# PEST MANAGEMENT STRATEGIC PLAN FOR WATERCRESS PRODUCTION IN HAWAII



Workshop Summary
May 25, 2004
Pearl City Urban Garden Center
University of Hawaii at Manoa
Honolulu, Hawaii

Editors
John J. McHugh, Jr.
Lynne N. Constantinides

Contact: Cathy Tarutani

e-mail: cathy@hpirs.stjohn.hawaii.edu

(808) 956-2004

# TABLE OF CONTENTS

Workshop Participants and Contributors	4
Executive Summary	6
Top Priorities for Hawaii Watercress Production	7
Background	9
Economic Importance	9
General Cropping Guidelines	9
Major Pests of Watercress	9
Integrated Pest Management	10
Outline of Plan	11
Invertebrate Pests	11
Diseases	19
Weeds	22
Photos	24
Table 1. Registered Pesticides for Watercress in Hawaii	28
Table 2. Description of Pests and Pathogens of Watercress	31
Table 3. Advantages and Disadvantages of Pesticides for Watercress	34
Table 4. Efficacy of Pest Management Tools for Control of Insects and other Invertebrate Pests on Watercress in Hawaii	
Table 5. Efficacy of Pest Management Tools for Control of Disease Pests on Watercress in Hawaii	38
Table 6. Efficacy of Pest Management Tools for Control of Weed Pests in Watercress in Hawaii	39
Table 7. Toxicity of Pest Management Tools to Beneficials of Watercress in Haw	aii40
Table 8. Pest Control Measures by Watercress Crop Stage	42

Table 9. Worker Activity Table for Watercress	45
---	----

# WORKSHOP PARTICIPANTS AND CONTRIBUTORS

John Armstrong Research Leader/Research Entomologist, USDA Agricultural

Research Service, Pacific Basin Agriculture Research Center,

Hilo

Wayne Borth Junior Researcher and Plant Pathologist, Department of Plant and

Environmental Sciences University of Hawaii at Manoa

Luisa Castro Educational Specialist, University of Hawaii at Manoa

Lynne Constantinides Crop consultant; Crop Care Hawaii, LLC

Carl Evensen Associate Extension Specialist, Department of Natural Resources

and Environmental Management, University of Hawaii at Manoa

Steve Fukuda County Extension Agent, University of Hawaii at Manoa

Richard Ha Grower; Mauna Kea Banana

Linda Herbst Assistant Director, Western Region Pest Management Center,

University of California at Davis

Ron Heu Survey Entomologist, Hawaii Department of Agriculture, Plant

Pest Control Branch

James Hollyer Facilitator; Agriculture Development in the American Pacific

Program, University of Hawaii at Manoa

Eric Jang Research Leader/Research Entomologist, USDA Agricultural

Research Service, Pacific Basin Agriculture Research Center,

Hilo

Michael Kawate Pesticide Registration Specialist, University of Hawaii at Manoa

Gerald Kinro Pesticide Specialist, Hawaii Department of Agriculture

Lance Kobashigawa Pesticide Registration Specialist, Hawaii Department of

Agriculture

Chin Nyean Lee Interim Oahu County Administrator, Cooperative Extension

Service, University of Hawaii at Manoa

John McHugh Hawaii Farm Bureau Federation

Don Nakatani Grower, Nakatani Farm, Inc.

Desmond Ogata Research Associate, Agricultural Diagnostic Service Center,

University of Hawaii at Manoa

Darcy Oishi Plant Quarantine Branch, Hawaii Department of Agriculture

Sikhay Sayphone Grower; Sayphone Farm

David Sumida Grower, Sumida Farm, Inc.

Cathy Tarutani Department of Plant and Environmental Sciences, University of

Hawaii at Manoa

Janice Uchida Associate Plant Pathologist, Department of Plant and

Environmental Sciences University of Hawaii at Manoa

#### **EXECUTIVE SUMMARY**

The watercress industry is extremely small. It is not only a minor crop but a microcrop compared to all other agricultural commodities produced in the United States. Additionally, watercress is grown in aquatic environments where there are additional challenges associated with pesticide toxicity to aquatic animals and endangered species. Many of the watercress farms in Hawaii have been in continuous production for over 75 years. During that time there have been numerous challenges including cyclamen mite, diamondback moth, and most recently the phytoplasma disease Aster Yellows. Watercress farmers are keenly aware of their relationship with the environment in which their crop is produced. Because of the care and sensitivity of the growers there have not been any documented adverse environmental impacts of their pest management practices during the entire tenure of their operations. The main pest management challenges of the watercress industry are the availability of effective, environmentally friendly pest control tools. The industry has been exemplary in developing a unique Integrated Pest Management (IPM) program for managing the devastating impact of the diamondback moth during the early 1980's. The current challenge is to devise an equally effective program for managing Aster Yellows so that another 75 plus years of watercress production will be possible and the people of Hawaii can continue to rely on a steady supply of this tasty and delicate aquatic cabbage.

#### TOP PRIORITIES FOR HAWAII WATERCRESS PRODUCTION

#### Research

- Develop resistance to Aster Yellows disease.
- Determine biology and ecology of Aster Yellows.
- Develop multiple control measures and strategies for management of Aster Yellows.
- Develop a "quick test" for determination of infection by Aster Yellows.
- Develop more control measures and strategies for management of the diamondback moth
- Develop more control measures for aphids.
- Develop more control measures for southern green stink bug and *Nysius nemorivagus*.
- Develop resistance to Black Rot.
- Develop more control measures and strategies for management of Black Rot.
- Develop resistance to *Cercospora* leaf spot.
- Develop more control measures and strategies for management of *Cercospora* leaf spot.
- Develop algal control measures.
- Develop more control measures for weeds.
- Develop economic and action thresholds for key pests.
- Investigate resistance management tools.
- Assess market acceptance of genetically engineered watercress.

#### Regulatory

- Strengthen State of Hawaii quarantine of incoming plants and planting material so that the introduction of new watercress pests is minimized.
- Change Hawaii laws and regulations to allow for import of beneficial insects and insect pathogens (natural enemies) for control of key pests.
- Amend Hawaii Revised Statutes to allow for registration of new chemistry pesticides in the state.
- Take a proactive (pre-emptive) approach to registering more pest management tools and options.
- Waiver of licensing fees for new, low-impact (low non-target, mammalian toxicity) chemical and beneficial control organisms.
- Registration of new control measures.
- Inter-island quarantine for new pest species.

#### **Education**

- Identification guide(s) for all watercress pest species.
- Conduct on-farm training to recognize and distinguish key pests.
- Conduct on-farm training to recognize various symptoms of Aster Yellows on watercress and alternative weed hosts.
- Identification of weed and alternative hosts for Aster Yellows and watercress leafhopper.
- Farmer training to distinguish aster leafhopper from other species of leafhoppers found on and adjacent to watercress farms.

- Farmer education in recognizing seasonal conditions which encourage outbreaks of key pests.
- Grower education and training for diamondback moth control measures and resistance management.
- Training sessions on how to grow, manage, and conserve on-farm natural enemy populations.
- Grower education on managing intermittent overhead sprinkling system to minimize Black Rot disease and *Cercospora* leaf spot.
- Consumer education effort to assure public that disease spots on watercress leaves are not harmful to human health.
- Educate lawmakers and regulators regarding pest management challenges in watercress.
- Educate quarantine officials on impact of undesirable pests on watercress industry.
- Hawaii Visitor Bureau education to keep out watercress pest host plants.

#### **BACKGROUND**

#### **Economic Importance**

Watercress is a staple leafy vegetable of diets of people in Hawaii. Historically, all of the demand for watercress has been met by production within the state. Production is limited to a total of 35 acres statewide. Because of the impact of the new disease, Aster Yellows, total production has been reduced from an industry-wide average of 1,000,000 lb. In 2002, an average of 22,857 lb. per acre was produced for a total annual production of approximately 800,000 lb. Total annual farm value for the watercress industry in Hawaii was \$944,000 in 2002 but has been greater than \$1M in previous years.

# **General Cropping Guidelines**

Commercial watercress production requires fresh water from springs or artesian wells for irrigation. Because watercress is a leafy vegetable a high percentage of sunshine is also needed for optimum production so leeward locations are the most suitable for the crop. Growing beds are prepared for watercress by firming with rock and gravel to allow a smooth, even, gravity flow of the irrigation water. The water film is maintained at less than 1 inch across the entire breadth of a watercress bed (Photo 1). Watercress is initially started by laying vegetative tip cuttings, approximately 12 inches in length, on top of the watercress beds in the direction of the water flow (Photo 2). The watercress grows and is ready for harvest within 6 to 7 weeks after planting. All subsequent harvests are grown as ratoons (Photo 3) of the mother crop so that replanting is minimal.

Watercress is grown continuously year-round. Several watercress farms have been in continuous production for over 70 years. Spring or artesian well water is the primary source of irrigation and nutrition needs for the crop. Watercress roots anchor to the beds of the paddies but feed on dissolved minerals in the water. Because the amount of dissolved nutrients in the irrigation water is low most of the watercress farmers use supplemental fertilization to supply adequate crop nutrition.

Watercress is a cool season vegetable crop which does best when day time air temperatures are less than 85°F. A majority of the watercress farms are located in urban or suburban areas of Honolulu on the island of Oahu. Because of this proximity to the city, and the concrete and asphalt heat sinks associated with urban areas, air temperatures are higher than ideal for 7 to 8 months out of the year. Intermittent overhead irrigation is used by watercress farmers to maintain temperatures which are more favorable for watercress growth by cooling through evaporation. Intermittent overhead irrigation is also useful for managing mites and some insect pests of watercress that cannot tolerate the extra moisture in the crop canopy.

#### **Major Pests of Watercress**

The most important insect pests of watercress in Hawaii are diamondback moth (*Plutella xylostella*) and watercress leafhopper (*Macrosteles* sp. nr. *severini*). Diamondback moth has been a pest of watercress in Hawaii for over 50 years and continues to be a challenge because of the ability of the insect to quickly develop resistance to the few insecticide options available to the watercress industry. Watercress leafhopper is a major pest because it transmits a strain of the Aster Yellows phytoplasma. Other invertebrate pests include cyclamen mite (*Stenotarsonemus pallidus*), grass sharpshooters (*Draeculecephala californica, Draeculecephala inscripta*, and *Draeculecephala minerva*), green peach aphid (*Myzus persicae*), buckthorn aphid (*Aphis nasturtii*), imported cabbageworm (*Pieris rapae*), southern green stinkbug (*Nezara*)

viridula), a Lygaeid seed bug (Nysius nemorivagus), and unidentified species of snails and slugs.

The most serious disease of watercress in Hawaii is caused by a strain of the Aster Yellows phytoplasma. Management of this pathogen can only be achieved by controlling its vector, the watercress leafhopper, intensive roguing of symptomatic plants, and complete fallow in severe circumstances. Leaf spotting diseases affecting watercress are black rot (*Xanthomonas campestris*) and *Cercospora* leaf spot (*Cercospora nasturtii*).

Weed pressure is relatively light in watercress fields because of the constantly flooded conditions. The few species that are problematic include California grass (*Brachiaria mutica*), honohono grass (*Commelina diffusa*), and water hyssop (*Bacopa sp.*). These weeds tend to invade watercress beds from the edge of the field and can quickly take over a paddy which is invaded. Additionally, some weed species on field borders can harbor Aster Yellows and be a source of continued spread of the disease when watercress leafhoppers are present.

#### **Integrated Pest Management**

The Hawaii watercress industry is among the smallest in the United States. The size of the industry, and the fact that the crop is aquatic, makes it difficult to register new products for use on the crop because of low economic incentive to pesticide manufacturers and the perceived impact on aquatic species found in watercress fields. Additionally, endemic, indigenous, and endangered species of birds can be found in watercress fields. The Hawaii watercress industry is keenly aware of the impact of pesticide use in the crop. In 1984 the watercress growers developed an Integrated Pest Management (IPM) program that minimizes the use of chemical pesticide sprays and relies heavily on the use of intermittent overhead irrigation, biological control, daily field scouting, and timely applications of pesticides to achieve economic control of key pests. However, the discovery of Aster Yellows in 2002 has undermined crucial elements of the industry IPM approach because of the need for regular pesticide sprays to control the watercress leafhopper that vectors the disease. Some of the insecticides used in the industry for control of watercress leafhopper are targeted for cancellation by the U.S. Environmental Protection Agency. There is an urgent need for target specific, low mammalian, avian, and fish toxicity pesticides that will allow the industry to maintain control of Aster Yellows while encouraging the conservation of natural enemies of key pests.

#### **OUTLINE OF PLAN**

The following is a pest-by-pest analysis of the current pest management practices in watercress production in Hawaii. Non-chemical, cultural, and biological control measures are also presented. A "to do" list for research, regulatory, and education needs is included with each pest analysis. Pests are presented in order of economic importance within each pest section. There is no attempt to prioritize importance between pest groups (e.g. invertebrates vs. pathogens).

#### **INVERTEBRATE PESTS**

# 1. Watercress leafhopper (Macrosteles sp. nr. severini)

The watercress leafhopper is a serious problem on watercress because it is the vector of Aster Yellows (AY) (Photo 4). There is a zero tolerance for the presence of watercress leafhopper because of the high rate of infection. All farms on the island of Oahu are affected. The leafhopper and the disease it carries have not been reported on any other island. The watercress leafhopper is closely related (and may be a "biotype") of the aster leafhopper. This leafhopper is reported to have a broad range of host plants which poses additional challenges to managing the disease. Growers spray insecticides on a regular basis (every 2 weeks) on the watercress crop and also on weeds and cultivated plants within a 50-ft. distance from the edge of the watercress fields. Because of the routine use of insecticides, control of another serious pest of watercress, diamondback moth, has been compromised due to the toxic impact on natural enemies of that pest.

# **Insecticides currently registered:**

- diazinon (Clean Crop Diazinon 500-AG, Diazinon 50W)
  - Efficacy: fair.
  - Limiting factors: registration has been cancelled by EPA with a withdrawal period allowed until May 2006.
  - Advantage/disadvantages: cost is reasonable/hazard to applicator, toxic to beneficial organisms, requires Restricted Use Pesticide applicators license.
- malathion (Atrapa 5E, Drexel Malathion 5EC, Malathion 5, Micro Flo Malathion 5EC, Prozap Malathion 57EC)
  - Efficacy: poor.
  - Advantage/disadvantages: inexpensive/strong smell, hazard to applicator, toxic to beneficial organisms.
- imidacloprid (Provado)
  - Efficacy: excellent.
  - Advantages/disadvantage: safe for applicator, low toxicity to natural enemies/expensive to purchase product.
- azadirachtin (Agroneem, Aza-Direct, Azatin XL, Azatrol, Bon-neem Insecticidal Soap, Ecozin, Ornazin 3%)
  - Efficacy: not known. Seldom used.
  - Disadvantage: very expensive at recommended rates.

#### Other pest management aids:

• Insecticidal soap (Bon-neem Insecticidal Soap, Concern Insect Killing Soap)

#### **Pipeline pest management tools:**

- dinotefuran
  - Efficacy: potentially excellent but research is needed.

### "To do" list for watercress leafhopper:

#### Research needs:

- Study ecology and behavior of the insect.
- Evaluate whether a fallow period eliminates the leafhopper.

# **Regulatory needs:**

• Need more effective pesticide registrations.

#### **Education needs:**

• Develop scouting and identification programs.

#### 2. Diamondback moth (*Plutella xylostella*)

Diamondback moth is a perennial pest that can be found on all islands and growing regions and is specific to cruciferous plants (cabbages – head and Chinese, broccoli, cauliflower, radish, sweet alyssum, and watercress). It has been reported as a pest of watercress in Hawaii for over 50 years. Damage is caused by feeding of the caterpillars on the leaves and growing shoots of the plant and all growth stages are affected. Heavy infestations of diamondback moth can destroy an entire field. Activity is higher during the warm, dry time of the year (May through November). Action threshold for treatment is one caterpillar per individual watercress plant. Increased bird (mostly sparrow) activity in fields can also be used as an indicator for diamondback moth activity as the birds are attracted by caterpillar feeding. Adult diamondback moths are less than ½ inch in length (Photo 5) and can lay up to 300 eggs during the adult stage. Control of diamondback moth has been obtained by growers through a combination of intermittent overhead irrigation (Photo 6) and biological control by the parasitic wasp *Cotesia plutellae* (Photo 7). However, recent intensification of chemical insecticides used to control the watercress leafhopper has negatively impacted the biological component used for diamondback moth control, thus complicating control efforts. Diamondback moth has been documented to develop resistance to all insecticides used against it rendering long term control methods with chemicals unsustainable.

# **Insecticides currently registered:**

- diazinon (Clean Crop Diazinon 500-AG, Diazinon 50W)
  - Efficacy: poor.
  - Limiting factors: registration has been cancelled by EPA with a withdrawal period allowed until May 2006.
  - Advantage/disadvantages: cost is reasonable/hazard to applicator, toxic to beneficial organisms, requires Restricted Use Pesticide applicators license.
- malathion (Atrapa 5E, Drexel Malathion 5EC, Malathion 5, Micro Flo Malathion 5EC, Prozap Malathion 57EC)
  - Efficacy: poor.
  - Advantage/disadvantages: inexpensive/strong smell, hazard to applicator, toxic to beneficial organisms.
- spinosad (Success)

- Efficacy: good. Used sparingly (no more than 4 times a year) to preserve effectiveness.
- Advantages/disadvantages: safe, target specific, soft on natural enemies/expensive, resistance potential.
- *Bacillus thuringiensis* (Crymax, Javelin, M-C Bioinsecticide, Monterey Caterpillar Clobber, Ortho B.T. Biospray)
  - Efficacy: poor to fair.
  - Advantages/disadvantages: safe, target specific, soft on natural enemies/not very effective, resistance is a problem.
- azadirachtin (Agroneem, Aza-Direct, Azatin XL, Azatrol, Bon-neem Insecticidal Soap, Ecozin, Ornazin 3%)
  - Efficacy: not known. Seldom used.
  - Disadvantage: very expensive at recommended rates.
- (Z)-11-Hexadecenal + (Z)-11-Hexadecenyl acetate (Checkmate DBM-F)
  - Efficacy: not known. Seldom used.
  - Advantages/disadvantage: safe, target specific, soft on natural enemies/expensive.

# Other pest management aids:

- Intermittent overhead irrigation
- Cotesia plutellae (parasitic wasp)
- Trap cropping

# Pipeline pest management tools:

• None.

#### "To do" list for diamondback moth:

#### Research needs:

- Investigate the effectiveness and optimum application methods of mating disruption pheromones.
- Develop new insecticides.
- Resistance management program for watercress.
- Develop economic thresholds for life stages.
- Look for additional natural enemies.

#### **Regulatory needs:**

- Register insecticides on watercress that are used on other cruciferous crops for diamondback moth control.
- Allow for direct importation of diamondback moth natural enemies.

#### **Education needs:**

- Educate public that diamondback moth damaged watercress is safe to eat.
- Disseminate economic threshold information, once developed, to watercress growers.

# 3. Buckthorn aphid (Aphis nasturtii) and Green Peach aphid (Myzus persicae)

Aphids are perennial pests that become more serious during warm and windy times (May through November) of the year. Aphids attack all stages of watercress growth. Heavy infestations can cause stunting and distortion of new shoots. Light infestations, while not directly injurious to the watercress crop, present an unsightly and unappetizing appearance causing consumers to reject the harvested product. Treatment threshold is determined by presence or absence of the insect pest. Resistance to pesticides is a concern because of limited tools available for their control.

# **Insecticides currently registered:**

- diazinon (Clean Crop Diazinon 500-AG, Diazinon 50W)
  - Efficacy: fair to good.
  - Limiting factors: registration has been cancelled by EPA with a withdrawal period allowed until May 2006.
  - Advantage/disadvantages: cost is reasonable/hazard to applicator, toxic to beneficial organisms, requires Restricted Use Pesticide applicators license.
- malathion (Atrapa 5E, Drexel Malathion 5EC, Malathion 5, Micro Flo Malathion 5EC, Prozap Malathion 57EC)
  - Efficacy: poor.
  - Advantage/disadvantages: inexpensive/strong smell, hazard to applicator, toxic to beneficial organisms.
- imidacloprid (Provado)
  - Efficacy: excellent.
  - Advantages/disadvantage: safe for applicator, low toxicity to natural enemies/expensive to purchase product.
- azadirachtin (Agroneem, Aza-Direct, Azatin XL, Azatrol, Bon-neem Insecticidal Soap, Ecozin, Ornazin 3%)
  - Efficacy: poor. Seldom used.
  - Disadvantage: very expensive at recommended rates.

#### Other pest management aids:

- Intensive scouting to determine timing of control application(s).
- Parasites and predators (parasitic wasps, ladybugs, Syrphid flies)
- Insecticidal soap (Bon-neem Insecticidal Soap, Concern Insect Killing Soap)

#### Pipeline pest management tools:

- dinotefuran
  - Efficacy: potentially excellent but research is needed.

#### "To do" list for aphids:

#### Research needs:

- Investigate effectiveness of dinotefuran.
- Rear and release natural enemies.
- Develop other aphid control measures to manage resistance.

#### **Regulatory needs:**

• Allow direct importation of natural enemies.

• Clarify use of insecticides in aquatic environments.

#### **Education needs:**

None

# 4. Stinkbugs: Southern green stink bug (*Nezara viridula*) and a Lygaeid bug (*Nysius spp.*)

Stinkbugs are found on all the Hawaiian islands and are occasional pests mostly in the months of May and June. Both types of stinkbugs feed on stems and leaf petioles causing irreversible wilting above the feeding point. Heavy infestations can cause complete crop loss. Stinkbugs will attack all stages of watercress growth during periods of high pressure. Established natural enemies are effective in controlling Southern Green stinkbug throughout most of the year.

# **Insecticides currently registered:**

- diazinon (Clean Crop Diazinon 500-AG, Diazinon 50W)
  - Efficacy: good.
  - Limiting factors: registration has been cancelled by EPA with a withdrawal period allowed until May 2006.
  - Advantage/disadvantages: cost is reasonable/hazard to applicator, toxic to beneficial organisms, requires Restricted Use Pesticide applicators license.
- malathion (Atrapa 5E, Drexel Malathion 5EC, Malathion 5, Micro Flo Malathion 5EC, Prozap Malathion 57EC)
  - Efficacy: poor.
  - Advantage/disadvantages: inexpensive/strong smell, hazard to applicator, toxic to beneficial organisms.
- imidacloprid (Provado)
  - Efficacy: not known but potentially good to excellent because of excellent control of other heteroptera insect pests.
  - Advantages/disadvantage: safe for applicator, low toxicity to natural enemies/expensive to purchase product.

#### Other pest management aids:

- Two species of Tachinid flies: *Trichopoda pennipes*, and *Trichopoda pilipes*. One species of parasitic wasp: Trissolcus basalis.
- Some natural enemies.

#### Pipeline pest management tools:

None.

# "To do" list for stinkbugs:

#### **Research needs:**

- Identify methods to conserve natural enemies.
- Identify additional natural enemies.
- Investigate effectiveness of imidacloprid.
- Investigate effectiveness of dinotefuran.
- Develop alternative control measures.

#### **Regulatory needs:**

• Allow direct import of natural enemies.

#### **Education needs:**

• Develop stinkbug(s) identification and biology guide.

#### 5. Imported cabbageworm (*Pieris rapae*)

The imported cabbageworm is found on all islands in Hawaii and is an occasional pest of watercress. The white butterflies are present year-round but outbreaks have been observed during the dry months of May through November. Heavy infestations of imported cabbageworm caterpillars can defoliate the watercress crop. Control of imported cabbageworm with existing measures is good but there is a potential for insecticide resistance in watercress because of the few pesticide tools registered on the crop.

#### **Insecticides currently registered:**

- diazinon (Clean Crop Diazinon 500-AG, Diazinon 50W)
  - Efficacy: good.
  - Limiting factors: registration has been cancelled by EPA with a withdrawal period allowed until May 2006.
  - Advantage/disadvantages: cost is reasonable/hazard to applicator, toxic to beneficial organisms, requires Restricted Use Pesticide applicators license.
- malathion (Atrapa 5E, Drexel Malathion 5EC, Malathion 5, Micro Flo Malathion 5EC, Prozap Malathion 57EC)
  - Efficacy: fair.
  - Advantage/disadvantages: inexpensive/strong smell, hazard to applicator, toxic to beneficial organisms.
- spinosad (Success)
  - Efficacy: excellent. Used sparingly (no more than 4 times a year) to preserve effectiveness.
  - Advantages/disadvantages: safe, target specific, soft on natural enemies/expensive, resistance potential.
- *Bacillus thuringiensis* (Crymax, Javelin, M-C Bioinsecticide, Monterey Caterpillar Clobber)
  - Efficacy: fair.
  - Advantages/disadvantages: safe, target specific, soft on natural enemies/not very effective, resistance potential.
- azadirachtin (Agroneem, Aza-Direct, Azatin XL, Azatrol, Bon-neem Insecticidal Soap, Ecozin, Ornazin 3%)
  - Efficacy: poor. Seldom used.
  - Advantages/disadvantages: very expensive at recommended rates.

# Other pest management aids:

- Intermittent overhead irrigation.
- Natural enemies: the Tachinid fly Frontina glomeratus and the parasitic wasp Apanteles glomeraus.
- Pathogenic microorganisms (microsporidium, bacterium, and viruses).

#### Pipeline pest management tools:

• None.

# "To do" list for imported cabbageworm:

#### **Research needs:**

• Trap cropping for pest management.

# **Regulatory needs:**

- Registration of additional insecticides for resistance management.
- Direct import of natural enemies.

#### **Education needs:**

• Public education to moderate reaction when a live imported cabbageworm is found on finished product.

#### 6. Cyclamen mite (*Phytonemus pallidus*)

Cyclamen mites are found on all islands and attack the growing point of watercress. Heavy infestations causes shoot distortion and curling and ultimately plant deformation. If cyclamen mite is not controlled the entire crop can be lost. Cyclamen mite is heaviest during the warm dry months of May through November. All crop stages can be attacked. Action thresholds for use of control measures are based on presence or absence of the pest. Cyclamen mite is completely controlled in watercress by intermittent overhead irrigation.

#### **Insecticides currently registered:**

- diazinon (Clean Crop Diazinon 500-AG, Diazinon 50W)
  - Efficacy: good.
  - Limiting factors: registration has been cancelled by EPA with a withdrawal period allowed until May 2006.
  - Advantage/disadvantages: cost is reasonable/hazard to applicator, toxic to beneficial organisms, requires Restricted Use Pesticide applicators license.

#### Other pest management aids:

• Intermittent overhead irrigation.

# Pipeline pest management tools:

• None.

#### "To do" list for cyclamen mite:

#### **Research needs:**

• Investigate natural enemies of cyclamen mite.

#### **Regulatory needs:**

• Allow direct importation of natural enemies.

#### **Education needs:**

• None.

# 7. Sharpshooters (Draeculacephala californica, Draeculacephala inscripta, Draeculacephala minerva)

Three sharpshooter species are found in watercress fields in Hawaii. Adult and juvenile sharpshooters are watercress sap suckers. Watercress can tolerate low populations of sharpshooters but under heavy infestation "hopper burn" can occur causing the crop to turn yellow. Sharpshooters increase in number during the warm and dry months of May through November. All growth stages of watercress are attacked. Growers rarely spray specifically for sharpshooter control. Control of the insect pest is obtained when insecticides are used to control other watercress pests.

#### **Insecticides currently registered:**

- diazinon (Clean Crop Diazinon 500-AG, Diazinon 50W)
  - Efficacy: excellent.
  - Limiting factors: registration has been cancelled by EPA with a withdrawal period allowed until May 2006.
  - Advantage/disadvantages: cost is reasonable/hazard to applicator, toxic to beneficial organisms, requires Restricted Use Pesticide applicators license.
- malathion (Atrapa 5E, Drexel Malathion 5EC, Malathion 5, Micro Flo Malathion 5EC, Prozap Malathion 57EC)
  - Efficacy: fair to good.
  - Advantage/disadvantages: inexpensive/strong smell, hazard to applicator, toxic to beneficial organisms.
- imidacloprid (Provado)
  - Efficacy: not known but potentially good to excellent because of excellent control of other heteroptera insect pests.
  - Advantages/disadvantage: safe for applicator, low toxicity to natural enemies/expensive to purchase product.
- azadirachtin (Agroneem, Aza-Direct, Azatin XL, Azatrol, Bon-neem Insecticidal Soap, Ecozin, Ornazin 3%)
  - Efficacy: not known. Seldom used.
  - Disadvantages: very expensive at recommended rates.

#### Other pest management aids:

None.

#### Pipeline pest management tools:

• None.

# "To do" list for sharpshooters:

#### Research needs:

- Investigate the effectiveness of dinotefuran.
- Determine economic thresholds and economic injury level of sharpshooters.
- Investigate the potential for insecticide resistance.

# **Regulatory needs:**

• Register additional effective chemical tools.

#### **Education needs:**

• Identification, biology, and ecology of the 3 species.

#### 8. Snails and slugs (various unidentified species)

Snails and slugs are found in all watercress fields and increase in density during the rainy season (December through April). Although they do not directly damage the watercress, the presence of a single snail or slug in a watercress bunch, when taken to market, will cause consumer rejection of the product. Night time operation of the intermittent overhead irrigation system used by growers to control diamondback moth can cause excess moisture to build in the watercress crop canopy which creates conditions favorable for snail and slug proliferation.

#### Pesticides currently registered:

• None.

#### Other pest management aids:

• Reduce intermittent overhead irrigation frequency where possible.

#### Pipeline pest management tools:

• None.

# "To do" list for snails and slugs:

#### Research needs:

- Use of citric acid to control snails and slugs.
- Determine if there is any relationship between snails and slugs in commercial watercress fields and transmission of liver fluke disease.

# **Regulatory needs:**

• Restrictions on movement of apple snails into natural aquatic systems.

#### **Education needs:**

- Make sure growers understand the seriousness of introducing apple snails into their fields.
- Make sure all growers understand the relationship between watercress irrigation water, snails, livestock such as cattle, and transmission of liver fluke.

#### **DISEASES**

#### 1. Aster Yellows

Aster Yellows is a phytoplasma disease and is the most serious pathogen infecting watercress in Hawaii. The symptoms of the disease were first observed in watercress fields on Oahu in 2000. The disease was confirmed in 2001 when the vector of the disease, the watercress leafhopper, was discovered at an infected farm. The Aster Yellows phytoplasms have a broad host range but appears to be especially severe on watercress farms in Hawaii. Plants infected with Aster Yellows are stunted with yellow upturned leaves (Photo 4), and a proliferation of yellow shoots which is called witch's broom. Control of the disease requires intensive roguing of symptomatic plants, regular insecticide sprays to kill the vector, and a fallow period in situations where the disease has infected the majority of a field. Control is also challenged by the fact that the disease symptoms may appear slowly and take as long as two to three

weeks to be expressed after being contaminated by an infective watercress leafhopper. The Aster Yellows disease has created a situation where growers need to be continuously vigilant, scout for the watercress leafhopper, and to take control measures immediately when disease symptoms and the leafhopper are observed. Aster Yellows cannot be controlled by pesticide sprays.

# **Pesticides currently registered:**

• None.

#### Other pest management aids:

- Elimination by spraying infected plants with an approved insecticide and then removing all plants within a 3 ft. radius of symptomatic plants.
- Border leafhopper control by spraying an approved insecticide on all vegetation within 50 ft. of the edge of a watercress field.
- Avoidance by using disease free planting material once all infected plants have been removed from a field.
- Careful monitoring of newly planted fields for symptomatic plants.

#### Pipeline pest management tools:

• Enhancing the plant's natural defenses.

#### "To do" list for aster yellows:

#### Research needs:

- Genetic engineering or traditional breeding for resistance.
- Investigate the potential for an eradication program.
- Screen available cultivars/varieties for naturally occurring resistance or tolerance.
- Understand and identify alternate hosts for the disease.
- Investigate the ecology of the disease.
- Differentiate between yellow leaves caused by Aster Yellows versus other conditions which may cause the leaves to turn yellow.
- Develop a site with disease free material.
- Develop a quick test which can be used to determine if plants are infected with Aster Yellows.

# **Regulatory needs:**

• Inter-island quarantine to prevent movement of the disease to other islands.

#### **Education needs:**

- Make sure growers are familiar with the disease, alternate hosts, and the vector of the disease.
- Do not take infected material for growing in uninfected areas.

#### 2. Black Rot (Xanthomonas campestris)

Black rot is a seasonal bacterial disease found mostly during the rainy season months of December through April. Black rot occurs on all islands and is more serious on farms that are protected from wind because of reduced air circulation. High humidity (>80% RH) can also promote the disease if overhead irrigation is

operating during the moist period. Under heavy black rot pressure all parts of the plant are affected but the disease usually starts at the newest leaves (Photo 8). Yield losses can be heavy if the disease is not controlled. The pathogen is found on all islands and sites where watercress is grown. Control measures are triggered based on presence or absence of the disease.

# **Bactericides currently registered:**

- copper hydroxide (Champ Formula 2, Champion, Kocide 101, Kocide 4.5LF, Nu-Cop 3L, Nu-Cop 50DF, Nu-Cop 50WP)
  - Efficacy: Fair to good.
  - Advantages/disadvantages: inexpensive, single application generally all that's needed/hazardous to applicator because of irreversible eye damage, toxic to aquatic animals.

#### Other pest management aids:

- Minimizing free moisture on leaves by reducing or turning off intermittent overhead irrigation during rainy periods or periods of high relative humidity (>80%).
- Increase air circulation, where possible, by removing windbreaks.

# Pipeline pest management tools:

• None.

#### "To do" list for black rot:

#### Research needs:

- Develop resistant varieties.
- Identify alternative control measures and pesticide tools.
- Determine effectiveness of systemic acquired resistance (SAR) chemicals.

#### **Regulatory needs:**

• Expedite registration of additional effective pesticide products.

#### **Education needs:**

• Correctly identify disease.

#### 3. Cercospora leaf spot (Cercospora nasturtii)

Cercospora leaf spot is an occasional pest found on all islands. Conditions which favor the disease are high heat and humidity. In general, air temperatures above 80°F and relative humidity above 80% with southerly or light winds will cause outbreaks of Cercospora leaf spot. All stages of growth can be affected by this pathogen. Watercress can tolerate a high amount of Cercospora leaf spot because the spots tend to be confined to the older leaves of the plant which are removed at the time of harvest. Occasionally the leaf spots will work their way to the top of the plant and the younger leaf tissue. Under high pressure the use of fungicides is helpful in controlling the disease.

#### **Fungicides currently registered:**

- azoxystrobin (Abound, Amistar, Dynasty, Heritage, Protege, Quadris)
  - Efficacy: good to excellent.
  - Advantages/disadvantages: reduced risk to applicator, soft on natural enemies/expensive, resistance can develop if used repeatedly.

- copper hydroxide (Champ Formula 2, Champion, Kocide 101, Kocide 4.5LF, Nu-Cop 50DF, Nu-Cop 50WP)
  - Efficacy: good.
  - Advantages/disadvantages: inexpensive, single application generally all that's needed/hazardous to applicator because of irreversible eye damage, toxic to aquatic animals.

#### Other pest management aids:

- Remove infected leaves by hand.
- Minimize free moisture on leaves

#### Pipeline pest management tools:

• None.

#### "To do" list for Cercospora leaf spot:

#### Research needs:

- Determine climatic conditions which favor the development of the disease.
- Examine benefits of reducing intermittent overhead irrigation to control the pathogen.

# Regulatory needs:

• Expedite registration of alternative control measures.

#### **Education needs:**

• Educate the consumer that it is OK (not hazardous) to eat leaves with *Cercospora* leaf spot.

#### WEEDS

Weed control within a watercress patch or paddy is generally not a concern because of the aquatic environment and the rapid growth of the watercress which completely covers the growing surface within 2 weeks of planting or reestablishment as a ratoon crop. Border control of weeds is extremely crucial because encroachment into a watercress patch can occur from the edge of the field and the presence of alternate weed hosts for the watercress leafhopper and aster yellows. Very few herbicides are registered in watercress but weed control efforts need to be maintained in field border areas up to 50 ft. from the edge of watercress fields to lessen the spread of aster yellows. Additionally, if weeds grow thickly at the openings and drains of the watercress fields water flow through the watercress patches will be blocked and will affect watercress growth and production. There are no pre-emergent herbicides registered for use in watercress and control efforts are directed to field edges. In-field weed competition is mostly from various species of algae which can grow prolifically during the warm months from May through October. Algal growth blocks water flow channels and competes with watercress for water-borne nutrients. Failure to control algae can result in yield reduction.

# Herbicides currently registered for grass and broad leaf weed control:

• glyphosate (Accord, Aqua Star, Aquamaster, Certified Quick Claim, Clearout 41 Plus, Eliminator Weed & Grass Killer, Enforcer Roots & All, Express Chem,

Gly Star Original, Glyfos X-tra, Glyphomax, Glyphomax Plus, Glyphosate 4, Glypro Plus, Green Light Com-Pleet, Helosate Plus, Hi-yield Super Concentrate Killzall, Kleenup, Gly-Flo, Maxide Super Concentrate 41%, Mon 007, Nufarm Aquaneat, Opti-Gro Trail Blazer, Protocol, Roundup Custom, Roundup Solugran, Roundup Ultradry, Roundup Ultramax, Roundup Weathermax, Roundup Weed & Grass Killer, Touchdown, Zep)

- Efficacy: excellent on grasses, fair on broadleaves.
- Advantages/disadvantages: inexpensive, single application generally all that's needed, multiple formulations, safe for handlers, soft on beneficials/ drift can damage crop, slow rate of kill, requires minimum of 6 hours of drying time for optimum effectiveness

#### Other pest management aids:

- Hand weeding.
- Plastic mulch paper or weed mat on field edges.

#### Pipeline pest management tools:

• None.

#### "To do" list for weeds:

#### Research needs:

- Determine weed hosts for watercress leafhopper and aster yellows disease.
- Investigate alternate weed controls.

# **Regulatory needs:**

• Register additional herbicides (not glyphosate) for weed control.

#### **Education needs:**

• Importance of weed control for aster yellows management.

# Photos All photos taken by J. McHugh



Photo 1. Watercress bed that is ready for planting.



<u>Photo 2</u>. Newly planted watercress bed.



Photo 3. Freshly harvested watercress bed which is used as a ratoon crop.



<u>Photo 4</u>. Symptoms of Aster Yellows on watercress.



Photo 5. Adult diamondback moth on leaves.



<u>Photo 6</u>. Intermittent overhead irrigation used to control diamondback moth and maintain cool canopy conditions.



<u>Photo 7</u>. Diamondback moth larva with *Cotesia plutellae* cocoon.



<u>Photo 8</u>. Black rot on new watercress leaves.

Table 1. Registered Pesticides for Watercress in Hawaii.

Active Ingredient	Trade name	Company			
INSECTICII	DES				
	Agroneem	Agro Logistic Systems, Inc.			
	Aza-Direct	Gowan Company			
azadirachtin	Azatin XL	Olympic Horticultural Products Co.			
	Ecozin 3% EC	Amvar Chemical Corporation			
	Ornazin 3% EC	Sepro Corporation			
	Crymax	Ceris USA, LLC			
D:11	Javelin	Ceris USA, LLC			
Bacillus thuringiensis	M-C Bioinsecticide	Dow AgroSciences, LLC			
subsp. kurstaki	Monterey Caterpillar Clobber	Lawn & Garden Products, Inc.			
	Ortho B.T. Biospray	The Ortho Group			
diazinon	Clean Crop Diazinon 500AG	Platte Chemical Company			
	Diazinon 50W	Makhteshim-Agan of North America			
	Atrapa 5E	Griffin, LLC			
	Drexel Malalthion 5EC	Drexel Chemical Company			
malathion	Malathion 5	Agriliance, LLC			
	Micro Flo Malathion 5EC	Micro Flo Company, LLC			
	Prozap Malathion 57EC	Loveland Industries, Inc.			
imidacloprid	Provado	Bayer CropScience			
insecticidal	Bon-Neem Insecticidal Soap	Bonide Products, Inc.			
soap	Concern Insect Killing Soap	Woodstream Corp.			
spinosad	Success	Dow AgroSciences, LLC			
sucrose octanoate	Sucrocide	AVA Chemical Ventures, LLC			
(Z)-11- Hexadecen-1- yl acetate (Z)-11- Hexadecenal	Checkmate DBM-F(mating disruption phermone)	Suterra, LLC			

FUNGICIDES				
	Abound	Syngenta Crop Protection, Inc.		
	Amistar	Syngenta Crop Protection, Inc.		
. 1:	Dynasty	Syngenta Crop Protection, Inc.		
azoxystrobin	Heritage	Syngenta Crop Protection, Inc.		
	Protégé	Syngenta Crop Protection, Inc.		
	Quadris	Syngenta Crop Protection, Inc.		
	Champ Formula 2	NuFarm Americas, Inc.		
	Champion	NuFarm Americas, Inc.		
	Kocide 101	Griffin, LLC		
copper hydroxide	Kocide 4.5LF	Griffin, LLC		
ny dromide	Nu-cop 50DF	Albaugh, Inc.		
	Nu-Cop 50WP	Albaugh, Inc.		
	Nu-Cop 50WP	Mico Flo Company LLC		
HERBICIDE	ES			
	Accord	Monsanto Company		
	Aqua Star	Albaugh, Inc.		
	Aquamaster	Monsanto Company		
	Certified Quick Claim	Certified Laboratories, Division of NCH Corp.		
	Clearout 41 Plus	Chemical Products Technologies, LLC		
	Eliminator Weed & Grass Killer	Gro Tec, Inc.		
glyphosate	Enforcer Roots & All	Enforcer Products		
	Express Chem	Chemical Products Technologies, LLC		
	Gly Star Original	Albaugh, Inc.		
	Glyfos X-tra	Cheminova, Inc.		
	Glyphomax	Dow AgroSciences, Inc.		
	Glyphomax Plus	Dow AgroSciences, Inc.		
	Glyphosate 4	Farmsaver.com, LLC		
	Glypro Plus	Dow AgroSciences, Inc.		
	Green Light Com-Pleet	Green Light Company		

	Helosate Plus	Helm Agro US, Inc.		
	Hi-Yield Super Concentrate KillzAll	Voluntary Purchasing Groups		
	Kleenup	Bonide Products, Inc.		
	Maxide Super Concentrate 41%	Gro Tec, Inc.		
	Micro Flo Gly-Flo	Micro Flo Company, LLC		
	Mon 007	Monsanto Company		
	Nufarm Aquaneat	Nufarm, Inc.		
	Opti-Gro Trailblazer	Check-Mark, Div. Of DM Resources, Inc.		
glyphosate (continued)	Protocol	Monsanto Company		
	Roundup Custom	Monsanto Company		
	Roundup Solugran	Monsanto Company		
	Roundup Ultradry	Monsanto Company		
	Roundup Ultramax	Monsanto Company		
	Roundup Weathermax	Monsanto Company		
	Roundup Weed & Grass Killer	Monsanto Company Lawn & Garden Products		
	Touchdown	Syngenta Crop Protection, Inc.		
	Zep	Zep Manufacturing Co. a Div. of ACU		

Table 2. Descri	ption of Pests	and Pathogens	of Watercress

Pest/Pathogen	Symptoms
INSECT PESTS	
Buckthorn aphid (Aphis nasturtii) Green peach aphid (Myzus persicae)	Aphids are an intermittent pest in watercress but are potentially a major problem if no controls are available. Outbreaks usually occur after several successive days of strong trade winds (greater than 10 mph). Heavy aphid infestations can cause an unmarketable appearance of watercress because the presence of a single live (or dead) aphid on the finished product can lead to customer rejection.
Diamondback moth (Plutella xylostella)	Diamondback moth is the most serious insect pest of watercress in Hawaii. The caterpillar stage of the insect does damage to the plant by feeding on the leaves and the young growing shoots. The life cycle of the moth is short. Eggs are laid on the under surface of the leaves and in the growing points. Egg to adult maturation can occur in as little as 12 days but averages 21 days in most watercress growing areas. The diamondback moth is world renown for its ability to quickly develop resistance to any insecticide used to control it. The diamondback moth feeds exclusively on cruciferous host plants (cultivated and weed hosts).
Imported cabbageworm (Pieris rapae)	Imported cabbageworm is an occasional pest of watercress. Damage to the crop is by the caterpillar stage of the butterfly. Adults are white butterflies commonly seen searching for nectar along roadside weed stands. Outbreaks often appear from the months of February through June. Leaves are damaged by larval feeding which render the crop unmarketable. Imported cabbageworm is easy to control with registered insecticides.
Sharpshooters (Draeculecephala minerva, D. californica, D. inscripta)	The grass sharpshooter is a minor pest of watercress. This small insect is commonly found on grass but can build to high numbers on watercress. Nymph and adult stages cause damage to watercress called "hopper burn". "Hopper burn" is a condition that results in localized yellowing of the watercress leaves and leaflets and can render the crop unmarketable. The grass sharpshooter is easy to control with timely application of approved insecticides.

Stinkbugs (Nezara viridula, Nysius spp.)	Stinkbugs are occasionally a problem. They suck the juice from the watercress stems causing the plant to wilt above the feeding site.
Watercress leafhopper (Macrosteles sp. nr. severini)	The watercress leafhopper is one of the most serious insect pests of watercress because it is the vector of the phytoplasma disease Aster Yellows. The leafhopper is a recent introduction to Hawaii and was first discovered on watercress in 2001. Aster Yellows disease causes severe chlorosis, stunting, and a witch's broom effect on new watercress shoots. Aster yellows infected watercress is unmarketable.
OTHER INVERTEBR	ATE PESTS
Cyclamen mite (Stenotarsonemus pallidus)	Cyclamen mite has been a pest of watercress since the 1950's. Cyclamen mite feeding begins in the apical shoot of the plant. Damage symptoms are shoot and leaf stunting, bronzing of leaf tissue, and deformation of the entire plant with heavy mite infestations. Cyclamen mite is widespread and found in all watercress growing areas.
Slugs and snails	Slugs and snails can be a problem when excessive water is on plants and during humid weather. These pests do not damage the watercress plants however, they are a quality control issue.
PATHOGENS	
Aster yellows (AY)	Aster Yellows is the most serious disease of watercress in Hawaii. AY was first detected in a watercress field in Pearl City, Oahu in 2001. The disease is caused by a phytoplasma with numerous hosts. AY is vectored by the watercress leafhopper which is also known to feed on a variety of host plants. Symptoms of AY on watercress are severe chlorosis and stunting, witch's broom effect on new shoots, and, in some cases, death of the plant. Since its introduction, AY has been found only on watercress or weed plants adjacent to watercress fields. Adoption of recommended watercress leafhopper control management practices is critical to control of this disease.

Black rot (Xanthomonas campestris)	Black rot can be a serious disease during prolonged rainy periods. The disease begins as a yellow spot at the edge of the watercress leaflets. The disease is spread by splashing water droplets. Under heavy rainy conditions, especially during "kona weather", black rot can spread to the apical growing shoot causing plant stunting and deformation. The use of intermittent overhead irrigation can also spread the disease if relative humidity is high (> 80%) and wind is light (< 10 mph).
Cercospora leaf spot (Cercospora nasturtii)	Cercospora leaf spot is an occasional pest caused by high humidity (>80%). Mostly older leaves are affected but the disease can sometimes be found high up on the plant if the conditions which favor the disease (heat and high humidity) are prolonged. Growers rarely spray for this disease.
WEEDS	
Algae	Algae can impede establishment of watercress in the early growth stages. It can also block water flow and cause the water to heat up.
California grass (Brachiaria mutica) Honohono grass (Commelina diffusa) Water hyssop (Bacopa sp.)	Weed control is generally not a major concern in watercress fields. Intermittent overhead irrigation used for diamondback moth control creates conditions which do not favor the proliferation of weed species. Additionally, flooded fields that are needed for watercress production limit the establishment of weeds in actively grown fields.

Table 3. Advantages and Disadvantages of Pesticides for Watercress

Active Ingredient	Disease/Pest	Advantages/Disadvantages			
INSECTICIDES					
azadiractin	no pests controlled	<ul><li> expensive</li><li> soft on beneficials</li></ul>			
Bacillus thruingiensis	diamondback moth imported cabbageworm	<ul><li>soft on beneficials</li><li>effective only on young larvae</li><li>reduced risk</li></ul>			
diazinon	aphids cyclamen mite imported cabbageworm sharpshooters watercress leafhopper stinkbugs	<ul> <li>effective</li> <li>inexpensive</li> <li>broad spectrum</li> <li>registration to expire 05/06</li> <li>hard on beneficials</li> </ul>			
malathion	aphids imported cabbageworm sharpshooters watercress leafhopper	<ul><li>inexpensive</li><li>broad spectrum</li><li>partially effective</li><li>hard on beneficials</li></ul>			
imidacloprid	aphids watercress leafhopper stinkbugs	<ul> <li>very effective</li> <li>low mammalian toxicity</li> <li>soft on beneficials</li> <li>safer for handlers</li> <li>expensive</li> </ul>			
spinosad	diamondback moth imported cabbageworm	<ul><li>effective</li><li>soft on beneficials</li><li>reduced risk</li><li>resistance concerns</li></ul>			
(Z)-11-Hexadecen-1-yl acetate (Z)-11-Hexadecenal (mating disruption hormone)	diamondback moth	• soft on the environment			
FUNGICIDES					
azoxystrobin	Cercospora leaf spot	<ul> <li>effective</li> <li>reduced risk</li> <li>soft on beneficials</li> <li>resistance concerns</li> <li>expensive</li> </ul>			

copper hydroxide	black rot Cercospora leaf spot	<ul> <li>effective</li> <li>inexpensive</li> <li>single application</li> <li>eye irritant to applicators</li> <li>may be toxic to aquatic animals</li> </ul>
HERBICIDES		
glyphosate	California grass honohono grass water hyssop	<ul> <li>effective</li> <li>multiple formulations</li> <li>safe for handlers</li> <li>soft on beneficials</li> <li>relatively inexpensive</li> <li>drift can kill the crop</li> </ul>

Table 4. Efficacy of Pest Management Tools for Control of Insects and Other Invertebrate Pests on Watercress in Hawaii.

	Pest							
Priority (Economic Impact)	3		2				1	4
Management Tool:	Aphids	Cyclamen Mite	Diamondback Moth	Sharpshooters	Imported Cabbageworm	Slugs & Snails	Watercress Leafhopper	Stink Bug
<b>Registered Pesticides</b>								
azadirachtin (Aza-Direct, Ecozin)	P	*	P	P	P	-	?	?
Bacillus thuringensis kurstaki (Biobit, Crymax, Dipel, Javelin)	-	-	P - F	-	F	-	-	-
diazinon (Diazinon, Clean Crop Diazinon)-registration to expire 5/06	F - G	E	P	E	G	-	F	G
malathion (Malathion)	P	P	P	F - G	F	-	P	P
mating disruption phermone (Checkmate)	-	-	*	-	-	-	-	-
imidacloprid (Provado)	$\mathbf{E}$	_	-	*	-	-	E	*
spinosad (Success)	-	-	G	-	E	-	-	-
Pipeline Pest Managemen	t Tools							
dinotefuran	*	-	-	*	-	-	*	*

Cultural/Non-chemical Controls								
intermittent overhead irrigation	P	E	F	-	F	-	-	-
Cotesia plutella	-	-	P - F	-	-	-	-	-
weed control	-	-	-	-	-	-	?	-
other predators	P	-	-	-	-	-	-	-
other parasites	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 5. Efficacy of Pest Management Tools for Control of Disease Pests on Watercress in Hawaii.

	Pest				
Priority (Economic Impact)	1	2	3		
Management Tool:	Aster Yellows	Black Rot	Cercospora Leaf Spot		
Registered Materials					
azoxystrobin (Abound, Amistar, Dynasty, Heritage, Protégé, Quadris)	-	P	G - E		
copper hydroxide (Champ, Griffin Kocide, Nu-Cop)	- F-G		G		
Pipeline Pest Management Too	ls				
Transgenic resistance	?	?	?		
Cultural/Non-chemical Contro	ls				
Elimination (spraying infected plants then roguing out)	G	-	-		
Roguing of asymptomatic plants (within 3 ft) around infected plants	E	-	-		
Spraying of vegetation bordering watercress field for leafhopper control	G	-	1		
Avoidance (use of disease free planting material)	E	-	-		
Minimizing free moisture on crop leaves	-	G	G		
Removing infected leaves by hand	-	-	-		

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 6. Efficacy of Pest Management Tools for Control of Weed Pests in Watercress in Hawaii.

<b>Priority (Economic Impact)</b>	3	2	1
Management Tool:	Grasses	Broadleaves	Algae
Registered Materials			
Post-emergence:			
glyphosate (various products)	E	F	-
Cultural/Non-chemical Controls			
hand weeding	E	E	F - G

Efficacy 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 7. Toxicity of Pest Management Tools to Beneficials of Watercress in Hawaii.

water cress in Hawaii.	Beneficial						
Management Tool:	Cotesia plutella	Other predators	Other parasites				
Registered Materials							
INSECTICIDES:							
azadirachtin (Aza-Direct, Ecozin)	*	*	*				
Bacillus thuringensis kurstaki (Biobit, Crymax, Dipel, Javelin)	-	-	-				
diazinon (Diazinon, Clean Crop Diazinon) -registration to expire 5/06	+	+	+				
malathion (Malathion)	+	+	+				
imidacloprid (Provado)	-	-	-				
mating disruption pheromone (Checkmate)	-	-	-				
spinosad (Success)	-	-	-				
FUNGICIDES							
azoxystrobin (Abound, Amistar, Dynasty, Heritage, Protégé, Quadris)	-	-	-				
copper hydroxide (Champ, Kocide, Nu- Cop)	-	-	-				
HERBICIDES							
glyphosate (various products)	-	-	-				
PIPELINE PEST MANAGEMEN	Γ TOOLS						
dinotefuran	*	*	*				
transgenic resistance	N/A	N/A	N/A				
CULTURAL / NON-CHEMICAL	CONTROLS						
intermittent overhead irrigation	-	-	-				
Cotesia plutella	-	-	-				
weed control	-	-	-				
other predators	-	-	-				
other parasites	-	-	-				

elimination (spraying infected plants then roguing out)	?	?	?
roguing of asymptomatic plants (within 3 ft) around infected plants	-	-	-
spraying of vegetation bordering watercress field for leafhopper control	+	+	+
avoidance (use of disease free planting material)	-	-	-
minimizing free moisture on crop leaves	-	-	-
removal of infected leaved by hand	-	-	-

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

**Table 8. Pest Control Measures by Watercress Crop Stage.** 

Table 6. Fest Control Measure	Crop Stage			
Pest / Control Measures	Pre-plant	Planting	0-6 wks	Harvesting
Aphids				<u>·</u>
diazinon			√	V
malathion			√	V
imidacloprid			$\sqrt{}$	V
insecticidal soap			$\sqrt{}$	$\sqrt{}$
natural enemies			$\sqrt{}$	√
Diamondback moth				
spinosad			√	V
Bacillus thuringiensis kurstaki			√	V
intermittent overhead irrigation			√	V
mating disruption pheromone			√	V
natural enemies			$\sqrt{}$	√
Imported cabbageworm				
diazinon			√	V
malathion			$\sqrt{}$	V
imidacloprid			$\sqrt{}$	$\sqrt{}$
spinosad			$\sqrt{}$	$\sqrt{}$
Bacillus thuringiensis kurstaki			√	V
natural enemies			√	V
intermittent overhead irrigation				V
Sharpshooters				
diazinon			$\sqrt{}$	
malathion			√	
imidacloprid			√	
Stinkbugs				
diazinon			V	V
malathion			√	V

imidacloprid				$\sqrt{}$
hand picking when harvesting			V	<b>V</b>
parasites ( <i>Trichopoda pilipes</i> , <i>T.</i> pennipes, and <i>Trissolcus</i> basalis)			V	V
Watercress leafhopper				
diazinon			√	
malathion			√	
imidacloprid			$\sqrt{}$	
insecticidal soap			√	
Cyclamen mite				
diazinon			√	V
intermittent overhead irrigation			√	V
Slugs and snails				
modify intermittent overhead irrigation				V
Aster yellows				
elimination			√	V
border leafhopper control	V	√	√	V
avoidance	$\sqrt{}$			
Black rot				
copper hydroxide			√	V
stop intermittent overhead irrigation			√	V
minimize free moisture on crop leaves			V	<b>V</b>
Cercospora leaf spot				
copper hydroxide			√	V
azoxystrobin			√	V
remove infected leaves when harvesting			V	V

Weeds				
glyphosate	$\sqrt{}$			
hand weeding	$\sqrt{}$	$\sqrt{}$	$\sqrt{}$	$\sqrt{}$
plastic mulch or weed mat (on paddy banks)	V			
Algae				
manual control	√	√	√	
ratoon regrowth	$\sqrt{}$			

 $<sup>\</sup>sqrt{\ }$  = when control is needed.

Table 9. Worker Activity Table for Watercress

		Crop Stage				
Type of Worker Activity	Pre-plant	Planting	0-6 wks	Harvesting		
planting	V	V				
fertilizing			√			
weed control	√	√	√			
disease control			√	√		
insect control			√	√		
irrigation	V	√	√	√		
harvesting				√		

 $<sup>\</sup>sqrt{\ }$  = worker activity associated with crop stage.