% of the crop delivered to processors, or \$784,000. Actual losses caused by TNB may be underestimated because feeding by TNB introduces mold. Therefore, some of the losses attributed by the Hawai'i Agricultural Statistics Service to mold may actually be caused by TNB.

Chemical Controls

Chemical treatment for TNB is not practical because the window of exposure of the insects to pesticides is very short.

Other pest management aids

- Frequent harvests help reduce damage.
- Shaker harvesting. The expense of shaker harvesting is economically justified when it is part of a TNB control program because shaker harvested nuts do not spend time on the ground, where TNB damage occurs.
- Grinding or composting husks.
- Mulching.
- Reducing sticktight.
- Removal of cultivars that produce more sticktight.
- Shaking sticktight from trees.
- Monitoring techniques to determine when to harvest.
- Funnel traps baited with ethanol, or sentinel bags of nuts to monitor populations.
- Increasing predator populations can be a management tool, however spraying for other pests may adversely affect the predators.

Critical Needs for Tropical Nut Borer

Research needs

- Enhance biological controls by encouraging predators.

- Identify pest management controls to manage nut borer populations.
- Research baiting application technology.

Regulatory needs

- None.

Education needs

- None.

3. *Cryptophlebia*: Koa Seedworm Moth (*C. illepada*) and Litchi Fruit Moth (*C. ombrodelta*)

Cryptophlebia is one of the most important genus of macadamia pests. *Cryptophlebia* bores into the nut causing premature nut fall and damaging the kernel. Nut quality is diminished and production is decreased. *Cryptophlebia* is found at all orchard locations in Hawai'i. Variations have been observed with orchard elevation.

Losses due to Koa seedworm moth (KSW) damage were estimated at \$1.1 million (16.1% of losses, 2.5% of delivered crop) in 2004-2005. However, *Cryptophlebia* causes significantly higher abortion rates. If the nuts fall when they are relatively small, they are unlikely to be harvested and, therefore, would not be counted and included in the statistics. Nuts which are larger but fall before they reach their full oil content may be a major cause of immature nuts observed by processors and reported by HASS. Where damage rates are high, *Cryptophlebia* may be responsible for as much as 50% of the reported immature nuts, resulting in higher losses than reported in the statistics.

Cryptophlebia damage occurs largely during the oil accumulation period; however, the insects are prevalent year-round. The highest levels of premature nut drop occur from May through mid-August.

Chemical Controls

- Azadirachtin (Neemix, Agroneem)
 - Efficacy: Poor.
 - Disadvantages: Non-efficacious. The spray needs to contact the nut but canopy prevents it; requires weekly sprays; not cost effective.
- *Bacillus thuringiensis* (Agree, Xentari, Dipel)
 - Efficacy: Poor.
 - Disadvantages: Larvae are on surface of the nuts, therefore the spray needs to contact the nut but canopy prevents it; requires weekly sprays; not cost effective.
- Pheromones
 - Efficacy: Oriental Fruit Moth (OFM) pheromone efficacy is fair.
 - Disadvantages: OFM pheromone is available but other pheromones are not easily available and are costly.

Other pest management aids

- None.

Critical Needs for *Cryptophlebia*

Research needs:

- Determine economic impacts of the pest.
- Develop biocontrol options.
- Description of biology in various microclimates.
- Research mating disruption possibilities.
- Efficacy trials and application technology.

Regulatory needs:

- Insure that any introduced biocontrol agents have passed appropriate environmental evaluations.
- Expedite registration of new pheromones specific to *Cryptophlebia*.
- Register new specific pheromones for KSW.

Education needs:

- Growers need to work with county agents to express concerns about any pest problems and pest management needs.
- Let growers know what pesticides are registered. Make educational materials available.

4. Red-banded thrips (*Selenothrips rubrocinctus*)

Red-banded thrips (RBT) damage is restricted to the outer surface of nuts with no impact on nut drop, maturation or nut quality. When populations increase to abnormal levels, leaves, especially recently hardened leaves, may be bronzed or damaged. This damage may become severe enough to reduce tree growth and vigor by destroying the productivity of the growth flush for the current season.

Pest pressures from this pest may be greater at lower elevations. Infestations are often localized within an orchard. Problems are more prevalent towards the end of the harvest season, but RBT are present in orchards year-round.

Growers take action against RBT when 5-6 adults are observed on 50% of new flush.

In the nursery where grafted macadamia trees are propagated, serious outbreaks of RBT can arrest the development of rootstock and grafted trees. The trees are grown outdoors (no roof or enclosures) and are exposed to infestations from surrounding host plants. RBT infestations will suppress seedling growth particularly during the first six months when growth is normally slow where seedling height will be 10-12 inches tall. Growth thereafter is relatively fast where seedlings can reach heights of 4-6 feet in the remaining 4 to 6 months. Serious outbreaks of RBT can also suppress seedling growth during the last 6 months of the first year. After the trees are grafted, the growth from the scion must also be protected from RBT infestation.

Chemical Controls

- Malathion
 - Efficacy: Fair – Good. Very effective in the nursery where grafted macadamia trees are propagated
 - Advantages/Disadvantages: Familiarity with this product, safe for employees to use and it is inexpensive; 12-hour PHI /Malathion has negative effects on beneficials, has a strong odor, and short residual activity.
- Spinosad
 - Efficacy: Good in the nursery where grafted macadamia trees are propagated
 - Advantages/Disadvantages: Short REI; relatively long residual activity; used to complement malathion in the nursery/only four applications allowed per year.
- Endosulfan
 - Disadvantages: not used in the nursery to mitigate worker exposure; restricted use pesticide.
- Lambda-Cyhalothrin
 - Disadvantages: not used in the nursery to mitigate worker exposure; restricted use pesticide.

Other pest management aids

- Weed control. Removal of alternate hosts may help.

Critical Needs for Red-banded Thrips

Research needs:

- Crop loss assessment.
- Determine effects of thrips damage on plant health.
- Determine economic consequences of loss of growth flush due to thrips damage.
- Determine specific effects on different cultivars.

Regulatory needs

- None.

Education needs

- Extension agents need to inform growers on control methods.

5. Hawaiian flower thrips (*Thrips hawaiiensis*)

Hawaiian flower thrips destroys macadamia flowers. Up to 30-40% of the flowers are affected. Problems occur whenever trees are flowering. Hawaiian flower thrips are widespread throughout macadamia growing areas. Treatment is not applied until a threshold of the destruction of 10% of flowers is met. However, the value of crop loss has not been determined.

Chemical Control

- Malathion
 - Efficacy: Fair - Good
 - Advantages/Disadvantages: Familiarity with this product, safe for employees to use and it is inexpensive; 12-hour PHI/Malathion has negative effects on beneficials, has a strong odor, and short residual activity.

Other pest management aids

- None.

Critical Needs for Hawaiian Flower Thrips

Research needs

- Determine economic thresholds.
- Determine ability of tree to compensate for loss of flowers.

Regulatory needs

- None.

Education needs

- Teach growers the monitoring technique of tapping the flower.

6. Red and Black Flat Mites (*Brevipalpus phoenicis*) and Broad Mites (*Polyphagotarsonemus latus*)

Flat and broad mites are widespread in macadamia growing areas. Foliage feeding by flat and broad mites impact crop production the year following infestation. Mites also damage flowers and infested flowers do not set nuts. Mite problems are most prevalent during growth flushes which occur after a period of dry weather. Dusty conditions exacerbate mite problems.

Flat and broad mites damage nuts, although there is no evidence that this damage affects yield or kernel quality. Broad mites cause silvering of husks and flat mites cause bronzing of husks. Areas which exhibit such damage should be monitored for mites during following years. Treatment is indicated when the mite population is high on more than 20% racemes sampled in the area being monitored.

Chemical Controls

- Sulfur (Micro Sulf, Microthiol)
 - Efficacy: Fair - Good
 - Advantages/Disadvantages: Inexpensive and has nutritional benefits./Can burn the trees under hot weather conditions and can cause allergy problems.

Other pest management aids

- None.

Critical Needs for Flat and Broad Mites

Research needs:

- Identification of biocontrol with predacious mites.
- Determine susceptibility of different cultivars.
- Determine efficacy of spraying with oils.

Regulatory needs:

- If you are using or would like to use or research predacious mites will approval from Hawai'i State Department of Agriculture for import.

Education needs:

- None.

Occasional Pest

Ambrosia Beetle (*Xyleborus affinis*)

Ambrosia beetles attack all trees but the worst impact is on weak trees. The beetle weakens the trunks of unhealthy trees. Over the long term, seriously impacted trees eventually die. The effects of ambrosia beetles are more aggravated where management practices are poor. Crop production is decreased. Damage can be observed at any time in weakened orchards.

Orchards that have become nutritionally imbalanced may suffer substantial damage from the ambrosia beetle. Resident populations attack all trees; however healthy trees incur only minor damage. The beetles culture fungi for feeding and reproduction, and trees in poor health present an opportunity for this activity. The culturing of fungi and extensive boring will eventually compromise the integrity of the wood structure of the tree. Disease vectoring can further reduce the health of the tree.

Overall damage to the tree is very difficult to determine. Boring activity is indicated by sap exudation and waste product collected at the base of the trunk. Simple traps to monitor for this insect can be made from plastic soda bottles and a small quantity of alcohol. Success with these devices, however, has been limited and they are especially ineffective when the strawberry guava fruits are falling and the population of fruit flies is high. Treatment for the entrenched adult is largely ineffective and little is known about the migratory habits and determinants in the spread of infestation. It is possible that susceptible trees become colonized and successive generations of beetles will live in the same tree.

While the tree may continue to produce adequately for a long period of time, it becomes very susceptible to wind damage. The ambrosia beetle is probably responsible for most mid-trunk and core wood deterioration in older orchards. It is likely to become a larger element in tree mortality in established orchards where the fertility program is inconsistent and governed largely by profitability of the crop. This is especially true for small growers.

Chemical Controls

- This pest is not treated because it is a sporadic pest and it does not cause enough damage to offset the treatment costs.

Other pest management aids

- Proper site selection.
- Proper cultivar selection.
- Avoiding compacted soil conditions.
- Maintain proper fertility.
- Wrapping or sheathing replant trunks

Critical Needs for Ambrosia Beetles

Research needs

- Elucidate infestation process.
- Determine when the adults are likely to migrate, how long the adults are exposed and when and how they move from one tree to the next.

Regulatory needs

- None.

Education needs

- None.

Diseases and Pathogens

1. Raceme & Blossom Blights (*Phytophthora capsici*)

Blights caused by *Phytophthora* destroy flowers and developing nuts. Yields are reduced and foliage flushes are adversely affected.

Phytophthora blights cause problems during the flowering stage. The diseases are more common in growing areas where there is lots of moisture, either rainy or foggy environments. This disease also tends to develop under warmer conditions at lower elevations. Areas where air circulation is lower and planting densities are higher are more susceptible to *Phytophthora* blights.

Chemical Controls

- Fosetyl-Al (Aliette)
 - Efficacy: Fair – Good
 - Advantages/Disadvantages: None.
- Metalaxyl (Ridomil)
 - Efficacy: Good.
 - Disadvantages: Timing of application is critical, very expensive, potential ground-water contaminant and produces skin rashes.

- Azoxystrobin (Abound)
 - Efficacy: Good.
 - Disadvantage: resistance development is possible.
- Phosphorus acid (Phostrol)
 - Efficacy: Good.

Other pest management aids

- Spacing. *Phytophthora* blight prevention is considered when determining planting densities.
- Pruning encourages better air flow.
- Keep lower portions of wind breaks clean (foliage-free) for good aeration.

Critical Needs for *Phytophthora* Blights

Research needs

- Research to determine composition, efficacy and application of compost teas.
- How to regulate nutrition to prevent excessive canopy development for growers who do not use growth regulators.
- Fungicide application technology.
- Pesticide efficacy, timing, and rates.

Regulatory needs

- None.

Education needs

- Teach small farmers about nutrition to prevent excessive canopy development.

2. Raceme Blight (*Botrytis cinerea*)

Blights caused by *Botrytis* occur during flowering and destroy the flowers. The amount of reduction to crop yield is unknown.

Botrytis blights are more common during rainy seasons or under foggy conditions. Disease is more prevalent in cooler areas and at higher elevations. Areas where air circulation is lower and planting densities are higher are more susceptible to *Botrytis* blights.

Chemical Controls

Fungicides are registered but not used. It is not economical to apply pesticides because the spray has to cover the entire flowering area of tree blights.

Other pest management aids

- Spacing. *Botrytis* blight prevention is considered when determining planting densities.
- Pruning encourages better air flow.
- Keep lower portions of wind breaks clean (foliage-free) for good aeration.

Critical Needs for *Botrytis* blights

Research needs:

- Research composition, efficacy and application of compost teas
- How to regulate nutrition to prevent excessive canopy development for growers who do not use growth regulators
- Fungicide application technology.
- Pesticide efficacy, timing, and rates.

Regulatory needs:

- None.

Education needs:

- Teach small farmers about nutrition to prevent excessive canopy development(?).

3. Macadamia Quick Decline

Macadamia quick decline (MQD) kills affected trees rapidly after onset of symptoms. Trees may die 2-3 months after the initial symptoms of yellowing and browning of some leaves in the canopy.

Historically, MQD had been the most important concern of the macadamia nut industry. Fewer trees are being lost, but some orchards still routinely lose trees to MQD. However, the Hawai'i Agricultural Statistics Service has not collected data regarding MQD losses since 1998 because of the decline in the rate of loss. Dead trees are replaced with varieties which are more resistant to MQD. MQD-resistant varieties are used for new plantings and for re-plantings.

MQD has been the subject of extensive research, but its cause has not been established and the interaction of organisms and environmental factors contributing to the disease syndrome have not been determined. There is substantial evidence that excess soil moisture may be a critical factor in MQD development. MQD occurs most frequently in high rainfall areas.

Chemical Controls

- None currently registered.

Other pest management aids

- Cultivar and rootstock selection.
- Removal of diseased trees (also helps remove reservoirs of other pests.)
- Adequate site preparation reduces incidence of decline.
- Injury avoidance.
- Pruning and spacing.
- Avoid cultural practices that affect drainage. Maintain good drainage.
- Mulching may help as long as it doesn't impede drainage.

Critical Needs for macadamia quick decline

Research needs

- Evaluation and development of resistant cultivars and rootstocks.

Regulatory needs

- None.

Education needs

- Educate growers about maintaining adequate drainage.
- Educate growers about good sanitation practices.

4. Macadamia Root Rot (*Kretzschmaria clavus*)

Macadamia root rot kills affected trees over several years. It most often occurs in areas with poor drainage, but it is rarely seen. Now considered to be a secondary problem, this disease is no longer a serious concern.

Chemical Controls

- Fungicides are not used because macadamia root rot is so rare.

Other pest management aids

- Proper orchard establishment.
- Cultivar selection.
- Removal of diseased trees.
- Avoid soil compaction.
- Injury avoidance.
- Pruning and spacing.

5. Potential Invasive Diseases

Critical Needs to prevent invasive pests

Regulatory needs:

- Maintain phytosanitary requirements.
- Provide a list of concerns to USDA Animal Plant Health Inspection Service-Plant Protection and Quarantine (APHIS-PPQ).
- Contact Hawai'i Department of Agriculture Plant Quarantine Branch (HDOA-PQB).

Nematode Pests

The impacts of nematodes on macadamia production are unknown. No treatments are made for them. Nematodes are not yet a problem in macadamia anywhere in Hawai'i.

Weeds

Weed management is an important component in macadamia nut production because weeds compete for water and nutrients. They also provide shelter for insect pests and their predators and can enhance or reduce insect damage. Weeds can make rodent management more difficult. Weeds can also interfere with harvesting. The orchard floor must be free of weeds to efficiently harvest nuts on the ground manually or with machines. Herbicides with short pre-harvest-intervals provide the grower with greater flexibility to manage weeds without having to delay harvest and negatively affect nut quality.

1. Grasses

Grass weeds prevent soil erosion and provide mulch material. They also compete for nutrients and water and impede harvesting. Control is done before harvesting, but weed control and mowing are activities which occur throughout the year. Control methods may vary with different harvesting methods.

There are minor differences in weed problems in different growing locations based on the amount and frequency of rainfall.

Chemical Controls

- Atrazine (Aatrex, Atrazine)
 - Efficacy: Good for certain species (pre-emergence)
 - Advantages/Disadvantages: Used as a spot treatment/Groundwater concerns.
- Diuron (Diuron, Direx, Karmex)
 - Disadvantage: Phytotoxic to the trees, so not commonly used.
- Glyphosate (Roundup, Buccaneer, Gly-Flo, Gly-Star, Honcho, Mirage)
 - Efficacy: Excellent
 - Advantages/Disadvantages: Cheap, safe for workers to use/ Not good for young trees—stunts them.
- Oryzalin (Oryza Ag, Surflan, Oryzalin)
 - Efficacy: Fair (preemergence)
 - Advantages/Disadvantages: None
- Oxyfluorfen (Goal)
 - Efficacy: Fair (post emergence) - Excellent (pre-emergence)
 - Advantages/Disadvantages: Can be applied as a broadcast, spot treatments or pre-emergent mixed with gramoxone/Requires water incorporation, rain or irrigation. Needs to be applied when weeds are very small to be an effective post emergence application.
- Paraquat dichloride (Gramoxone)
 - Efficacy: Fair - Good
 - Advantages/Disadvantages: Quick kill, complements glyphosate/Worker protection issues.
- Pelargonic acid (Scythe)
 - Efficacy: Poor

- Simazine (Princep, Simazine)
 - Efficacy: Good (pre-emergence)
 - Disadvantages: Short window of opportunity to spray and has groundwater concerns; can't spray when nuts are on ground.

Other pest management aids

- Mowing provides additional benefits: mulches, reduces nutrient competition, reduces weed seed bank, and conditions the orchard floor. However a disadvantage is that mowing must be done **constantly**.
- Sheep are effective and available; however there are concerns that sheep may transmit human disease pathogens.
- Goats also may transmit human disease pathogens. Goats have other disadvantages because the goats will eat the trees and are more selective in what they'll eat.

Critical Needs for grass weeds:

Research needs

- Research mulching as a tool to control grass weeds.
- Research on varieties of permanent grasses that can tolerate shading and can be used for erosion control.

Regulatory needs

- None.

Education needs

- None.

2. Broadleaves and Sedges

Broadleaf weeds prevent soil erosion and provide mulch material. They also compete for nutrients and water and impede harvesting. Some broadleaf weeds are hosts for stinkbugs.

Broadleaf weeds present problems year-round for macadamia growers in Hawai'i. Different species are problems in different areas. In particular, *maile pilau* is a problem in wetter areas.

Herbicides currently registered:

- Atrazine (Aatrex, Atrazine)
 - Efficacy: Good (pre-emergence)
 - Disadvantages: Groundwater concerns
- 2,4-D (2,4-D Amine, Formula 40, Saber, Savage, Weedar, Weedestroy)
 - Efficacy: Good (preemergence and postemergence)
 - Advantage: Used outside of orchards for weed control that eliminates them as a host to stinkbugs.

- Glyphosate (Roundup, Buccaneer, Gly-Flo, Gly-Star, Honcho, Mirage)
 - Efficacy: Fair - Good
 - Advantages/Disadvantages: Cheap and safe for workers to use/Not good for young trees because it can stunt them.
- Oryzalin (Oryza Ag, Surflan, Oryzalin)
 - Efficacy: Fair
 - Advantages/Disadvantages: None
- Oxyfluorfen (Goal)
 - Efficacy: Excellent (preemergence)
 - Advantages/Disadvantages: Can be applied as a broadcast, spot treatments, or pre-emergent, mixed with gramoxone/Requires water incorporation.
- Paraquat dichloride (Gramoxone)
 - Efficacy: Good - Excellent
 - Advantages/Disadvantages: Quick kill and complements glyphosate/ It does have worker protection issues
- Pelargonic acid (Scythe)
 - Efficacy: Poor

Other pest management aids

- Mowing provides additional benefits: mulches, reduces nutrient competition, reduces weed seed bank, and conditions the orchard floor. However there are disadvantages: mowing must be done **constantly**; and mowing results in rapid migration of the stink bugs to the trees.

Critical Needs for broadleaf weeds and sedges

Research needs

- Identify effective natural enemies for *maile pilau*.
- Alternatives for resistance problem with Roundup Ultra.
- Develop non-restrictive pesticides options for small growers who may have difficulty getting certified.

Regulatory needs

- None.

Education needs

- Pesticide training for restricted-use pesticide application.

Vertebrate Pests

1. Roof rats (*Rattus rattus*)

Roof rats eat nuts both on trees and the ground. They also eat immature nuts. Roof rats present a problem year-round. They damage an estimated 5 to 10 percent of the nut crop in Hawaiian macadamia orchards. They gnaw holes 1/4-1/2 inch in diameter through the shell and consume the kernel. Rats may contribute to immature nut counts by knocking or

dropping nuts from trees during their foraging. Rats burrow and nest in cavities and crevices in the porous lava rock substrate or build nests from leaf clippings in the tree canopy.

Orchards with denser canopies are more prone to higher populations and thus incur more damage. Interlocking branches facilitate movement of rats among mature trees.

There was an unusually high rat infestation at a large macadamia orchard in 2002. USDA researchers conducted a 6 month study of the problem and they found populations of both the Polynesian (*Rattus exulans* ssp. *hawaiiensis*) and Norwegian (*Rattus norvegicus* ssp. *norvegicus*) species. Finding these species was unexpected. Rat infestations have not been nearly as severe since 2002.

Chemical Controls

- Diphacinone (Ramik Mini-Bars)
 - Efficacy: Poor
 - Disadvantages: Not useful because one feeding doesn't kill the rat; must keep bait box off the ground; very expensive to bait orchard
- Zinc phosphide (Prozap, ZP)
 - Efficacy: Fair - Good
 - Disadvantages: Environmental concerns; hazards to non-target animals

Other pest management aids

- Trapping is not practical for large acreage.
- Owl boxes are ineffective.

Critical Needs for roof rat - None

2. Feral Pigs

Feral pigs eat macadamia nuts. They can also damage young trees and destroy irrigation systems. Feral pigs cause problems year-round.

Chemical Controls

- None.

Other pest management aids:

- Shooting.
- Trapping.
- Fencing: very expensive.

Critical Needs for feral pigs - None

Overall Critical Needs for Macadamia Nut Production in Hawai‘i

Research

- Biology, control and monitoring of insect pests (stinkbug; *Cryptophlebia* spp.: koa seedworm moth and litchi fruit moth; and tropical nut borer).
- Improve rootstock for macadamia nut disease resistance.
- Evaluate biocontrol agents to control stinkbug and *Cryptophlebia*.
- Assess economic impact and thresholds of Hawaiian flower and red-banded thrips, and mites.
- Screen pesticides and pesticide application methods (including baiting).
- Market assessment for promotion of local biocontrol businesses.
- Evaluate organic foliar sprays and compost teas on insect and disease pests.

Regulatory

- “Strict quarantine regulations” on all macadamia plants and plant parts, including kernels.
- Ban importation of raw kernels into Hawai‘i.

Education

- Prepare educational materials or diagnostic materials for HDOA and APHIS to recognize serious pests
- Educate growers, purchasers of kernels, retailers, etc., about the risks of importing pests.

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Table 1. Description of Pests and Pathogens of Macadamia Nut

Pest/Pathogen	Symptoms
INSECT PESTS	
<p>Koa seedworm moth (<i>Cryptophlebia illepada</i>) and Litchi fruit moth (<i>Cryptophlebia ombrodelta</i>)</p>	<p>The koa seedworm moth and litchi fruit moth cause the same types of damage.</p> <p>Eggs are laid on the surface of macadamia nuts. After 3-5 days, caterpillars emerge and bore through the husk. Tunneling and webbing on kernels provide strong evidence of feeding. Kernel damage is rare because females normally select larger (older) nuts for oviposition and larvae do not have enough time to burrow into the kernel before the shell hardens. Nuts affected by feeding fall within 3-4 weeks, resulting in significantly higher abortion rates. Nuts which are larger but fall before they reach their full oil content may be a major cause of immature nuts observed by processors.</p>
<p>Red-banded thrips (<i>Selenothrips rubrocinctus</i>)</p>	<p>Damage is restricted to the outer surface of nuts with no impact on nut drop, maturation or nut quality. When populations increase to abnormal levels, leaves, especially recently hardened leaves, may be bronzed or damaged. This damage may become severe enough to reduce tree growth and vigor by destroying the productivity of the growth flush for the current season.</p> <p>In the nursery where grafted macadamia trees are propagated, serious outbreaks of RBT can arrest the development of rootstock and grafted trees</p>
<p>Southern green stinkbug (<i>Nezara viridula</i>)</p>	<p>The stinkbug inserts its hollow needle-like mouthpart into the nut and injects saliva into the kernel. The saliva liquifies the tissue around the tip of the mouthparts and the bug consumes the liquid. This feeding activity causes pitting of the kernel. Nuts infested on the ground may also have white discoloration. Heavy infestation on nuts that are not fully sized often results in premature abscission.</p> <p>Damage occurs when nuts are in the trees or within approximately the first week after dropping. The damage rate for nuts on the ground is about four times greater than for nuts in the trees. Southern green stinkbugs strongly prefer green nuts rather than dried.</p>

Pest/Pathogen**Symptoms**

INSECT PESTS (continued)

Tropical nut borer
(*Hypothenemus obscurus*)

TNB degrades nut quality by boring holes through the shell and laying eggs within the kernel. TNB prefers nuts that have dried to a low moisture content: the sticktights and mature nuts which have fallen from the trees and have been on the ground for more than one week.

OTHER INVERTEBRATE PESTS

Broad mite
(*Polyphagotarsonemus latus*)

The broad mite utilizes piercing and sucking mouthparts to damage fruits, flowers and young leaves. The most significant damage occurs when mites feed on young developing flowers. Heavy mite feeding may result in discoloration, distortion, and abscission of flower buds. Infested flowers do not set fruit. The husk may be bronzed when mites feed on large nuts. However, bronzing of the husk does not affect nut quality. Broad mites may also attack growth flushes. This damage is most severe in nurseries or in young transplanted trees.

PATHOGENS

Macadamia quick decline

Initial symptoms are yellowing and browning of some leaves in the canopy. Trees may die 2-3 months after the appearance of initial foliage symptoms.

Macadamia root rot
(*Kretzschmaria clavus*)

Affected trees grow poorly and have few leaves. Smooth or slightly knobby black fungal spores appear on the bark of the trunk at the soil line and surface of exposed roots. Another common symptom is the formation of new shoots at the base of trees. Trees decline over a period of years rather than rapidly as in the case of MQD. Trees that decline are usually 10-12 years old.

Pest/Pathogen**Symptoms**

PATHOGENS (continued)

Raceme blights
(*Botrytis cinerea*)

Raceme blight caused by *B. cinerea* reduces nut set and crop yields. Infections on the rachis or flowers initially appear as tiny necrotic flecks. The entire raceme can be affected within 2 days. Blighted racemes are blackish-brown, and under humid conditions are covered with grayish mycelia. Brown racemes can dry and remain on the tree until after the flowering season.

Raceme and blossom blights
(*Phytophthora capsici*)

Raceme and blossom blights caused by *P. capsici* usually affect all flower stages and developing nuts, reducing nut set and crop yields. The disease progresses rapidly. Blighted racemes die, becoming brownish in color and remain on the tree for months. Infection on nuts develops on the husk and causes a black-brownish discoloration. If infection occurs before shell development, the fungus invades and destroys the kernel and the diseased fruit abscises.

Table 2. Efficacy of Pest Management Tools for Control of Insects & Other Invertebrate Pests on Macadamia Nuts in Hawai'i.

Management Tool:	Pest						
	Southern Green Stinkbug	Tropical Nut Borer	Koa Seedworm	Litchi Fruit Moth	Red-Banded Thrips	Mites	Hawaiian Flower Thrips
Registered Pesticides							
azadirachtin (Neemix, Agroneem)	P	?	P	P	?	?	?
<i>Bacillus thuringiensis</i> (Agree, Xentari, Dipel)	-	-	?	P	-	-	-
lambda-Cyhalothrin (Warrior)	?	?	?	?	?	?	?
Z-8-dodecenyl acetate (CheckMate)	-	-	P	F	-	-	-
garlic oil	?	?	?	?	?	?	?
hydramethylnon (CB 441, Eclipse, Seige)	?	?	?	?	?	?	?
kaolin (Surround)	?	?	?	?	?	?	?
malathion	G	?	-	-	F-G	?	F-G
phosmet (Imidan)	?	?	?	?	?	?	?
piperonyl butoxide + pyrethrins (Pyrenone, Pyronyl)	?	?	?	?	?	?	?
potassium salts of fatty acids (M-pede)	?	?	?	?	?	?	?
propargite (non-bearing) (O-mite)	-	-	-	-	-	?	?
pyrethrins + rotenone (Pyrellin)	?	?	?	?	?	?	?
pyridaben (Pyramite)	-	-	-	-	-	?	?
pyriproxyfen (Esteem)	?	?	?	?	?	?	?
spinosad (Entrust,GF-120, Success)	?	?	?	?	?	?	?
sulfur (Micro Sulf, Microthiol)	-	-	-	-	-	F	-
SLN Registered Materials							
endosulfan (Thionex)	F-G	P	?	?	?	-	-
ethephon (Ethrel)	-	P	-	-	-	-	-

Efficacy rating scale:

E = excellent (90-100% control), G = good (80-90% control),

F = fair (70-80% control), P = poor (<70% control),

? = no data, more research needed, - = not applicable or not used,

+ = no data, but successful on other related organisms, * = not enough experience to rate.

Table 2. Efficacy of Pest Management Tools for Control of Insects & Other Invertebrate Pests on Macadamia Nuts in Hawai'i (continued).

Management Tool:	Pest						
	Southern Green Stinkbug	Tropical Nut Borer	Koa Seedworm	Litchi Fruit Moth	Red-Banded Thrips	Mites	Hawaiian Flower Thrips
Cultural/Non-chemical Control Aids							
frequent harvesting	-	E	-	-	-	-	-
removing infested materials	-	E	-	-	-	-	-
cultivar selection	?	G	?	?	?	F	?
<i>Cathartus quadricollis</i>	-	G	-	-	-	-	-
<i>Leptophloeus</i> spp.	-	G	-	-	-	-	-
<i>Trissolcus basal</i> <i>is</i> , <i>Trichopoda pilipes</i> , and <i>Trichopoda pennipes</i>	G	-	-	-	-	-	-
weed control	?	-	-	-	?	?	?
other predators	?	?	?	?	?	?	?
other parasites	?	?	?	?	?	?	?

Efficacy rating scale:

E = excellent (90-100% control), G = good (80-90% control),

F = fair (70-80% control), P = poor (<70% control),

? = no data, more research needed, - = not applicable or not used,

+ = no data, but successful on other related organisms, * = not enough experience to rate.

Table 3. Efficacy of Pest Management Tools for Control of Disease and Nematode Pests on Macadamia Nut in Hawai'i.

Management Tool:	Pest				
	Macadamia Quick Decline	Macadamia Root Rot	Raceme Blight (<i>Botritis cinerea</i>)	Raceme & Blossom Blights (<i>Phytophthora capsici</i>)	Nematodes
Registered Materials -- Fungicides					
azoxystrobin (Abound)	-	-	?	G	-
copper hydroxide (Bac-Stop, Champ, Kocide)	-	-	P	P	-
cuprous oxide (Nordox)	-	-	P	P	-
dichloropropene/chloropicrin (Telone)	-	-	-	-	?
fosetyl-AI (Aliette)	-	-	-	F-G	-
harpin protein (Messenger)	-	-	?	?	-
metalaxyl (Ridomil)	-	-	-	G	-
<i>Myrothecium verrucaria</i> (DiTera)	-	-	?	-	?
phosphorous acid (Phostrol)	-	-	-	G	-
<i>Trichoderma harzianum</i> Rifai (RootShield)	-	-	-	-	-
Cultural/Non-chemical Control Aids					
cultivar selection	E	E	-	-	?
removal of diseased trees	G	G	-	-	?
avoid soil compaction	E	E	-	-	?
injury avoidance	F	F	-	-	-
pruning and spacing	-	-	E	E	-

Rating Scale: E = excellent (90-100% control), G = good (80-90% control), F = fair (70-80% control), P = poor (<70% control), ? = no data/more research needed, - = not applicable or not used, * = not enough experience to rate

Table 3. Efficacy of Pest Management Tools for Control of Disease and Nematode Pests on Macadamia Nut in Hawai'i (continued).

Management Tool:	Pest				
	Macadamia Quick Decline	Macadamia Root Rot	Raceme Blight (<i>Botritis cinerea</i>)	Raceme & Blossom Blights (<i>Phytophthora capsici</i>)	Nematodes
Registered Materials -- Nematicides					
azadirachtin	?	?	?	?	-
dichloropropene/chloropicrin	-	-	-	-	?
methyl bromide	-	-	-	-	-
<i>Myrothecium verrucaria</i>	-	-	-	-	-

Rating Scale: E = excellent (90-100% control), G = good (80-90% control), F = fair (70-80% control), P = poor (<70% control), ? = no data/more research needed, - = not applicable or not used, * = not enough experience to rate

Table 4. Efficacy of Pest Management Tools for Control of Weed Pests in Macadamia Nut in Hawai‘i.

Management Tool:	Grasses	Broadleaves & Sedges	Comments
Registered Materials			
Pre-emergence:			
atrazine (Aatrex, Atrazine)	G	G	
2,4-D (2,4-D Amine, Formula 40, Saber, Savage, Weedar, Weedestroy)	-	G	Not used in orchards
diuron (Diuron, Direx, Karmex)	-	-	
oryzalin (Oryza Ag, Surflan, Oryzalin)	F	E	
oxyfluorfen (Goal)	G-E	G-E	Not effective on sedges
simazine (Princep, Simazine)	-	G	
Post-emergence:			
atrazine (Aatrex, Atrazine)	P	G	
2,4-D (2,4-D Amine, Formula 40, Saber, Savage, Weedar, Weedestroy)	-	G	Not used in orchards
glyphosate (Roundup, Buccaneer, Gly-Flo, Gly-Star, Honcho, Mirage)	G-E	G	
oxyfluorfen (Goal)	F-G	F-G	
paraquat dichloride (Gramoxone)	F-G	G-E	Not effective on sedges
pelargonic acid (Scythe)	P	P	
sethoxydim (Poast)	?	-	
Cultural/Non-chemical Control Aids			
mowing	E	E	
goats	G	F	
sheep	G	F	

Rating Scale: E = excellent (90-100% control), G = good (80-90% control), F = fair (70-80% control), P = poor (<70% control), - = not applicable or not used

Table 5. Toxicity of Pest Management Tools to Beneficials of Macadamia Nut in Hawai‘i.

Management Tool:	Beneficial					
	<i>Cathartus quadricollis</i>	<i>Leptophloeus</i> spp.	<i>Trissolcus basalis</i>	<i>Trichopoda pilipes</i>	Other predators	Other parasites
Registered Materials						
Insecticides:						
azadirachtin (Neemix, Agroneem)	-	-	-	-	-	-
<i>Bacillus thuringensis</i> (Agree, Xentari, Dipel)	-	-	-	-	-	-
lambda-Cyhalothrin (Warrior)	?	?	?	?	?	?
Z-8-dodecenyl acetate (CheckMate)	-	-	-	-	-	-
endosulfan (Thionex, Thiodan)	+	+	+	+	+	+
ethophon (Ethrel)	-	-	-	-	-	-
hydramethylnon (CB 441, Eclipse, Seige)	-	-	-	-	-	-
kaolin (Surround)	-	-	?	-	?	?
magnesium phosphide (Fumi-Cels, Fumi-Strip)	N/A	N/A	N/A	N/A	N/A	N/A
malathion	+	+	+	+	+	+
phosmet (Imidan)	+	+	+	+	+	+
piperonyl butoxide + pyrethrins (Pyrenone, Pyronyl)	+	+	+	+	+	+
potassium salts of fatty acids (M-pede)	-	-	+	-	+	?
propargite (non-bearing) (O-mite)	?	?	?	?	+	?
					predatory mites	

Rating Scale: + = toxic or detrimental; - = not known to be toxic or detrimental; ? = no data, more research needed, * = not enough experience to rate

Table 5. Toxicity of Pest Management Tools to Beneficials of Macadamia Nut in Hawai‘i (continued).

Management Tool:	Beneficial					
	<i>Cathartus quadricollis</i>	<i>Leptophloeus</i> spp.	<i>Trissolcus basalis</i>	<i>Trichopoda pilipes</i>	Other predators	Other parasites
Insecticides (continued):						
pyrethrins + rotenone (Pyrellin)	+	+	+	+	+	+
pyridaben (Pyramite)	?	?	?	?	+ predatory mites	?
pyriproxyfen (Esteem)	-	-	-	-	-	-
spinosad (Entrust,GF-120, Success)	?	?	?	?	?	?
sulfur (Micro Sulf, Microthiol)	-	-	-	-	+ predatory mites	-
Fungicides/Nematicides:						
azadirachtin (Neemix, Agroneem)	-	-	-	-	-	-
azoxystrobin (Abound)	-	-	-	-	-	-
copper hydroxide (Bac-Stop, Champ, Kocide)	-	-	-	-	-	-
cuprous oxide (Nordox)	-	-	-	-	-	-
dichloropropene/chloropicrin (Telone)	+	+	?	?	?	?
fosetyl-Al (Aliette)	-	-	-	-	-	-
harpin protein (Messenger)	-	-	-	-	-	-

Rating Scale: + = toxic or detrimental; - = not known to be toxic or detrimental; ? = no data, more research needed, * = not enough experience to rate

Table 5. Toxicity of Pest Management Tools to Beneficials of Macadamia Nut in Hawai'i (continued).

Management Tool:	Beneficial					
	<i>Cathartus quadricollis</i>	<i>Leptophloeus</i> spp.	<i>Trissolcus basalis</i>	<i>Trichopoda pilipes</i>	Other predators	Other parasites
Fungicides/Nematicides (continued):						
metalaxyl (Ridomil)	-	-	-	-	-	-
<i>Myrothecium verrucaria</i> (DiTera)	-	-	-	-	-	-
phosphorous acid (Phostrol)	-	-	-	-	-	-
<i>Trichoderma harzianum</i> Rifai (RootShield)	-	-	-	-	-	-
Herbicides:						
atrazine (Aatrex, Atrazine)	*	*	*	*	*	*
2,4-D (2,4-D Amine, Formula 40, Saber, Savage, Weedar, Weedestroy)	*	*	*	*	*	*
diuron (Diuron, Direx, Karmex)	*	*	*	*	*	*
fluazifop-P-butyl (Fusilade)	*	*	*	*	*	*
isoxaben (Gallery)	*	*	*	*	*	*
isoxaben + oryzalin (Snapshot 80DF)	*	*	*	*	*	*
glufosinate-ammonium (Rely)	*	*	*	*	*	*
glyphosate (Roundup, Buccaneer, Gly-Flo, Gly-Star, Honcho, Mirage)	*	*	*	*	*	*

Rating Scale: + = toxic or detrimental; - = not known to be toxic or detrimental; ? = no data, more research needed, * = not enough experience to rate

Table 5. Toxicity of Pest Management Tools to Beneficials of Macadamia Nut in Hawai‘i (continued).

Management Tool:	Beneficial					
	<i>Cathartus quadricollis</i>	<i>Leptophloeus</i> spp.	<i>Trissolcus basalis</i>	<i>Trichopoda pilipes</i>	Other predators	Other parasites
Herbicides (continued):						
oryzalin (Oryza Ag, Surflan, Oryzalin)	*	*	*	*	*	*
oxyflurofen (Goal)	*	*	*	*	*	*
paraquat dichloride (Gramoxone)	*	*	*	*	*	*
pelargonic acid (Scythe)	+	+	+	+	+	+
sethoxydim (Poast)	*	*	*	*	*	*
simazine (Princep, Simazine)	*	*	*	*	*	*
trifluralin + isoxaben (Snapshot 2.5 TG)	*	*	*	*	*	*
EPA Exempt Chemicals						
garlic oil	?	?	?	?	?	?
Pipeline Pest Management Tools:						
Cultural/Non-chemical Controls:						
frequent harvesting	+	+	-	-	-	-
removing infested materials	+	+	-	-	-	-

Rating Scale: + = toxic or detrimental; - = not known to be toxic or detrimental; ? = no data, more research needed, * = not enough experience to rate

Table 5. Toxicity of Pest Management Tools to Beneficials of Macadamia Nut in Hawai‘i (continued).

Management Tool:	Beneficial					
	<i>Cathartus quadricollis</i>	<i>Leptophloeus</i> spp.	<i>Trissolcus basalis</i>	<i>Trichopoda pilipes</i>	Other predators	Other parasites
Cultural/Non-chemical Controls (continued):						
cultivar selection	-	-	-	-	-	-
<i>Cathartus quadricollis</i>	N/A	?	?	?	?	?
<i>Leptophloeus</i> spp.	?	N/A	?	?	?	?
<i>Trissolcus basalis</i> , <i>Trichopoda pilipes</i> , and <i>Trichopoda pennipes</i>	?	?	?	N/A	?	?
weed control	?	?	?	?	?	?
other predators	?	?	?	?	?	?
other parasites	?	?	?	?	?	?
cultivar selection	?		?	?	?	?
removal of diseased trees	?		?	?	?	?
avoid soil compaction	-	-	-	-	-	-
injury avoidance	-	-	-	-	-	-
pruning and spacing	-	-	-	-	-	-
mowing	?	?	?	?	?	?
goats/sheep	?	?	?	?	?	?

Rating Scale: + = toxic or detrimental; - = not known to be toxic or detrimental; ? = no data, more research needed, * = not enough experience to rate

