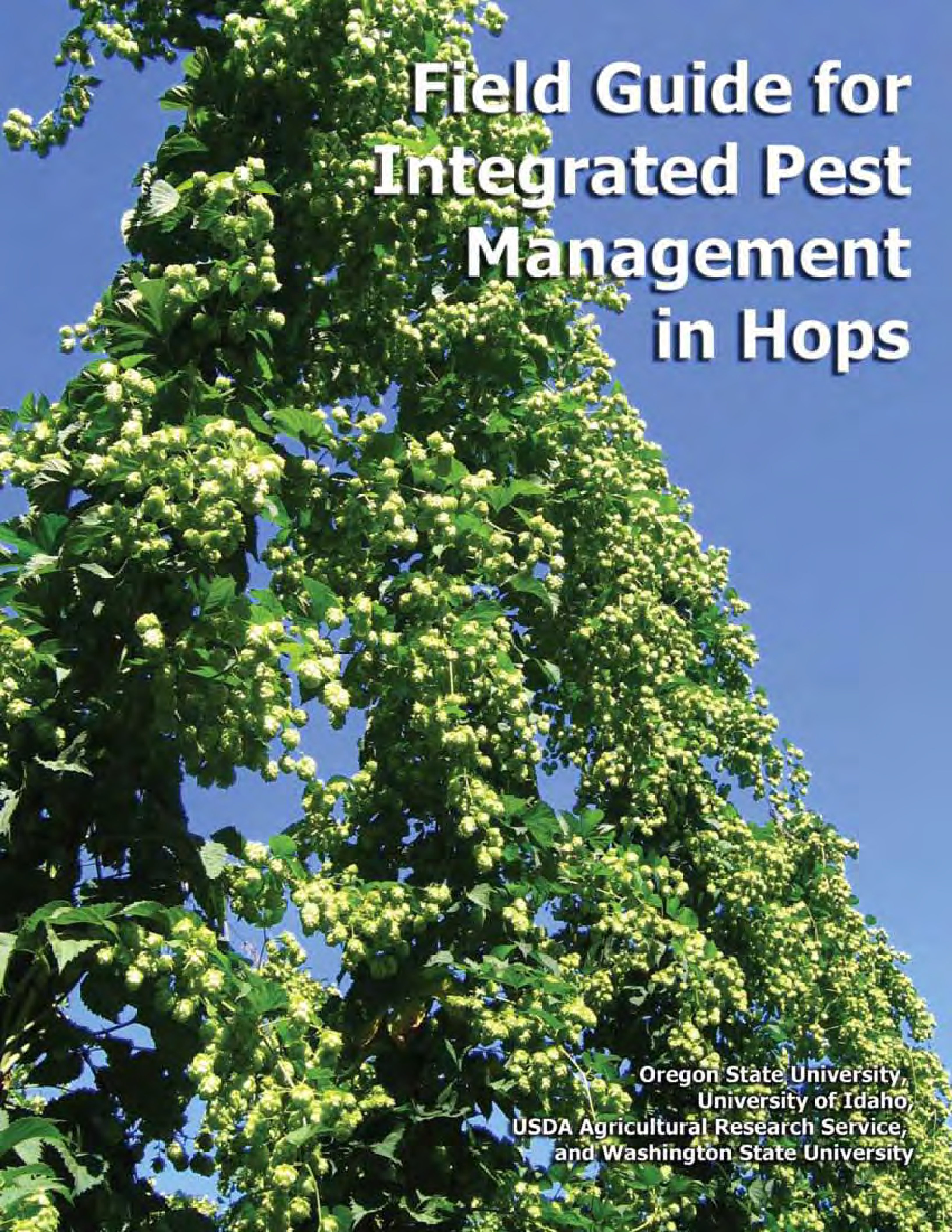
Field Guide for Integrated Pest Management in Hops



Oregon State University,
University of Idaho,
USDA Agricultural Research Service,
and Washington State University

Field Guide for Integrated Pest Management in Hops

Second Edition • 2010

A Cooperative Publication Produced by
Oregon State University, University of Idaho,
U.S. Department of Agriculture - Agricultural Research Service,
and Washington State University

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Acknowledgements

Funding for this handbook was made by possible by a grant from the U.S. Environmental Protection Agency Pesticide Environmental Stewardship Program. Financial support also was provided by Oregon Hop Commission, Oregon State University, University of Idaho, U.S. Department of Agriculture Agricultural Research Service, Washington Hop Commission, Washington State University, and the Western IPM Center. The editors gratefully acknowledge the many reviewers and authors who contributed to this publication. We also recognize the U.S. hop industry for its continued support of research, extension, integrated pest management, and environmental stewardship.

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Use pesticides with care. Apply them only to plants, animals, or sites listed on the label. When mixing and applying pesticides, follow all label precautions to protect yourself and others around you. It is a violation of the law to disregard label directions. If pesticides are spilled on skin or clothing, remove clothing and wash skin thoroughly. Store pesticides in their original containers and keep them out of the reach of children, pets, and livestock.

Introduction

Pest Management, Crop Loss, and IPM

David H. Gent

Production of high quality hops requires careful attention to numerous arthropod, disease, and weed pests, as well as horticultural practices that may exacerbate or suppress these pests. Multiple plant pathogens and arthropods have been documented as pests of hop in the Pacific Northwestern United States, and many plants common in the region can become weeds in hop yards in certain circumstances. The damage these organisms may cause ranges from insignificant to complete loss due to direct reduction in quantity of yield or diminished yield quality that can render hops unsalable.

The goal of the *Field Guide for Integrated Pest Management in Hops* is to provide growers, consultants, extension personnel, and other pest managers with current, science-based information on identification and management of arthropod pests, beneficial organisms, diseases, and weeds affecting hops in the Pacific Northwest. Principles of IPM, farm IPM planning, pesticide toxicology, and nutrient management are presented so that the grower or pest manager can better utilize this information in the context of an entire farming system. Correct identification of pest problems is the first step in IPM, and color images have been included as diagnostic aids wherever possible. Information is presented on the life cycle and biology of the primary pests of hops in the Pacific Northwest to provide key concepts underlying management recommendations.

Information on current pesticide registrations for hops is available in the Pacific Northwest pest management handbooks (see sidebar), which are revised annually.

The editors also acknowledge the significant contributions of the general references at right that provided the foundation and scaffolding for this book.

Principles of Integrated Pest Management

Jim D. Barbour

Integrated pest management (IPM) is a pest management strategy formally developed in the 1950s by entomologists and other researchers in response to widespread development in agricultural settings of pesticide resistance in insects and mites, outbreaks of secondary and induced insect and mite pests resulting from pesticide use, and transfer and magnification of pesticides in the environment. Initially focusing on biological control of insects and mites in agricultural systems, IPM over the last 60 years has assumed a broader role and meaning, encompassing management of diseases and weeds as well as insects and mites (and other arthropods) in agricultural, horticultural, and urban settings. Broadly speaking, IPM emphasizes selecting, integrating, and implementing complimentary pest management tactics to maintain pests at economically acceptable levels while minimizing negative ecological and social impacts of pest management activities. Although the details of IPM programs vary to meet the needs of individual cropping situations, all are based on several related principles.

Systems-level Management

Modern IPM emphasizes the management of agricultural systems, rather than individual pests, so as to prevent or reduce the number and severity of pest outbreaks. This is also referred to as agro-ecosystem planning or whole-farm planning. A focus on whole-farm planning is also a focus on prevention, which expands management efforts in time and space. In agricultural crops, this includes using cultural methods such as crop rotations and fallow periods, tillage, and variety selection (i.e., use of pest-resistant or tolerant varieties and pest-free rootstock), and legal methods such as quarantines. Of these, crop rotation may be the most difficult to implement in hop because the perennial nature of the crop and the trellis system limit the production of alternative crops in hop yards. Included in prevention is the conscious selection of agronomic procedures such as irrigation and fertilizer management that optimize plant production and reduce plant susceptibility to pests. Prevention can be very effective and cost-efficient and presents little or no risk to people or the environment.

Pacific Northwest Pest Management Handbooks

Pacific Northwest Plant Disease Management Handbook, http://plant-disease.ippc.orst.edu/

Pacific Northwest Insect Management Handbook, http://pnwpest.org/pnw/insects

Pacific Northwest Weed Management Handbook, http://pnwpest/pnw/weeds

General References

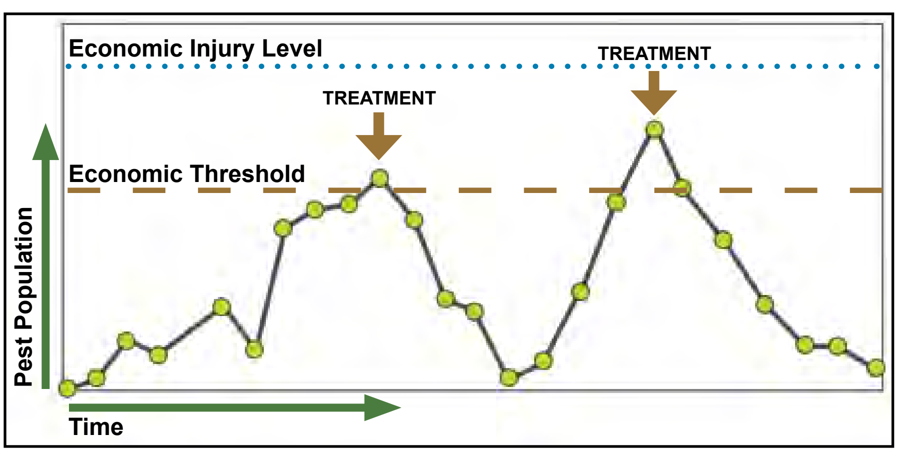
Burgess, A. H. 1964. *Hops: Botany, Cultivation and Utilization*. World Crop Books, Interscience Publication, NY.

Mahaffee, W. F., Pethybridge, S. J., and Gent, D. H., eds. 2009. *Compendium of Hop Diseases and Pests*. American Phytopathological Society Press, St. Paul, MN.

Neve, R. A. 1991. *Hops*. Chapman and Hall, London.

PHOTOS ABOVE:
D. G. James

FIGURE BELOW:
Graphic illustration of the use of an economic injury level and economic threshold for pest management decision making. The economic injury level is the break-even point where management costs equal the damage caused by a pest. The economic threshold is the pest density at which control efforts are triggered so as to prevent pest populations from reaching the economic injury level. The short brown arrows illustrate times when a treatment should be applied because the economic threshold was exceeded.



Pest and Natural Enemy Identification

The ability to accurately identify pests or pest damage is central to IPM, as is the ability to recognize and accurately identify a pest's important natural enemies. Many plants and other organisms live in agricultural fields and most of these are innocuous or even beneficial. Accurate identification is needed to determine if pests are present and to obtain information on pest biology and life history that may be critical to effective monitoring and control efforts. For example, damage to hop caused by the California prionus beetle, Verticillium wilt, and Fusarium canker can be superficially similar in appearance, but the first is a root feeding insect and the other two are caused by pathogenic fungi. Management options for these pests are very different, therefore positive identification is required to select effective treatment options.

Pest and Natural Enemy Biology and Life History

An understanding of the biologies and life histories of pests and their natural enemies, as well as an understanding of the environmental conditions affecting growth and reproduction, provide valuable information for pest management. Knowing which development stage of a particular pest causes damage; knowing when and where the pest is located within or near the crop when this development stage occurs; knowing which pest stage is susceptible to particular management tactics; and knowing what host plant(s) and climatic conditions are favorable (or unfavorable) to pest development—all of these help determine when, where, and how to control the pests of interest. The continuing trend toward more biologically-based pest management systems requires detailed information on the life cycles of pests, their natural enemies, unintended consequences of applying certain control measures, and the complex interaction of these factors with the environment.

Economic Injury Levels and Economic (Action) Thresholds

In most situations it is not necessary, desirable, or even possible to eradicate a pest from an area. The presence of an acceptable level of pests in a field can help to slow or prevent development of pesticide resistance and maintain populations of natural enemies that slow or prevent pest population build-up. In IPM, acceptable pest levels are defined in terms of economic injury levels (EIL): the pest density (per leaf, cone, or plant, for example) that causes yield loss equal to the cost of tactics used to manage the pest. The economic injury level provides an objective basis for making pest management decisions. At densities below this level, management costs exceed the cost of damage caused by the pest and additional efforts to manage the pest do not make economic sense and are not recommended. At densities above the economic injury level, losses in yield exceed the cost of management and avoidable economic losses have already occurred: management efforts should have been used earlier.

Ideally, an EIL is a scientifically determined ratio based on results of replicated research trials over a range of environments. In practice, economic injury levels tend to be less rigorously defined, but instead are nominal or empirical thresholds based on grower experience or generalized pest-crop response data from research trials. Although not truly comprehensive, such informal EILs in combination with regular monitoring efforts and knowledge of pest biology and life history provide valuable tools for planning and implementing an effective IPM program. Economic injury levels are dynamic, changing with crop value (decreasing as crop value increases) and management costs (increasing as management costs increase). In theory, economic injury levels can vary from year to year or even from field to field within a year depending on crop variety, market conditions, and available management options.

The economic threshold (sometimes called an action threshold) is the pest density at which control efforts are triggered so as to prevent pest populations from reaching the economic injury level. Economic thresholds are probably more familiar to growers and field personnel than economic injury levels. The economic threshold may be close to or the same as the economic injury level for quick-acting management tactics, such as some pesticides, or much lower than the economic injury level for slower-acting tactics such as some biological control tactics. Planning for any lag period between application of a management tactic and its impact on pest numbers is an important part of utilizing economic injury levels and economic (action) thresholds an IPM program.

Monitoring for Pests, Damage, and Treatment Success

The concepts of acceptable pest levels, economic injury levels, and economic thresholds imply a need to monitor for levels of pests or pest damage in relation to these levels. Monitoring is fundamental to IPM because it is used to objectively determine the need for control and also to assess the effectiveness of control after action has been taken. Sampling and monitoring requires the ability to identify pests, pest damage, and key natural enemies of pests, as well as knowledge of pest and natural enemy biology and life history. In monitoring, the grower or a scout takes representative samples to assess the growth status and general health of the crop, the presence and intensity of current pest infestations or infections, and the potential for development of future pest problems. Monitoring may take many forms such as presence/absence or counts of pests from visual inspection of plants or plant parts or traps placed in or around fields (e.g., sticky traps, pheromone traps, spore traps). Sampling should be conducted to provide a representative assessment of the pest population in all areas to be similarly treated, such as part of a field, a single field, or adjacent fields. Various sampling schemes have been developed to assist in monitoring efforts.

Monitoring an area for environmental conditions (especially temperature and relative humidity) that are favorable or unfavorable for pest development is also important. This includes the use of models (e.g., the powdery mildew risk index, degree-day for downy mildew spike emergence and spider mites) to forecast conditions conducive to disease or pest development, and surveying the area for the presence of alternate hosts of hop pests (e.g., agricultural or ornamental varieties of prune that might harbor overwintering hop aphids) and natural enemies (e.g., flowering weeds that provide habitat for natural enemies).

Monitoring, when conducted routinely—at least weekly during the growing season—and in combination with good record keeping and awareness of model forecasts, can help determine trends in pest and natural enemy population growth over time. This assists in planning for pest management decisions and assessing the effectiveness of control actions.

Check the AgWeatherNet website at URL http://weather.wsu.edu/ for available disease and pest models.

Consult with local experts for information on uses and limitations of pest forecast models in IPM.

Photos Above: A. J. Dreves, D. H. Gent, D. H. Gent

Multi-tactic Management Approaches

When prevention is not effective or possible and monitoring indicates that a pest population has reached or exceeded an action threshold, intervention is required to lower pest numbers to acceptable levels. For any given pest situation, pest/crop managers will need to choose one or more appropriate and compatible management tactics. The basic types of controls are mechanical, biological, and chemical.

Mechanical controls include simple hand-picking, erecting barriers, using traps, vacuuming, and tillage to disrupt pest growth and reproduction. Tillage is commonly used to manage weeds in hop, and can be important in managing arthropod pests such as the garden symphylan.

Biological controls are beneficial organisms that prey on or parasitize pests, or organisms that do not damage crops but compete with pests for habitat and displace pests (e.g., *Bacillus pumilus* for powdery mildew management). Some biological control agents are commercially available for release into cropping systems (i.e., fields, greenhouses) in numbers that can overwhelm pests or that supplement existing natural enemy populations. Adding agents to the ecosystem is referred to as augmentative biocontrol; an example would be the release of predatory mites *Galendromus occidentalis* and/or *Neoseiulus fallacis*, which can be purchased and released for management of twospotted spider mites. Natural enemy populations also can be augmented using commercially available chemical attractants, such as methyl salicylate. Biological control also can be implemented by managing crops to conserve existing natural enemies (conservation biological control) through preserving habitat (including alternative hosts and prey) necessary for normal natural enemy growth and reproduction, or by using management tactics (e.g., selective pesticides or pesticide uses) that have minimal negative impact on natural enemies. In hop, biological control is most widely practiced in the form of conservation biological control through the use of selective pesticides and modified cultural practices.

Chemical controls include synthetic and natural pesticides used to reduce pest populations. Many newer synthetic pesticides are much less disruptive to non-target organisms than older, broad-spectrum chemistries (e.g., organophosphate, carbamate, and pyrethroid insecticides). Insecticides derived from naturally occurring microorganisms such as *Bacillus thuringiensis*, entomopathogenic fungi and entomopathogenic nematodes, and natural insecticides such as nicotine, pyrethrin, and spynosins are important tools in many organic farming operations, and are playing larger roles in non-organic crop production. Selective pesticides should be chosen over non-selective pesticides to preserve natural enemies and allow biological control to play a greater role in suppressing pest outbreaks. However, broad-spectrum pesticides remain useful and necessary components of IPM programs as measures of last resort when other management tactics fail to maintain pests at acceptable levels.




Photos: D. H. Gent, W. S. Peng J. D. Barbour, D. G. James

Pesticide Toxicology and Selectivity

Pesticide Toxicity Ratings

Douglas B. Walsh

Pesticides are essential tools in IPM when other management tactics fail to control pests at acceptable levels. Approximately 250 to 300 pesticide active ingredients are used in the Pacific Northwestern United States, and inevitably pesticide use involves some degree of exposure and risk to humans, non-target organisms, and the environment. Table 1 is provided as a guide to the relative impact of specific pesticides registered for use on hop on non-target beneficial arthropods. The pesticide "signal word" (column 2 of table) indicates the potential hazard these pesticides could pose to a mixer or applicator. The signal word "Danger" identifies a product as being a Category 1 pesticide, and includes products such as 2,4-D, ethoprop, and folpet. These products have a toxicological profile that could cause injury or irritation to individuals exposed to low concentrations. The signal word "Warning" identifies a product as a Category 2 pesticide, and includes products such as clethodim, cymoxanil, and beta-cyfluthrin. These are materials that will typically require the use of fairly extensive personal protective equipment, but exposure levels required to cause injury or irritation are substantially greater than Category 1 pesticides. The signal word "Caution" identifies a Category 3 pesticide, and includes products such as the biocontrol bacterium *Bacillus pumilus*, carfentrazone, and various Bt formulations (e.g., *Bacillus thuringiensis* subsp. *kurstaki*). A Category 3 pesticide is a product that can cause injury or irritation at a relatively high exposure rate. Personal protective equipment is required, typically including safety glasses, pants, rubber boots, gloves, and long-sleeved shirts. No signal word is required for a Category 4 pesticide. Simple safety rules should be followed with these products to avoid exposure.

Pesticide impacts on humans do not necessarily mirror the impacts those same pesticides would have on beneficial hop yard arthropods. Human physiology differs from arthropod physiology, and substantial differences exist among arthropods as well. Differences in both susceptibility and resilience factor into a pesticide's impact on a population of beneficial arthropods. Large predatory insects, for example, may be able to survive greater doses (i.e., be less susceptible) than smaller predatory insects and mites. However, larger insects typically will complete only one or a few generations over the course of a growing season in the Pacific Northwest, whereas a smaller insect might complete more generations and have a greater chance of recovering its population level (i.e., be more resilient). If a population is depressed due to pesticide exposure it may not recover in a hop yard unless there is an immigration of new individuals from outside of the yard.

To standardize topical mortality studies, the International Organization for Biological Control (IOBC) has categorized pesticides using a ranking of 1 to 4. Category 1 pesticides in the IOBC rating system are rated as "harmless" to a candidate population of beneficial arthropods if less than 30% of a populations dies following a direct exposure. A Category 2 pesticide in the IOBC rating system is defined as "slightly harmful" to the beneficial. Direct exposure to the pesticide will result in mortality levels between 30 and 79%. A Category 3 pesticide in the IOBC rating system is defined as "moderately harmful" to the beneficial arthropod. Direct exposure to the pesticide will result in mortality levels between 79 and 99%. A Category 4 pesticide in the IOBC rating system is defined as "harmful" to the beneficial. Direct exposure to the pesticide will result in mortality levels greater than 99%. (IOBC categories 1-4 should not be confused with the categories 1-4 relating to human exposure and indicated by signal words "Danger," "Warning," and "Caution" as described in the first column of this section.) Table 1 provides information on three key beneficial arthropods that occur on hop: predatory mites, lady beetles, and lacewing larvae. The rankings are summarized from an amalgam of research projects that have been conducted on these organisms in the Pacific Northwes on crops including tree fruit, hop, mint, and grape.

Table 1. Signal Words and Relative Impact of Pesticides Registered for Use on Hop on Representative Non-target Beneficial Arthropods

Active Ingredient	Signal Word	Trade Name	Beneficial Arthropod IOBC Ranking[a]		
			Predatory Mites	Lady Beetles	Lacewing Larvae
Fungicides					
Bacillus pumilus	Caution	Sonata	1	ND	ND
Boscalid	Caution	Pristine	1	ND	ND
Copper	Caution	Various formulations	1	ND	ND
Cymoxanil	Warning	Curzate 60DF	ND	ND	ND
Dimethomorph	Caution	Acrobat	ND	ND	ND
Famoxadone & cymoxanil	Caution	Tanos	ND	ND	ND
Folpet	Danger	Folpan 80WDG	ND	ND	ND
Fosetyl-Al	Caution	Aliette WDG	ND	ND	ND
Kaolin	Caution	Surround	3	ND	ND
Mandipropamid	Caution	Revus	OK[b]	OK[b]	ND
Mefenoxam	Caution	Ridomil	ND	ND	ND
Metalaxyl	Warning	MetaStar	ND	ND	ND
Mineral oil/petroleum distillate	Caution	Various formulations	2	ND	ND
Myclobutanil	Warning	Rally 40W	2	1	ND
Phosphorous acid	Caution	Fosphite and other formulations	ND	ND	ND
Pyraclostrobin	Caution	Pristine	ND	ND	ND
Quinoxyfen	Caution	Quintec	1	ND	ND
Sodium borate	Warning	Prev-Am	2	ND	ND
Spiroxamine	Caution	Accrue	ND	ND	ND
Sulfur	Caution	Various formulations	2	ND	ND
Tebuconazole	Caution	Folicur 3.6F	1	ND	ND
Trifloxystrobin	Caution	Flint	1	ND	ND
Herbicides					
2,4-D	Danger	Weedar 64 and other formulations	ND	ND	ND
Carfentrazone	Caution	Aim EC	1	ND	ND
Clethodim	Warning	Select Max	1	ND	ND
Clopyralid	Caution	Stinger	1	ND	ND
Flumioxazin	Caution	Chateau	OK[b]	OK[b]	ND
Glyphosate	Caution	Roundup and other formulations	1	ND	ND
Norflurazon	Caution	Solicam	ND	ND	ND
Paraquat	Danger	Gramoxone and other formulations	1	ND	ND
Pelargonic acid	Warning	Scythe	ND	ND	ND
Trifluralin	Caution	Treflan and other formulations	2	ND	ND
Insecticides/Miticides					
Abamectin	Warning	Agri-Mek and other formulations	3	3	ND
B. thuringiensis subsp. aizawai	Caution	Xentari and other formulations	1	2	ND
B. thuringiensis subsp. kurstaki	Caution	Dipel and other formulations	1	2	ND
Beta-cyfluthrin	Warning	Baythroid XL	4	4	4
Bifenazate	Caution	Acramite-50WS	1	2	ND
Bifenthrin	Warning	Brigade and other formulations	4	4	4
Cyfluthrin	Danger	Baythroid 2E	4	4	4
Dicofol	Caution	Dicofol	1	1	ND
Ethoprop	Danger	Mocap	4	4	ND
Etoxazole	Caution	Zeal	OK[b]	OK[b]	ND
Fenpyroximate	Warning	Fujimite	1	3	ND
Hexythiazox	Caution	Savey 50DF	1	1	ND
Imidacloprid	Caution	Provado and other formulations	1	3	3
Malathion	Warning	Various formulations	2	4	3
Naled	Danger	Dibrom	2	4	3
Pymetrozine	Caution	Fulfill	1	1	1
Pyrethrin	Caution	Pyganic and other formulations	2	2	2
Spinosad	Caution	Success and other formulations	2	2	1
Spirodiclofen	Caution	Envidor	2	2	1
Spirotetramat	Caution	Movento	1	1	1
Thiamethoxam	Caution	Platinum Insecticide	1	1	ND

[a] International Organization for Biological Control (IOBC) has categorized pesticides using a ranking of 1 to 4. Rankings represent relative toxicity based on data from studies conducted with tree fruit, hop, mint, and grape. 1 = less than 30% mortality following direct exposure to the pesticide; 2 = 30 to 79% mortality; 3 = 79 to 99% mortality; and 4 = greater than 99% mortality. ND = not determined.

[b] IOBC rankings not available for this newly registered product. Tests in 2009/2010 determined these compounds safe on predatory mites and *Stethorus*.

Pesticide Resistance Management

Mark E. Nelson, Robert Parker, and David H. Gent

Many of the most widely used pesticides pose an inherent risk of resistance development. Pesticide resistance is a consequence of repeated use of an herbicide, fungicide, or insecticide/miticide with the same mode of action, resulting in a lack of efficacy for a particular pesticide against a particular pest. Resistance has been documented among numerous pests that may affect hop. Examples include herbicide resistance in kochia and pigweed, organophosphate resistance in hop aphid and twospotted spider mite, and Ridomil resistance in the downy mildew pathogen.

Resistance develops in a pest population and not in individuals. It occurs when a pesticide is applied repeatedly and susceptible pests are controlled but naturally resistant individuals of the same species reproduce and increase in absence of competition. Resistant strains of the pest become prevalent in a population over time due to this selection pressure. For example, studies have shown that kochia is a genetically diverse weed species and in a kochia population a small number of plants (i.e., 1 in 1,000,000 plants) may be naturally resistant to a particular herbicide. Repeatedly exposing kochia populations to the same herbicide may result in a rapid buildup of resistant weeds. Resistant weeds will then dominate over time due to this selection pressure and previously effective herbicides will fail to control the population.

Resistance can be quantitative or qualitative. Quantitative resistance manifests as a gradual loss of control that occurs as a pest population becomes more tolerant to a pesticide. In these situations, a product may perform brilliantly when first used and then over a period of years slowly deteriorate in efficacy. As a result, the compound must be applied at higher rates and/or shorter intervals in order to maintain control. An example of this quantitative resistance is fosetyl-Al (Aliette WDG) against the downy mildew pathogen. The registered label rate for Aliette has been 2.5 lbs. per acre (and remains so in most hop production areas), but this rate is no longer effective for control of the downy mildew pathogen in Oregon, where a Section 24c "Special Local Needs" registration was sought and received for the higher rate of 5 lbs. per acre. Alternatively, qualitative resistance is "all or none," where a pesticide performs brilliantly for a period of time but provides no control after resistance develops. A good example of qualitative resistance is metalaxyl (Ridomil) against the downy mildew pathogen. Once useful, this fungicide now provides no control in yards where resistance is present.

Pigweed. (H. F. Schwartz, Colorado State University, Bugwood.org)

Note that persistence of resistance in a pest population varies among pesticides and pests. For instance, resistance to metalaxyl can still be detected in the downy mildew pathogen in hop yards that have not been treated with this fungicide in over 10 years. Conversely, resistance to abamectin (Agri-

Hop aphids on leaf. (D. G. James)

Strategies to Minimize Development of Pesticide Resistance

◆ Utilize cultural practices to reduce pathogen, weed, and pest populations whenever possible. For example, removing overwintering flag shoots or basal spikes and basal sucker growth by mechanical or chemical methods helps reduce the inoculum level of powdery mildew and downy mildew.

◆ Limit the number of applications of resistance-prone pesticides as directed by the label.

◆ Apply pesticides at rates specified on the label; do not reduce rates.

◆ Adjust application volume per acre based on the size and volume of the crop to attain excellent spray coverage.

◆ Alternate or tank mix products with diverse modes of action within and between seasons.

Twospotted spider mites. (D. G. James)

Mek) in spider mite populations appears to diminish over time when abamectin is not used over a period of years.

The risk of resistance development is linked closely to the reproductive and dispersal ability of a pest. Pests that have a high reproductive potential (e.g., powdery mildew and spider mites) generally have a higher risk of resistance development than pests with a low fecundity. Other factors that influence resistance development are the fitness (relative vigor) of resistant strains versus susceptible strains, dispersal ability of the pest, availability of nearby populations of susceptible strains of the pest, the number of individuals needed to initiate an infestation or infection, and reproductive mechanisms of the pest (asexual or sexual reproduction). On hop, many pesticides used for management of powdery mildew, downy mildew, spider mites, and hop aphid have a risk of resistance due to the highly specific mode of action of the pesticides and biological characteristics of the pests.

Given that few pesticides with novel modes of action are currently under development, it becomes readily apparent that sustained profitability of the hop industry requires efforts to prevent or delay resistance development. A key point in resistance development is that only a very small percentage of individuals in a population have the potential for resistance to a given mode of action. Therefore, the overall objectives of resistance management are to reduce the populations of pests exposed to a given mode of action, as well as reduce the duration and frequency of that exposure, thereby reducing the opportunity for those few individuals with resistance potential to become predominant in the population. Utilizing diverse modes of action and limiting the total number of applications of a particular mode of action are fundamental to resistance management.

For downy mildew and powdery mildew, resistance generally can be prevented or delayed by limiting the number of applications of any resistance-prone fungicide class (no more than three per season and no more than two sequential applications), use of single or block applications in alternation with fungicides from a different group, and use early in the season before the diseases are well established. Do not alternate resistance-prone products with other products in the same fungicide class as cross-resistance has been documented in the DMI and strobilurin fungicide classes. For example, a rotation of Flint and Pristine would not be effective since both fungicides have active ingredients with the same mode of action. Thorough application coverage is essential.

Similar principles apply to resistance management for spider mites and hop aphids. Limit the number of applications of any resistance-prone product as directed by the label (ideally not more than once per two seasons in a given yard), use single or block application in alternation with products with a different group mode of action, target applications against the most vulnerable life stage of the pest, and integrate non-chemical control measures before pests exceed economic thresholds. Selection of products with a high degree of selectivity for beneficial arthropods can allow biological control to reduce populations of resistant pest strains, and thus help to delay resistance.

Powdery mildew. (D. H. Gent)

Strategies, cont.

◆ Include low-resistance-risk compounds in spray programs as much as and whenever possible. Do not rely on resistance-prone compounds to attempt to control severe pest outbreaks. For example with powdery mildew, petroleum oils and carbonates are the best eradicative fungicides.

◆ Select miticides and insecticides with a high degree of selectivity for beneficial arthropods to allow biological control to reduce populations of resistant pest strains.

◆ Utilize synthetic fungicides prone to resistance development protectively before powdery mildew or downy mildew has become a problem. Avoid making more than two consecutive applications of synthetic fungicides (e.g., DMI, quinoline, strobilurin, carboxamide or morpholine classes).

At-A-Glance: Alternaria Cone Disorder

◆ Symptoms easily confused with powdery and/ or downy mildew.

◆ Promote air circulation in the canopy.

◆ Time irrigations to reduce periods of wetness on cones.

◆ Some powdery and downy mildew fungicides likely provide some suppression of Alternaria cone disorder when applied later in the season.

◆ Confirm cone browning is caused by Alternaria cone disorder before implementing any control measures.

Disease Management
Fungal & Bacterial Diseases

Figure 1. Reddish-brown discoloration of the tips of bracts and bracteoles of a cone affected by Alternaria cone disorder. (D. H. Gent)

Figure 2. Further discoloration of cones affected by Alternaria cone disorder. (S. J. Pethybridge)

Alternaria Cone Disorder

David H. Gent

Alternaria cone disorder is caused by the fungus *Alternaria alternata*, which is widespread in hop yards and other agricultural systems worldwide. Strains of Alternaria fungus are known to attack more than 100 other plants, including crops such as apple, potato, sunflower, and wheat.

While the presence of the fungus is widespread, the disease is not known to be associated with direct yield losses in the U.K. and Australia and is thought to be of minor importance in the United States. The disease can occasionally damage cones and reduce crop quality. It is reported to occur most commonly on late-maturing varieties exposed to wind injury, humid conditions, and extended periods of wetness on cones. Cone browning caused by powdery mildew and downy mildew is commonly misdiagnosed as Alternaria cone disorder.

Symptoms

Alternaria cone disorder symptoms vary depending on the degree of mechanical injury to cones; they may be limited to one or a few bracts and bracteoles or in severe cases entire cones may become discolored. Symptoms appear first on the tips of bracteoles as a light, reddish-brown discoloration (Fig. 1). Bracts may remain green, which gives cones a striped appearance. When cones have been damaged by wind, disease symptoms may appear on both bracteoles and bracts as a more generalized browning that can cover entire cones (Fig. 2). The disease can progress rapidly; the killed tissue becomes dark brown and is easily confused with damage caused by powdery or downy mildew. Affected bracts and bracteoles may display a slight distortion or shriveling of the diseased tissues.

Disease Cycle

Alternaria alternata generally is a weak pathogen that invades wounds created by insect feeding, mechanical injury, or lesions created by other pathogens. Other strains of the fungus may survive as a decay organism on textiles, dead plants, leather, or other organic materials. On hops, Alternaria cone disorder is primarily a disease of cones damaged by mechanical injury. Severe outbreaks often are associated with wind injury accompanied with high humidity or extended periods of dew. The pathogen survives between seasons on decaying plant material, organic matter, and/or as a weak pathogen on other plants.

Management

Management of Alternaria cone disorder requires accurate diagnosis of the disease, which is confounded by its symptomatic resemblance to powdery mildew or downy mildew. Simply recovering the fungus from discolored cones does not necessarily indicate that it was the cause of the browning since the pathogen also is found on healthy cones. The disease can be minimized by reducing damage to burrs and cones caused by strong winds, pesticide applications, and other pests and pathogens; promoting air circulation in the canopy; and timing irrigations to reduce periods of wetness on cones. No fungicides are registered for control of Alternaria cone disorder. However, certain fungicides (e.g., Flint and Pristine) applied for control of powdery and downy mildew likely provide some suppression of Alternaria cone disorder when applied later in the season.

Black Root Rot

Frank Hay and David H. Gent

The fungus-like organism *Phytophthora citricola* causes a crown and root rot of hop referred to as black root rot. The disease tends to be most damaging to hop plants in poorly drained soils and areas with high water tables. Certain Cluster varieties such as Cluster types E-2 and L-8 are particularly susceptible. The pathogen has a relatively broad host range that includes cherry, fir trees, raspberry, strawberry, and walnut.

Symptoms

Infected roots and crowns have a characteristic water-soaked and blackened appearance with a distinct boundary between diseased and healthy tissue (Fig. 3). Infection can spread from the crown for several inches up the base of the bine. In severe cases, leaves become yellow and bines wilt rapidly during warm weather or when plants become moisture-stressed. Young plants irrigated heavily to encourage production in the first year can wilt later in the season as a result of black root rot. As the disease progresses, leaves turn black and remain attached to the bine. Severely infected plants are weakened and may die during winter or the following spring. Affected plants often are found in areas of hop yards with poor drainage. Wilting symptoms caused by black root rot can be mistaken for Verticillium wilt, Fusarium canker, or damage caused by California prionus beetle.

Disease Cycle

The black root rot pathogen survives in soil as dormant sexual spores (oospores), which can survive 18 months or more. In the presence of free water and host roots, oospores or the asexual spores (sporangia) germinate and infect the plant directly or may release motile spores (zoospores) that are attracted to compounds released from host roots (e.g., ethanol and certain amino acids and sugars). The motile zoospores settle on roots and later produce mycelia that infect and grow through the host tissues.

Management

Growers should avoid establishing hop yards in areas with poor water drainage, especially with highly susceptible varieties such as Cluster types E-2 and L-8. Cluster L-1 and Galena are considered partially resistant, while Brewers Gold, Bullion, Cascade, Columbia, Comet, Eroica, Fuggle, Hallertauer, Nugget, Olympic, Tettnanger, and Willamette reportedly are highly resistant to black root rot. Reducing cultivation and avoiding injury to crowns and roots can provide some reduction in disease since infection is favored by wounds. Certain phosphorous acid fungicides are registered for control of black root rot, but their efficacy has not been reported. Phenylamide fungicides (i.e., various formulations of Ridomil) applied for control of downy mildew may provide some control, although these products are not registered specifically for control of black root rot.

Figure 3. Extensive black discoloration caused by black root rot. Notice the distinct margin between healthy tissue and the black, diseased tissue. (R. A. Beatson)

At-A-Glance:
Black Root Rot

- ◆ Plant resistant varieties when possible.
- ◆ Avoid poorly drained fields and excessive irrigation.
- ◆ Avoid damaging roots during cultivation.
- ◆ Phosphorous acid fungicides and various Ridomil formulations may provide some control.

See the Pacific Northwest Plant Disease Management Handbook at http://plant-disease.ippc.orst.edu/ for a current list of registered herbicides.

***At-A-Glance:* Downy Mildew**

- Select the most resistant variety that is available for the intended market.
- Establish hop yard with disease-free planting materials.
- Thoroughly remove all basal foliage during spring pruning.
- Prune yards as late as possible without adversely affecting yield.
- Strip leaves from bines after training and remove basal foliage with chemical desiccants.
- Apply appropriate fungicides during the first year of production and when weather is favorable to the disease.
- Rotate and tank-mix fungicides to delay development of resistance.

Downy Mildew

David H. Gent and Dennis A. Johnson

Downy mildew is caused by the fungus-like organism *Pseudoperonospora humuli*. It is one of the most important diseases of hop in the Pacific Northwest and worldwide. Yield and quality losses from downy mildew vary depending on susceptibility of the variety and timing of infection, and may range from non-detectable to 100% crop loss if significant cone infection or plant death from crown rot occurs.

Figure 4. Basal spikes: Hop shoots systemically infected with the downy mildew pathogen. (D. H. Gent)

Figure 5. Profuse sporulation on the underside of a hop leaf appears dark purple to black. (D. H. Gent)

Figure 6. Infection of shoots after training. Notice the yellowing, stunting, and down-curling of the leaves. (D. H. Gent)

Figure 7. Stunted lateral branches resulting from downy mildew. Production from these branches will be lost. (D. H. Gent)

See the Pacific Northwest Plant Disease Management Handbook at http://plant-disease.ippc.orst.edu/ for a current list of registered herbicides for downy mildew and other diseases.

Figure 8. Angular leaf lesions on hop leaves. The black discoloration is due to sporulation by the pathogen. (D. H. Gent)

Figure 10. Dark brown discoloration of bracts and bracteoles on cones severely affected by downy mildew. (B. Engelhard)

Figure 9. Dry, angular leaf lesions caused by downy mildew. (D. H. Gent)

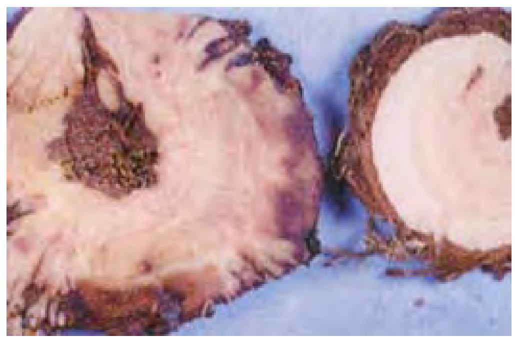


Figure 11. Left, Dark discoloration of rhizomes infected with *Pseudoperonospora humuli*. Right, Healthy rhizome. (C. B. Skotland)

Symptoms

The disease first appears in spring on newly emerged and infected shoots that are called “basal spikes.” Basal spikes are stunted and have brittle, downward-curled leaves (Fig. 4), upon which masses of purple to black asexual spores (sporangia) are visible (Fig. 5). After training, the main bines and lateral branches may become infected, arresting the development of these shoots and leading to “aerial spikes” (Figs. 6 and 7). Infection of trained bines causes these bines to cease growth and fall from the string, requiring retraining with healthy shoots and often leading to yield loss. Lesions commonly are present on leaves next to spikes. These leaf lesions are confined between leaf veins and appear angular (Fig. 8). Leaf lesions tend to dry quickly in warm, dry weather, becoming brown areas of dead tissue (Fig. 9).

Infected burrs turn dark brown, shrivel, dry up, and may fall from the plant. Infected cones become dark brown, harden, and cease development. Bracteoles of affected cones tend to become discolored more readily than bracts, and affected cones may develop a striped appearance. Under high disease pressure entire cones may become dark brown (Fig. 10). Sporulation on the underside of bracts and bracteoles is diagnostic for downy mildew on cones, although it is common for sporulation to be absent on infected cones.

In infected roots and crowns, reddish-brown to black flecks and streaks are apparent when roots are cut open (Fig. 11). The crown may be completely rotted and destroyed in varieties susceptible to crown rot from downy mildew, such as Cluster varieties.

Table 2. Disease Susceptibility and Chemical Characteristics of the Primary Public Hop Varieties Grown in the U.S.

Variety	Usage	Disease Susceptibility[a]		
		Powdery Mildew	Downy Mildew	Verticillium Wilt
Brewers Gold	Bittering	S	MR	MR
Bullion	Bittering	S	MR	R
Cascade	Aroma	MR	MR	MR
Centennial	Bittering	MR	S	U
Chinook	Bittering	MS	MR	R
Columbia	Aroma	MS	MR	S
Comet	Bittering	R	S	R
Crystal	Aroma	R	S	R
East Kent Golding	Aroma	S	S	MR
First Gold	Bittering	R	S	MR
Fuggle	Aroma	MS	R	S
Galena	Bittering	S	S	R
Glacier	Aroma	S	S	U
Hall. Gold	Aroma	MS	R	S
Hall. Magnum	Bittering	S	R	MR
Hall. Mittelfrüh	Aroma	MS	S	S
Hall. Tradition	Aroma	MR	R	MR
Horizon	Bittering	MS	S	MR
Late Cluster	Aroma	S	S	R
Liberty	Aroma	MR	MR	U
Mt. Hood	Aroma	MS	S	S
Newport	Bittering	R	R	U
Northern Brewer	Bittering	S	S	R
Nugget	Bittering	R	S	S
Olympic	Bittering	S	MS	R
Perle	Aroma	S	R	MR
Pioneer	Bittering	MR	MR	U
Saazer	Aroma	S	MS	S
Saazer 36	Aroma	S	MS	S
Spalter	Aroma	S	R	MR
Sterling	Aroma	MS	MR	U
Teamaker	Aroma	MR	MR	S
Tettnanger	Aroma	MS	MS	S
Tolhurst	Aroma	S	S	U
U.S. Tettnanger	Aroma	MS	MS	S
Vanguard	Aroma	S	S	U
Willamette	Aroma	MS	MR	S

[a] Disease susceptibility ratings are based on greenhouse and field observations in experimental plots and commercial yards in the Pacific Northwest as of 2009. Disease reactions may vary depending on the strain of the pathogen present in some locations, environmental conditions, and other factors, and should be considered approximate. S = susceptible; MS = moderately susceptible; MR = moderately resistant; R = resistant; U= unknown

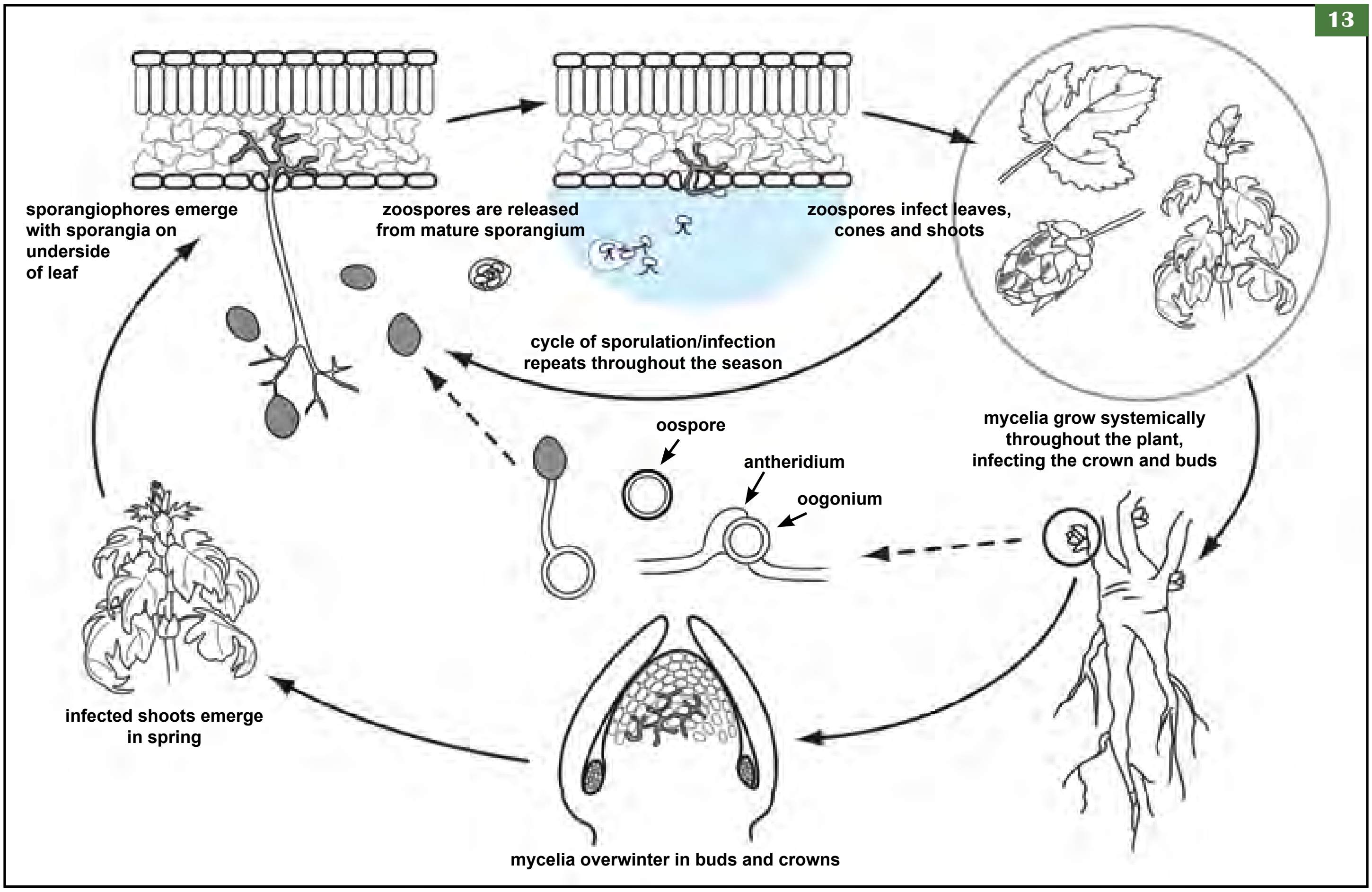
Disease Cycle

The downy mildew pathogen overwinters in infected dormant buds and crowns (Fig. 12). It spreads into developing buds during the winter and early spring, and some (but not all) infected buds give rise to basal spikes when shoots emerge in the spring. The pathogen sporulates profusely on the undersides of leaves of spikes when nighttime temperatures are greater than 43 °F and humidity is greater than 90% in the hop yard. Sporangia are released in mid-morning to early afternoon, and germinate indirectly to produce swimming zoospores when the temperature is favorable and free water is present on leaves, shoot tips, or cones. Zoospores enter hop tissues through open stomata, and consequently the most severe infections occur when wetness occurs on plant surfaces during daylight. Infection is favored by mild to warm temperatures (60 to 70 °F) when free moisture is present for at least 1.5 hours, although leaf infection can occur at temperatures as low as 41 °F when wetness persists for 24 hours or longer.

Infection of shoots can become systemic, producing secondary spikes and additional sporangia that perpetuate the disease cycle. When shoots near the crown (approximately 6 inches in height or less) become infected, mycelia can progress through the shoot and invade the crown. Carbohydrate reserves are reduced in systemically infected rhizomes and the plants become weakened over time, resulting in reduced yield or plant death.

Management

No single management tactic provides satisfactory control of downy mildew. Careful attention to cultural practices, judicious irrigation management, and timely fungicide applications are needed to manage the disease successfully. Varieties vary widely in their susceptibility to downy mildew (Table 2), although no varieties are completely immune. When possible, select the most resistant variety that is available for the intended market and plant the most resistant varieties in areas with known downy mildew pressure (e.g., next to rivers or in low-lying areas with cool air pooling). Cascade, Fuggle, Magnum, Newport, and Perle are among the most resistant to downy mildew. Cluster is notably susceptible.



ABOVE: Figure 12. The life cycle of *Pseudoperonospora humuli* on hop. (Prepared by V. Brewster) BELOW: Figure 13. Hop plants pruned thoroughly mechanically (A) or chemically by a desiccant (C) in early spring. Notice in A and C that all shoots on the sides of the hills have been removed. Incomplete mechanical (B) or chemical pruning (D) can result in more severe outbreaks of both downy mildew and powdery mildew. (D. H. Gent)

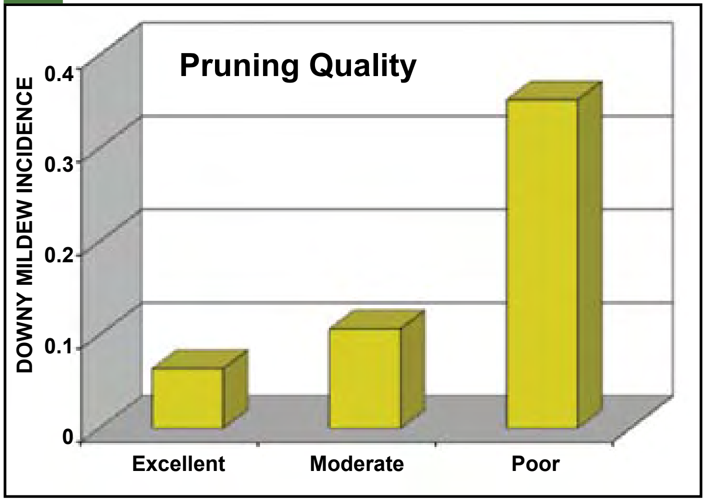


Figure 14. Association of spring pruning quality to the incidence of plants with downy mildew in 97 commercial hop yards in Oregon during 2005 to 2008. Excellent = No foliage or green stems remaining after pruning, Moderate = Foliage or green stems on some hills after pruning, and Poor = No pruning was conducted or foliage and green stems were present on all hills after pruning.

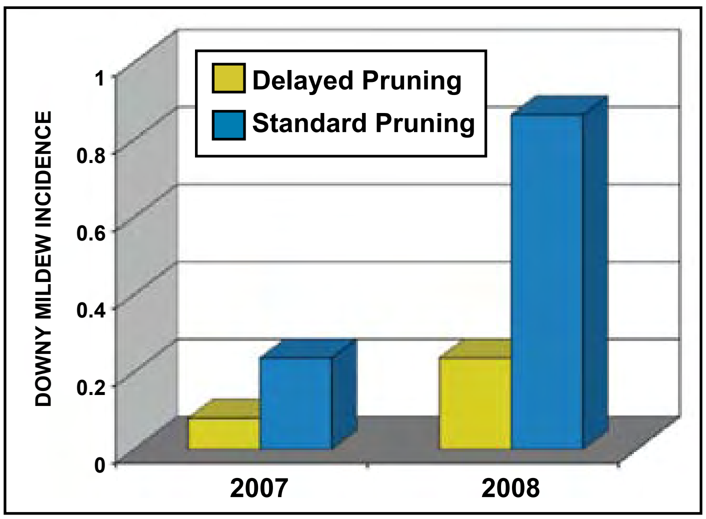


Figure 15. Association of spring pruning timing to the incidence of plants with downy mildew in 6 commercial yards of Willamette in Oregon. Hop yards that received the delayed pruning treatment were chemically pruned 10 to 14 days later than the growers' standard pruning timing.

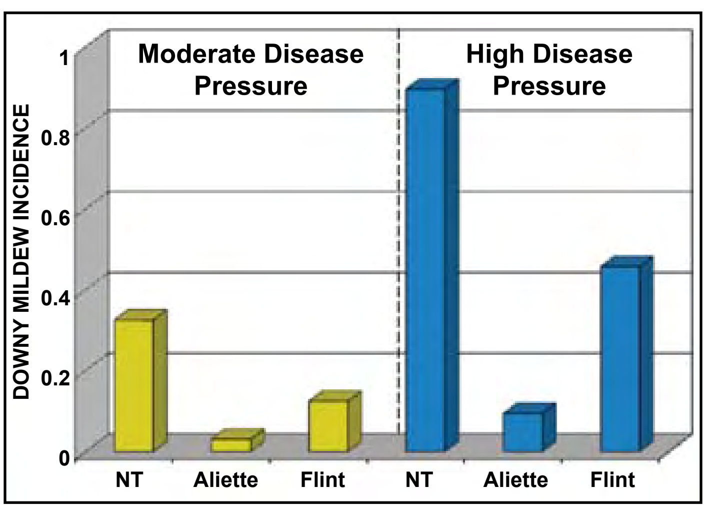


Figure 16. Efficacy of Aliette WDG and Flint under moderate and high disease pressure in Washington. NT = Non-treated.

Non-infected rhizomes or softwood cuttings should be selected when establishing new hop yards since planting material may harbor the pathogen. Thoroughly remove all basal foliage during spring pruning (Figs. 13 and 14). Pruning yards as late as possible, provided all green tissue is removed, generally reduces the severity of downy mildew (Fig. 15). However, optimum timing for pruning must be determined carefully for each variety since pruning too late can reduce yield.

In high disease pressure situations, strip leaves from bines after training and remove basal foliage with chemical desiccants to reduce disease spread higher into the canopy. Decisions on stripping and the intensity of basal foliage removal also depend on the severity of downy mildew, presence of powdery mildew, and consideration of the negative impacts on beneficial insects and mites. In situations where downy mildew is threatening late in the season, early harvest of yards can minimize cone infection. However, yield and alpha acid content is reduced when plants are harvested too early and this practice also needs to be considered carefully.

Timely fungicide applications often are needed to manage the disease when weather is favorable to the pathogen. Fungicide applications during the first season a yard is planted may be beneficial to help minimize crown infection and disease levels in ensuing seasons. Under high disease pressure in western Oregon, a fungicide applied just after the first spike emerges and before spring pruning significantly enhances control of downy mildew later in the season. Later fungicide applications should be timed to coincide with major infection events. See the Pacific Northwest Plant Disease Management Handbook at http://plant-disease.ippc.orst.edu/ for a current list of registered herbicides.

The downy mildew pathogen has a high potential for developing resistance to certain fungicides. Strict adherence to resistance management tactics is essential to delay the development of resistance. Resistance to phenylamide fungicides (e.g., various Ridomil formulations) and fosetyl-Al (Aliette WDG) is common in the Pacific Northwest. Phenylamide fungicides should not be used where resistant populations have been detected, since resistance to this class of fungicides appears to persist for many years (>15 years) in the pathogen population. Where phosphonate fungicides such as fosetyl-Al have been used extensively, resistance to low rates (e.g., 2.5 pounds Aliette WDG per acre) of these products is likely to occur. High rates of phosphonate fungicides are needed for disease control where this resistance is present. Strobilurin fungicides (e.g., Flint and Pristine) applied for management of powdery mildew can provide suppression of downy mildew. The activity of strobilurin fungicides against both downy mildew and powdery mildew can be exploited on varieties susceptible to both diseases, bearing in mind that strobilurins have a high risk of inciting resistance development in both the downy mildew and powdery mildew pathogens. Efficacy of Aliette WDG and Flint under both moderate and high disease pressure is shown graphically in Figure 16.

Fusarium Canker

David H. Gent

Fusarium canker is caused by the fungus *Fusarium sambucinum*. The disease is often present at a low incidence in hop yards, although in some circumstances a high incidence of plants may be affected. Symptoms of the disease are conspicuous and diseased plants are easily identified. Yield losses from Fusarium canker have not been quantified rigorously.

Symptoms

The base of an affected bine is swollen and tapers near the point of attachment at the crown (Fig. 17). Affected bines can be detached from the crown with a gentle tug. Older leaves on the lower part of the bine may become yellow. Disease symptoms often are not recognized until affected bines wilt suddenly (Fig. 18) at flowering or in response to high temperatures and moisture stress. Leaves on wilted bines remain attached. Bine wilting is often most evident after mechanical injury to bines from cultivation, pesticide applications with an air blast sprayer, or high winds, since bines break off from crowns at these times. Severely affected plants may be killed during the winter, particularly when the disease occurs on young plants.

Disease Cycle

The disease cycle of Fusarium canker has not been investigated thoroughly. The fungus that causes the disease is widespread in soil and also can be found in association with plant debris, diseased crowns, and apparently healthy planting materials. It is thought that the pathogen infects hop plants primarily through wounds created by mechanical damage (e.g., wind, tractors) at or below the soil line. Insect feeding also may create wounds that allow the pathogen to gain entry into the hosts.

Figure 17. Swollen basal portion of a bine affected with Fusarium canker. (D. H. Gent)

Figure 18. Wilted bine due to Fusarium canker. Notice that wilted leaves remain attached to the bine. (D. H. Gent)

Management

Growers should remove diseased tissue from affected hills, if practical, and avoid propagation from diseased hills. Hilling up soil around the base of bines promotes growth of healthy roots and can reduce the incidence of bine wilting. Reducing free moisture near the crown due to irrigation can help. Application of lime to increase pH near the crown and avoiding use of acidifying ammonium nitrogen fertilizers can help to reduce disease incidence. Minimizing injury to bines during field operations, arching (i.e., tying bines and strings together to facilitate equipment passage), and preventing damage to bines from arthropod pests can all help to reduce wounds that allow the fungus to gain entry into the plant. No fungicides are registered for control of Fusarium canker.

At-A-Glance:
Fusarium Canker

- ◆ Avoid propagation from diseased hills.
- ◆ Mound soil around the base of bines to promote growth of healthy roots and reduce wilting.
- ◆ Reduce free moisture near the crown.
- ◆ Add lime to increase pH near the crown and avoid use of ammonium nitrogen fertilizers.
- ◆ Minimize injury to bines during field operations and from pests.
- ◆ Arching strings may help to reduce bine injury.

***At-A-Glance:* Fusarium Cone Tip Blight**

◆ Time irrigations to reduce periods of wetness on cones.

◆ Fungicide applications do not appear to be effective.

◆ This sporadic disease does not warrant specific control measures in most yards.

Fusarium Cone Tip Blight

David H. Gent

Cone tip blight generally is a disease of minor importance in the Pacific Northwestern United States, although in some instances up to 30% of cones can be affected. The disease has been attributed to several *Fusarium* species, including *Fusarium crookwellense*, *F. sambucinum*, and *F. avenaceum*.

Symptoms

Affected bracts and bracteoles at the tip of the cone become a medium to dark brown as the cone matures (Fig. 19). The browning may be limited to a small portion of the tip of the cone or in severe cases encompass as much as 60% of the cone. A characteristic symptom of the disease is that all bracts and bracteoles in the whorl of the cone tip tend to be affected. Browning and death of the tip of the strig (central axis that bears the nodes) generally are apparent when the affected bracts and bracteoles are removed (Fig. 20).

Disease Cycle

Little is known about the disease cycle. The pathogens may survive in soil, plant debris, and/or in association with hop crowns. The cone tip blight pathogens, as well as other *Fusarium* species, may be recovered from apparently healthy burrs, bracts, strigs, and stigma. Anecdotal reports suggest that the disease is favored by high humidity during cone development.

Management

Control measures have not been developed for cone tip blight, but the disease occurs sporadically enough that specific control measures are not needed in most yards. Limited evaluations of fungicides indicate *Fusarium* spp. are recovered at a lower rate from burrs and cones treated with strobilurin fungicides, but these treatments have not been successful for management of cone tip blight.

Figure 19. Medium brown discoloration of bracts and bracteoles on a cone with cone tip blight. (S. J. Pethybridge)

Figure 20. Discoloration of strigs due to cone tip blight. (Courtesy J. C. Bienapfl. Reproduced with permission from *Compendium of Hop Diseases and Pests*, 2009, W. Mahaffee, S. Pethybridge, and D. H. Gent, eds., American Phytopathological Society, St. Paul, MN.)

Gray Mold

David H. Gent

Gray mold generally is a disease of minor importance in hops of the Pacific Northwestern United States. The disease is favored by prolonged wet, humid conditions, and can result in cone discoloration and poor cone quality. The disease is caused by the fungus *Botrytis cinerea*, a widespread and common pathogen found on numerous crops including bean, raspberry, strawberry, and tree fruit.

Symptoms

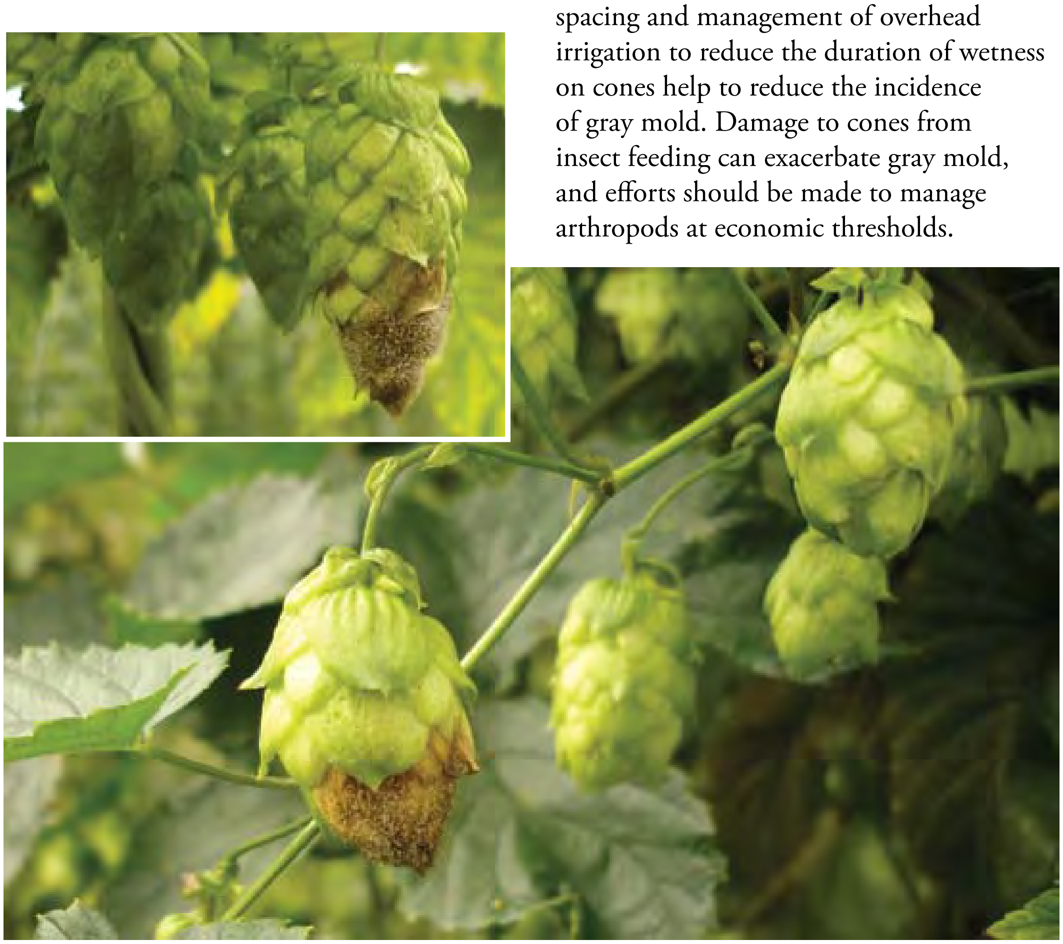
Affected cones have light to dark brown spots on the tips of bracts and bracteoles, which can enlarge with time and cause discoloration of entire cones. Bracteoles are more susceptible to damage than bracts, and diseased cones can develop a striped appearance. Gray mold symptoms are similar to Alternaria cone disorder but can be distinguished by the presence of gray, fuzzy fungal growth that begins at the tip of the cone (Figs. 21 and 22). Signs of the pathogen may not be present in dry weather.

Disease Cycle

The gray mold fungus may survive as a decay organism on organic materials, in and on leaves, and in the soil as dormant resting structures known as sclerotia. The pathogen is active over a range of temperatures when free moisture is available, with an approximate temperature of 68 °F being optimal. The fungus can remain dormant in or on plant tissues during unfavorable conditions and become active when weather or host factors are favorable. Infection on cones is favored by wet weather and injury caused by field operations, insect feeding, or other diseases.

Management

Fungicide applications can reduce gray mold damage to hops. (See the Pacific Northwest Plant Disease Management Handbook at http://plant-disease.ippc.orst.edu/ for a current list of registered herbicides.) However, in most years the disease causes minimal damage to hops in the Pacific Northwest and special control measures have not been necessary. Cultural practices such as increasing row and plant spacing and management of overhead irrigation to reduce the duration of wetness on cones help to reduce the incidence of gray mold. Damage to cones from insect feeding can exacerbate gray mold, and efforts should be made to manage arthropods at economic thresholds.



Figures 21 and 22. Medium brown discoloration and fungal growth on the tip of a cone due to gray mold. (S. Radisek)

At-A-Glance
Gray Mold

- ◆ Minimal damage to PNW hops.
- ◆ Control measures generally not needed.
- ◆ Manage irrigation and promote air movement to reduce wetness on cones.
- ◆ Manage arthropod pests at economic thresholds to prevent injury to cones.
- ◆ Fungicide applications can reduce gray mold damage to hop cones during wet weather.

At-A-Glance
Powdery Mildew

◆ Select early-maturing or resistant varieties when possible.

◆ Apply adequate but not excessive irrigation and fertilizer.

◆ Remove all green tissues during spring pruning.

◆ Apply appropriate fungicides as soon as possible to protect regrowth after pruning and throughout season.

◆ Eliminate basal growth with chemical desiccants to remove diseased tissue.

◆ Apply highly effective fungicides to protect burrs and young cones.

◆ Harvest timely to minimize crop losses in the field when powdery mildew occurs on cones.

Powdery Mildew

David H. Gent and Mark E. Nelson

Powdery mildew is caused by the fungus *Podosphaera macularis*, and is one of the most important diseases of hop in the Pacific Northwest. The disease can cause severe crop damage, in some cases resulting in complete loss of marketable yield due to lost production and reduced cone quality.

Symptoms

Disease symptoms appear as powdery white colonies on leaves, buds, stems, and cones (Fig. 23-25). During periods of rapid plant growth, raised blisters often are visible before sporulation can be observed. Infection of burrs and young cones causes abortion or severe distortion of the cone as it develops. Affected cones may develop a characteristic white powdery fungal growth, although in some cases fungal growth is visible only under bracts and bracteoles and only with magnification. Affected cones become reddish-brown as tissues are killed (Fig. 25), or may turn a medium brown after kiln drying.

Disease Cycle

In the Pacific Northwest, the pathogen is known to overwinter only in infected buds. Where sexual mating occurs there is potential for overwintering structures (called chasmothecia or cleistothecia) to form and survive in and on crop debris and soil. However, the sexual stage of the fungus has not been confirmed in the Pacific Northwestern United States. Shoots that emerge from an infected bud often are rapidly covered with fungal growth, and are termed “flag shoots” (Fig. 26). Flag shoots occur on a small percentage of hills, on average approximately 0.7% in Washington and 0.02% of hills in Oregon, and provide the initial spores to begin outbreaks each spring. Flag shoots often are not detected until they become heavily covered with powdery mildew, although infected shoots can be found at a low level as soon as shoots emerge in spring.

As the plant develops, the pathogen spreads and infects young leaves, moving up the bine in sync with plant growth. Leaves become increasingly resistant to infection as they age, especially when they are produced during hot weather (> 85 °F). Disease development is favored by rapid plant growth, mild temperatures (47 to 82 °F), high humidity, and cloudy weather. Under ideal conditions at 65 °F, the fungus can complete its life cycle in as little at 5 days. Burrs and young cones are very susceptible

Figure 23. Powdery, white colonies on a leaf severely affected by powdery mildew. (D. H. Gent)

to infection, and their development is arrested by infection, resulting in reduced crop yield and quality. Infections occurring later in the season are thought to lead to browning and an apparent premature ripening. Extremely cold weather during the overwintering period is thought to reduce, but not eliminate, survival of the fungus in infected buds (Fig. 27).

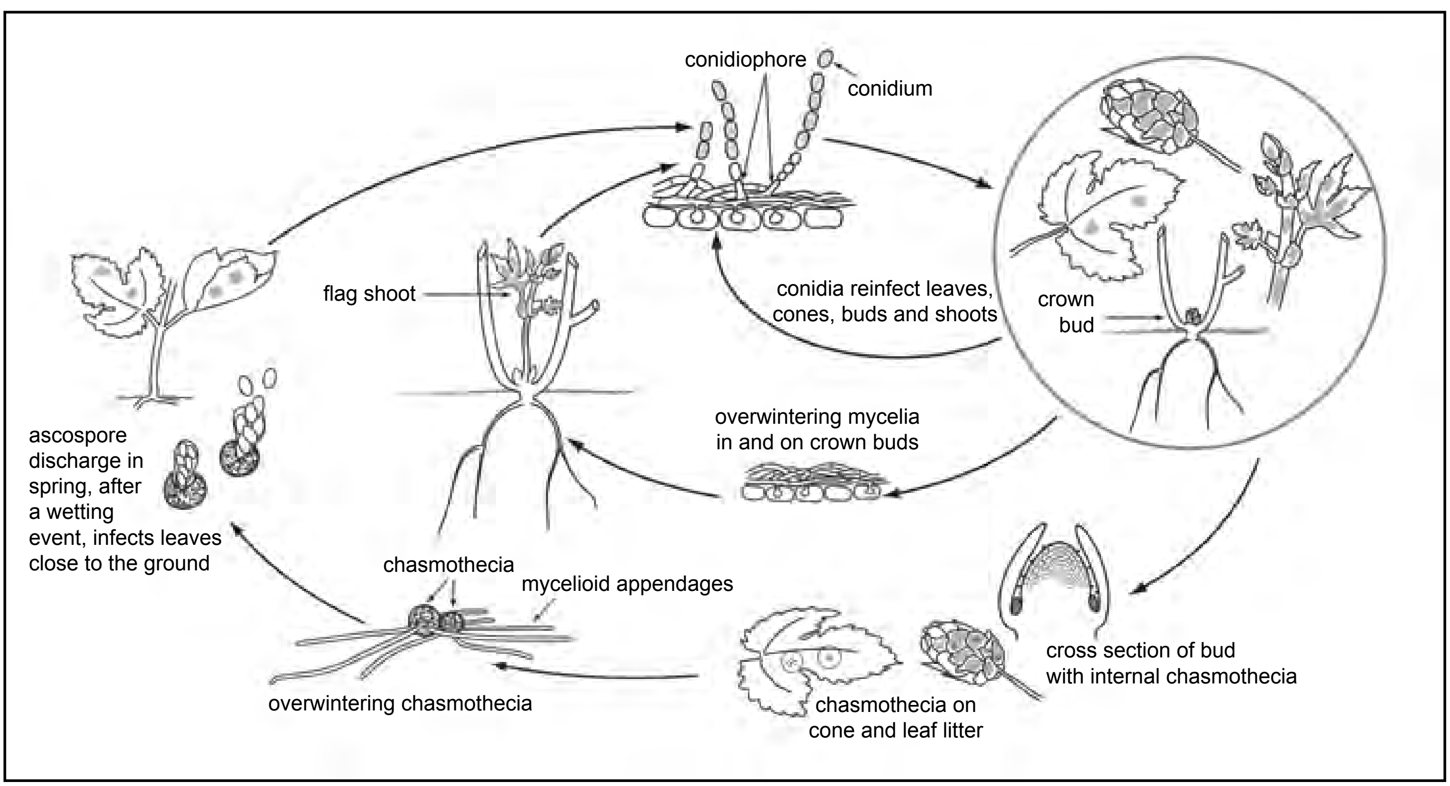
PHOTOS THIS PAGE, CLOCKWISE FROM FAR LEFT

Figure 24. Leaves and stems extensively colonized by the powdery mildew fungus surrounding and originating from a flag shoot. (D. H. Gent)

Figure 25. Cone with severe browning caused by late-season infection by the powdery mildew fungus. Note white fungal growth (mycelium) on bracts. (D. H. Gent)

Figure 26. A young shoot with severe powdery mildew ("flag shoot") resulting from bud infection and overwintering. (D. H. Gent)

Figure 27. Life cycle of *Podosphaera macularis* on hop. The sexual stage of *P. macularis* (shown by arrows on the bottom and left side of the figure) is not known to occur in the Pacific Northwestern U.S. (Prepared by V. Brewster)



See the Pacific Northwest Plant Disease Management Handbook at http://plant-disease.ippc.orst.edu/ for a current list of registered herbicides.

Management

Control of powdery mildew requires integration of crop sanitation practices, adequate but not excessive fertilization and irrigation, and timely fungicide applications to keep disease pressure as low as possible during the season and up to harvest. Although growers often have little ability to select resistant varieties because of market factors, many resistant varieties are available (Table 2, page 12). Newport, Nugget, and several proprietary varieties are resistant to powdery mildew, while Cascade and Liberty have useful levels of tolerance. Selection of early-maturing varieties (e.g., Fuggle) can help to escape late-season powdery mildew.

Management of powdery mildew should begin in early spring by thoroughly removing all green tissues during spring pruning, including shoots on the sides of hills (Fig. 13, page 13, and Fig. 28). The timing of the first fungicide application after spring pruning is critical in affecting the severity of disease later in the season. This application should be made as soon as possible after shoot growth resumes.

Regular fungicide applications are essential for economic production of most susceptible varieties. However, fungicide applications alone are not sufficient to manage the disease economically. Under high disease pressure, removal of basal growth with chemical desiccants is essential to remove diseased tissue and delay disease development. Desiccants should be applied once bines have grown far enough up the string so that the growing tip will not be damaged. Achieving adequate cover of dense basal growth during fungicide applications is difficult, and removal of basal foliage is critical for reducing later infection of leaves and cones. Results of a field trial using desiccants alone are shown in Figure 29.

Several factors influence the development and severity of powdery mildew on cones, including disease severity on leaves, temperature and rain during cone development, late-season fungicide applications, and harvest date. Highly effective fungicides, such as Quintec, applied to young, developing cones can significantly reduce incidence of powdery mildew on cones at harvest (Fig. 30). The efficacy of any fungicide, however, can vary greatly depending upon the severity of the disease pressure present (Fig. 31). The incidence of cone infection is also correlated with timing of the last fungicide application, and applications should continue until the pre-harvest interval as specified by the label. The powdery mildew pathogen has an extremely high ability to reproduce, therefore careful attention to fungicide resistance management guidelines is critical to delay the development of resistance.

When powdery mildew is present on cones near harvest, timely picking will minimize crop losses in the field. Early harvest also can help to reduce damage to cones, although yield can be reduced.

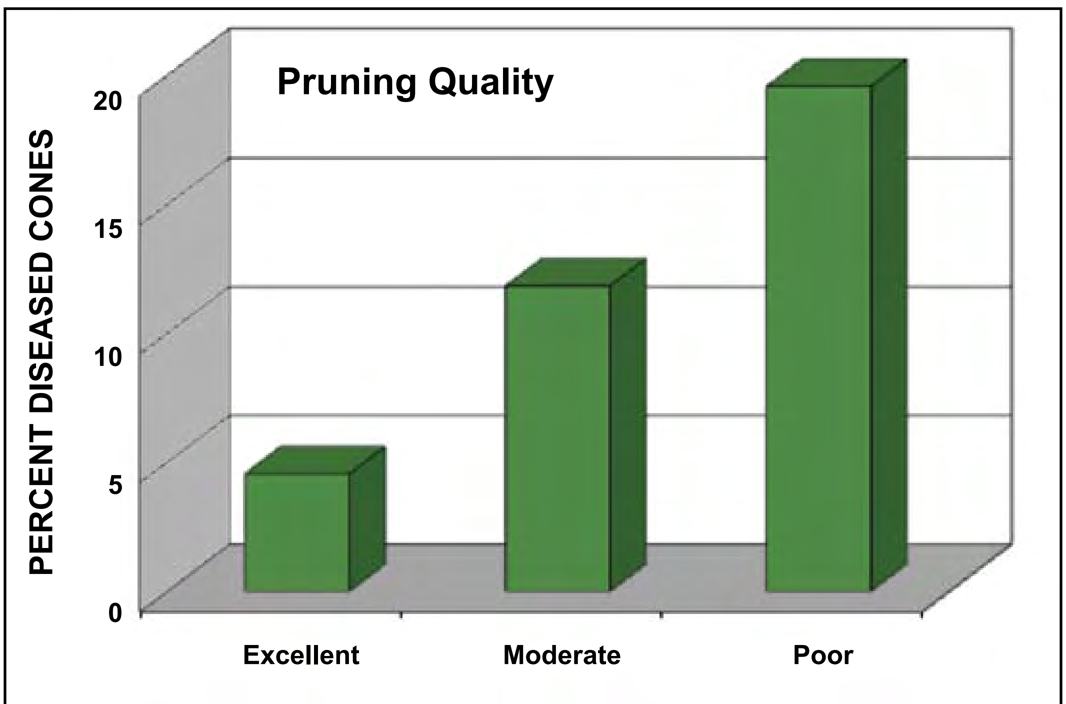


Figure 28. Association of spring pruning quality to the incidence of cones with powdery mildew in 50 commercial hop yards in Oregon and Washington during 2000, 2005, and 2006. Excellent = No foliage or green stems remaining after pruning, Moderate = Foliage or green stems on some hills after pruning, and Poor = No pruning conducted or foliage and green stems present on all hills after pruning.

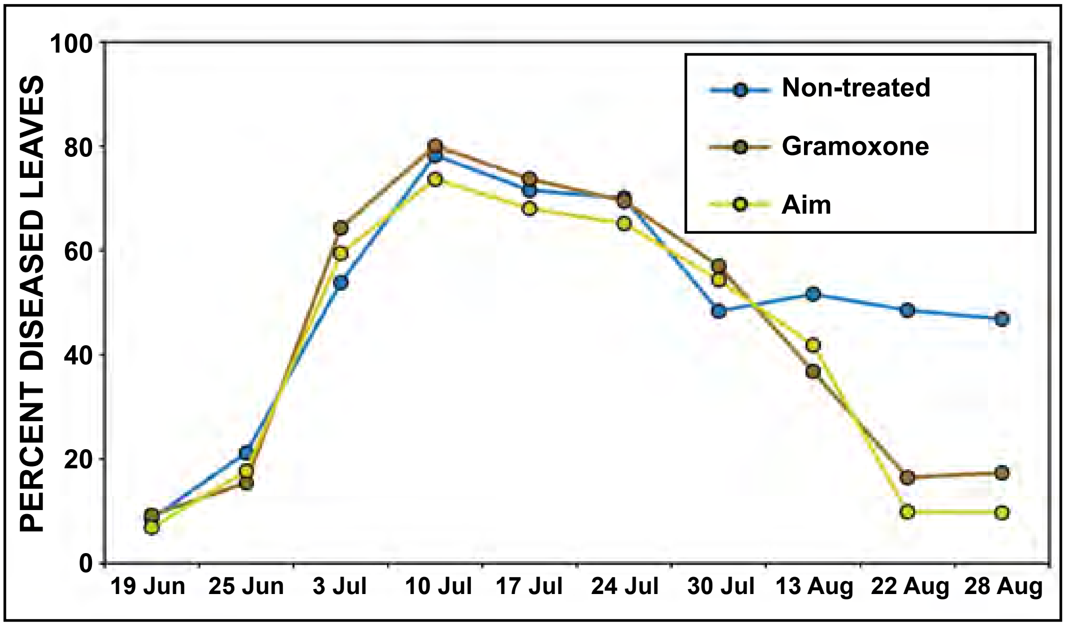


Figure 29.
Incidence of hop leaves with powdery mildew in relation to herbicide treatments to remove basal leaf growth in Washington. Applications of Aim EW were applied 6 July, 3 Aug, and 20 August. Applications of Gramoxone Max + Desicate II were applied 6 July and 3 August. No fungicides were applied in this trial.

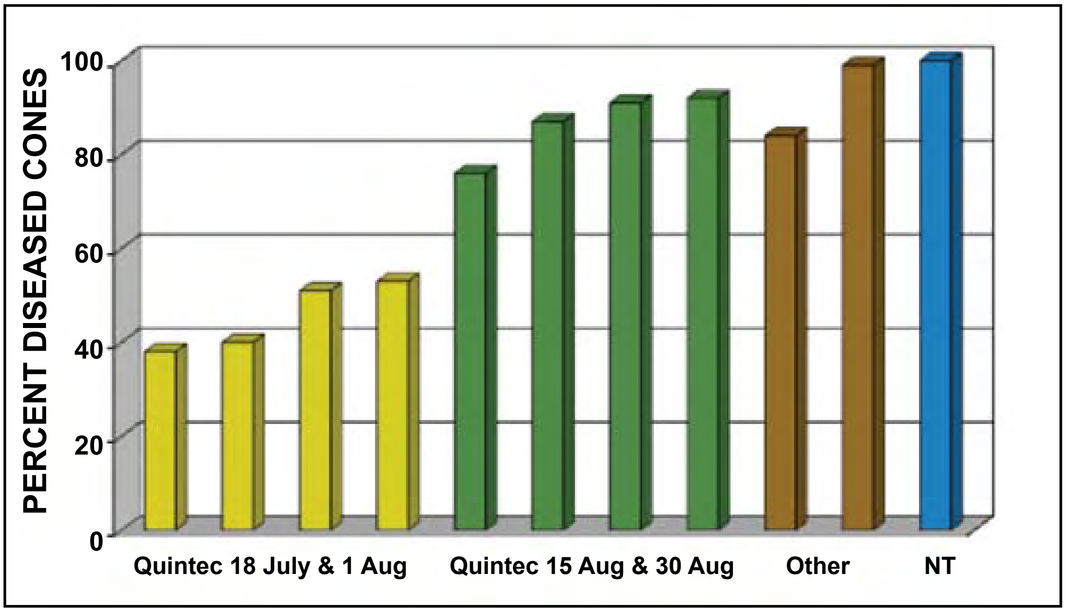


Figure 30.
Effect of Quintec timing on incidence of cones with powdery mildew in Washington in 2008 under extremely high disease pressure. NT = Non-treated. Other = Another fungicide applied during 18 July to 30 August.

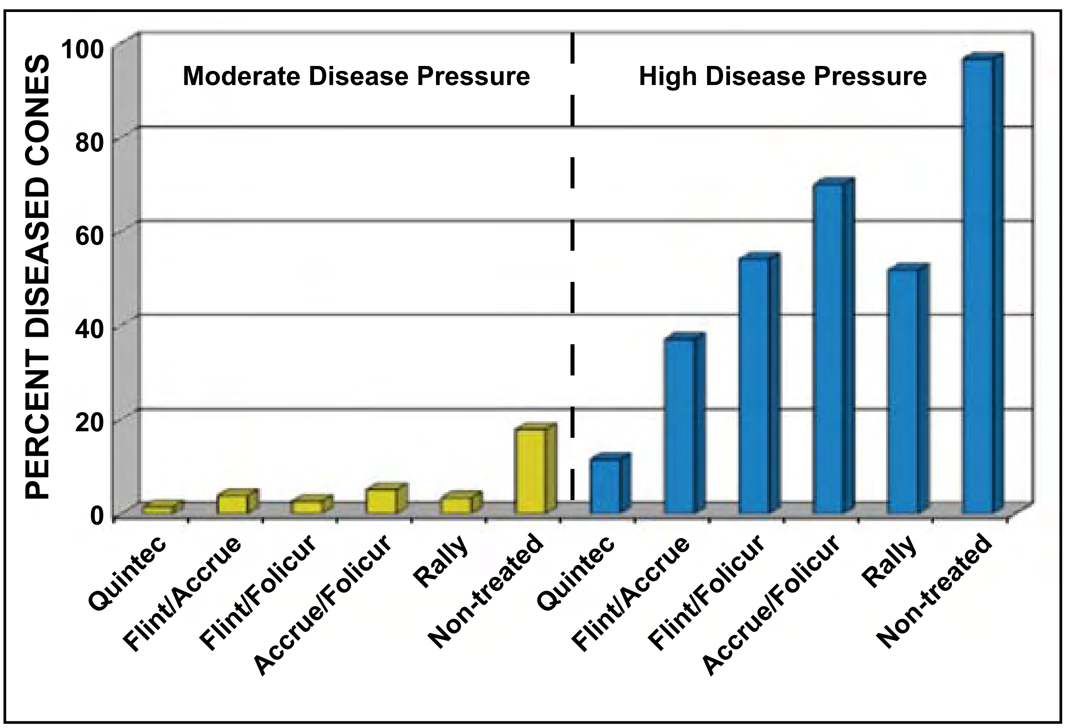


Figure 31.
Efficacy of powdery mildew fungicides under moderate and high disease pressure in Washington. Notice that most fungicides provide acceptable control when disease pressure is moderate.

At-A-Glance
Red Crown Rot

- Select and plant only high-quality planting materials.
- Avoid wounding crowns during spring pruning.
- Maintain plant vigor by avoiding early harvests, maintaining basal foliage, and avoiding soil-applied herbicides that reduce root development.
- Avoid replanting in the hole left by removing a diseased plant.
- Fumigation can improve plant vigor and yield, but has not been adopted widely in Australia where this disease primarily occurs.

Figure 32. Reddish-brown decay and dry rot of a crown affected by red crown rot. (D. R. Smith)

Red Crown Rot

David H. Gent

Red crown rot has been described on hop plants in Australia and Oregon. In Australia the disease was attributed to a fungus described as a *Phacidiopycnis* sp. The naming of this fungus was in flux, and the proper name of this organism is now thought to be *Phomopsis tuberivora*. Data from Australia indicate affected plants may suffer yield losses of up to 20%. In Oregon, plants have been killed by red crown rot and yield losses appear to be higher than 20% in some instances.

Symptoms

The pith tissue of affected roots and crowns is orange to red, which develops into a dry rot of the root (Figs. 32-33) with a distinct boundary between diseased and healthy tissue (Fig. 33). Roots and crowns of apparently healthy plants also may have this appearance, but the degree and severity of rot is more pronounced in diseased plants. In the advanced stages of the disease, entire crowns are destroyed, leading to weak, uneven shoot growth and yellowing of lower leaves (Fig. 34). Bines on severely affected plants often fail to reach the top wire and have limited development of lateral branches. Severely affected plants can be killed. Affected plants tend to be aggregated in roughly circular patches, although in some young hop yards diseased plants may be more generally scattered across a yard.

Disease Cycle

The only data available on the disease cycle of red crown rot are from research conducted in Victoria, Australia. In that environment, the disease was thought to be associated with planting poor quality

Figure 33. Reddish-brown rot of a young hop root caused by red crown rot. Notice the distinct margin between diseased and healthy pith tissues. (D. H. Gent)

Figure 34. Weak growth of bines and plant death caused by severe red crown rot. Notice that affected plants are aggregated in this yard. (D. R. Smith)

rootstock, injury to crowns during spring mowing of shoots (slashing), and cultural practices that reduced plant vigor, such as early harvest and leaving insufficient foliage on plants after harvest. The causal organism can be recovered from soil, plant debris, and healthy crowns. The host range of the pathogen also includes alfalfa, beet, potato, and several trees and woody ornamentals. The fungus is a weak pathogen and disease symptoms rarely develop on these hosts.

Management

Control measures for red crown rot have not been investigated or validated in the Pacific Northwest; the disease currently appears to cause economic damage in relatively few yards. Red crown rot has been managed successfully in Australia through a combination of careful selection of high quality, disease-free planting materials, avoidance of crown wounding during spring pruning, and cultural practices that maintain plant vigor. Other management recommendations promoted in Australia include removing diseased plants and avoiding replanting in the hole left by removing a diseased plant. Efforts should be made to improve plant vigor by avoiding early harvests, maintaining as much foliage as possible after harvest to help plants increase carbohydrate reserves, and avoiding soil-applied herbicides that reduce root development. Boron deficiency has been implicated in red crown rot in Victoria, although conclusive evidence of a link between boron deficiency and the disease is lacking. In Victoria, fumigation with dazomet provided an approximate 60% increase in yield in year one and 14% in year two. However, this practice has not been adopted in Australia due to the high cost of fumigation.

Sclerotinia Wilt (White Mold)

David H. Gent

Sclerotinia wilt, also referred to as white mold, affects nearly 400 weed and crop plant species, including important crops in the Pacific Northwest such as numerous legumes (e.g., green bean and pea), canola, carrot, lettuce, potato, and squash. The disease is caused by a fungus, *Sclerotinia sclerotiorum*, and is an occasional problem on hop in wet, cool climates such as those found in the hop production regions in New Zealand or western Oregon. However, the disease occurs rarely on hop in the Pacific Northwest. Sclerotinia wilt can cause damage when soil and plants remain continuously wet and temperatures are mild.

Symptoms

Disease symptoms generally appear in late spring or early summer as soft, water-soaked lesions on bines just below or near the soil surface at the crown. The infected tissue collapses, creating a light brown to grayish lesion approximately 1 to 4 inches long. During wet weather, fluffy white growth of the fungus may form on the infected tissue (Fig. 35). Small, hardened black overwintering structures (sclerotia) form on and in diseased bines. As the disease progresses, the lesions expand and may girdle the bine, causing a wilt. Leaves generally remain green until the bine is girdled completely. Disease symptoms may appear similar to those caused by Fusarium canker or Verticillium wilt. However, the presence of fluffy white mycelia and sclerotia are diagnostic for Sclerotinia wilt.

Disease Cycle

The pathogen overwinters as long-lived resting structures (sclerotia) in infested crop debris and in the soil. Sclerotia can germinate directly and infect roots, or, if conditioned by exposure to moist conditions and cool temperatures, can germinate to produce one or numerous small mushroom-like structures called apothecia (Fig. 36). The soil surface must remain wet for several days or longer for apothecia to form, and with hops this generally occurs when plants produce abundant, lush foliage that shades the soil near the crown. A sclerotium may produce one or numerous apothecia, and each apothecium may produce produce several million airborne spores called ascospores. Ascospores require a nutrient source upon which to grow before invading a host, and often this nutrient source is senescent leaves or other plant tissues near the crown. Severe epidemics of Sclerotinia wilt on hop reportedly are associated with hilling soil infested with sclerotia onto crowns and with frost injury of developing basal buds. New sclerotia are formed in and on infected bines and are returned to the soil, where they may survive five years or longer and perpetuate the disease cycle. The pathogen also may survive on numerous broadleaf weeds in and around hop yards.

Management

Control measures for Sclerotinia wilt of hop usually are not needed in the Pacific Northwest. Avoiding varieties reported to be especially susceptible (e.g., Fuggle, Bramling) might be useful in wet, mild areas. Cultural practices that reduce the duration of wetness on plants and the soil surface can reduce disease incidence. These cultural practices may include limiting nitrogen fertilization, removing excess basal shoots and leaves, stripping leaves from lower bines, and timing irrigations to allow the top two inches of the soil to dry completely between irrigations. Formulations of the parasitic fungus *Coniothyrium minitans* (marketed under the trade name Contans WG) are available for biological control of *Sclerotinia sclerotiorum*. The efficacy of this product for Sclerotinia wilt in hop has not been investigated.

At-A-Glance Sclerotinia Wilt or White Mold

- Control measures usually are not needed in the Pacific Northwest.
- Utilize less susceptible varieties where possible.
- Limit excessive basal growth and time irrigations to reduce wetness on plants and soil.
- Commercial formulations of a biological control agent are available.

ABOVE: Figure 35. White fungal mycelia and sclerotia (small black survival structures) on hop bines affected by Sclerotinia wilt. (T. J. Smith)

AT LEFT: Figure 36. Sclerotium of *Sclerotinia sclerotiorum* that has germinated to produce an apothecium. Numerous apothecia can be produced from a single sclerotium. (D. H. Gent)

At-A-Glance
Sooty Mold

◆ Sooty mold is controlled by controlling hop aphids.

◆ Natural enemies of hop aphid can provide significant levels of control when not disrupted by broad-spectrum insecticides.

Sooty Mold

David H. Gent

Sooty mold is not a disease, but rather a complex of common fungi that grow superficially on insect excretions deposited on leaves and cones. The appearance of sooty mold is due to the presence and development of phloem-feeding insects, most importantly the hop aphid. Hop aphids probe the phloem strands of hop plants, ingesting more plant fluids than can be processed by their digestive systems. Aphids expel the excess plant fluids as a dilute solution known as "honeydew," comprised of sugars, amino acids, and other substances, which provides a food source that supports the growth of dark-pigmented fungi that grow on the surface of leaves and cones, reducing the quality of cones.

Symptoms

Once aphids colonize and commence feeding, plant tissues become covered with sticky honeydew and develop a shiny appearance before sooty mold becomes evident. Signs and symptoms of sooty mold soon develop on this honeydew as a flattened, black mass of fungal growth that resembles a fine layer of soot (Fig. 37). Burrs and developing cones later may become covered with honeydew, quickly becoming black and sooty in appearance. Entire bracts, bracteoles, and lupulin glands may become black and sticky, but sooty mold tends to be most prevalent on the undersides of bracts and bracteoles and on leaves shaded from the sun (Fig. 38).

Figure 37. Black sooty mold on hop leaves. (D. H. Gent)

Figure 38. Black sooty mold on a cone. Notice the white aphid castings present under the bracts and bracteoles. (D. H. Gent)

Management

Sooty mold is managed by controlling hop aphids (Fig. 39) when populations exceed economic thresholds. Natural enemies of hop aphid can provide significant levels of control when not disrupted by insecticides, therefore when possible broad-spectrum insecticides should be avoided.

Figure 39: Hop aphids are a major contributing factor in sooty mold. This is the winged form of the hop aphid. For aphid photos and control information, see the arthropod pest control section of this handbook. (L. C. Wright)

Verticillium Wilt

David H. Gent and Mark E. Nelson

Verticillium wilt is a potentially damaging disease of hop and numerous other crops including alfalfa, cherry, maple, mint, potato, as well several herbaceous plants, woody ornamentals, and common weeds. On hop, Verticillium wilt may be caused by two related fungi, *Verticillium albo-atrum* and *V. dahliae*. The host range and severity of disease caused by these pathogens varies. Several strains of *V. albo-atrum* have been described. Some may cause relatively minor wilting symptoms (non-lethal or fluctuating strains) while others can cause severe symptoms (lethal or progressive strains) that rapidly can kill susceptible varieties. Non-lethal strains of *V. albo-atrum* are common in the Pacific Northwest and have been reported on hop. Lethal strains of *Verticillium albo-atrum* have not been reported from the United States. *Verticillium dahliae* causes a relatively minor wilt disease on hop. This pathogen has a broader host range than *V. albo-atrum*, and occurs commonly on hop in the United States.

Symptoms

Disease symptoms vary depending on the aggressiveness of the *Verticillium* pathogen that is attacking the plant. With non-lethal strains of *V. albo-atrum,* disease symptoms often appear initially on lower leaves as yellowing and death of tissue between major veins and upward curling of leaves (Fig. 40). Affected bines become noticeably swollen (Fig. 41) and when these stems are cut open the vascular tissue is discolored a medium to dark brown (Fig. 42). These symptoms generally are first recognized near flowering or when plants become moisture stressed. Eventually, one or all of the bines on a hill harboring the infection completely wilt (Fig. 43). Lethal strains of *V. albo-atrum* can cause rapid death of leaves, side arms, and plant death. Bine swelling is less apparent with lethal strains of *V. albo-atrum*, but the degree of vascular browning is more severe than that associated with non-lethal strains of the pathogen. *Verticillium albo-atrum* has been reported on hop more frequently in Oregon than Idaho or Washington.

Figure 40. Upward curling and wilting of leaves associated with Verticillium wilt caused by a non-lethal strain of *Verticillium albo-atrum*. (D. H. Gent)

Figure 41. Swollen bine with wilted leaves resulting from infection by a non-lethal strain of *Verticillium albo-atrum*, one of the Verticillium wilt pathogens. (D. H. Gent)

Symptoms of Verticillium wilt caused by *Verticillium dahliae* may vary depending on environment and variety. In some cases, such as with the variety Willamette, plants may be infected but the only noticeable symptom is swelling of the bines and a general yellowing of lower leaves near the main bines. Some degree of browning often is present when these bines are cut open. *Verticillium dahliae* tends to cause more severe symptoms on hop plants in Washington than Oregon.

***At-A-Glance* Verticillium Wilt**

- Plant resistant varieties when possible.
- Clean equipment between yards to minimize spreading the pathogen.
- Plant only disease-free rhizomes or cuttings.
- Do not return trash or compost from yards with Verticillium wilt to hop yards.
- Control weeds with herbicides and reduce cultivation where possible.
- Reduce nitrogen fertilization as much as possible.

Figure 42. Diagnostic browning of vascular tissues caused by Verticillium wilt. A healthy bine is shown at top. (D. H. Gent)

Figure 43. Wilting of bines affected by Verticillium wilt caused by a non-lethal strain of *Verticillium albo-atrum*. (D. H. Gent)

Disease Cycle

The Verticillium wilt pathogens survive in soil, invade hop roots, and later grow into water-conducting tissues. Fungal growth and plant toxins produced by the pathogen disrupt the movement of water and nutrients, leading to the wilt symptoms. The fungus also spreads systemically in the plant and invades leaves.

The pathogens are spread in hop yards during soil cultivation, in hop trash, and in planting materials from infested yards. Several common weeds of hop yards can be infected by *Verticillium* spp., including lambsquarter, pigweed, and shepherd's purse, and these weeds can allow the pathogens to survive even after hop plants have been removed from a yard. The pathogens produce long-lived survival structures that can persist in soil. In the absence of a host, *V. albo-atrum* can survive three to four years in soil and *V. dahliae* can survive for 15 years or longer.

Management

Planting of resistant varieties and strict sanitation procedures are essential where lethal strains of the pathogen exist to limit spread among yards. Less susceptible varieties include Cascade and Perle, whereas Fuggle is notably susceptible. Planting materials should only be obtained from disease-free yards. Hop trash from yards with Verticillium wilt should not be returned to hop yards. A small percentage of Verticillium wilt propagules can survive composting, therefore composted trash from yards with the disease should not be spread on hop yards.

In the Pacific Northwest where only non-lethal strains of Verticillium wilt are present, a minimum crop rotation of four years to a non-host (e.g., small grains, corn) can help to reduce levels of *V. albo-atrum* in soil. Reduced cultivation, weed control, and limited nitrogen fertilization (i.e., less than 140 pounds per acre per year) also help to reduce the incidence of Verticillium wilt. Although *V. dahliae* usually causes only minor Verticillium wilt symptoms, management practices for *V. albo-atrum* minimize damage from this pathogen as well.

Diseases of Minor Importance

Armillaria Root Rot
(Shoestring Root Rot)

Armillaria root rot, also known as shoestring root rot, is a common disease of numerous forest and orchard trees, shrubs, and vines caused by species of the fungus *Armillaria*. On hop, disease symptoms appear initially as wilting of plants. Plaster-white sheets of the pathogen grow under the bark of infected bines near the soil surface. As the disease progresses, the crown may display a powdery rot. The disease generally is a minor concern for hop. However, new yards should not be planted after susceptible tree crops. If a hop yard must be established following a tree crop, all roots and stumps should be removed and destroyed if the disease was present.

Black Mold

Black mold is caused by an unidentified species of the fungus *Cladosporium*. The disease can cause a brown discoloration of bracts that gives affected cones a striped appearance somewhat similar to Alternaria cone disorder. In the case of black mold, the bracts become brown and the bracteoles remain green. The darkly pigmented spores of the fungus are easily observed on affected bracts under low magnification. The discoloration is most prominent on cones protected from direct sunlight, such as those on low lateral branches. The disease causes negligible damage, but black mold is easily confused with downy mildew or Alternaria cone disorder and misdiagnosis may lead to the unnecessary application of fungicides.

Crown Gall

Crown gall, caused by the bacterium *Agrobacterium tumefaciens*, is the only bacterial disease of hop reported in the United States. The disease results in fleshy to hard tumors (galls) on bines at or near the soil surface close to the crown, resulting in weak bine growth, wilting of affected bines, and, in severe cases, plant death. The disease appears to be most damaging in nurseries and on young plants; older plants can be affected without obvious symptoms or damage. Generally, no special disease management strategies are needed for crown gall. Softwood cuttings and rhizomes should be harvested only from plants free of the crown gall bacterium.

Rhizoctonia solani

Rhizoctonia solani has been reported in very rare instances to cause lesions on young shoots of 'Brewers Gold' in British Columbia. Lesions are sunken and brick red to black in color. Affected shoots are stunted and may collapse if girdled by a lesion near the crown. The occurrence of the disease in British Columbia was attributed to hilling soil on top of plants immediately after spring crowning. This practice is uncommon, and should continue to be avoided.

At-A-Glance Minor Diseases

- Avoid planting hops following trees susceptible to Armillaria root rot.
- Black mold symptoms are easily confused with those of downy mildew or Alternaria cone disorder.
- Crown gall can impact young plants; take care to harvest cuttings and rhizomes from uninfected plants.
- While rare, *Rhizoctonia solani* may be favored by hilling plants after spring crowning.

***At-A-Glance* Carlavirus Complex**

◆ Use only certified virus-free planting stock when establishing new yards.

◆ Insecticide use for aphid control is inefficient for limiting the introduction of viruses, but can reduce the rate of spread within a yard.

Carlavirus Complex: *American hop latent virus, Hop latent virus,* and *Hop mosaic virus*

Kenneth C. Eastwell and Dez J. Barbara

Three carlaviruses are known to infect hop plants: *Hop mosaic virus*, *Hop latent virus* and *American hop latent virus*. All are known to occur in mixed infections and all but *American hop latent virus* are found worldwide. *American hop latent virus* is found primarily in North America.

Symptoms

Hop latent virus and *American hop latent virus* do not cause visually obvious symptoms on any commercial hop varieties. Of the three carlaviruses, *Hop mosaic virus* is the most likely to cause both symptoms and crop loss. On sensitive varieties, chlorotic mosaic mottling can develop between major leaf veins (Fig. 44). Severely affected plants may establish poorly when planted, have weak bine growth, and often fail to attach to the string. The varieties that develop these symptoms typically are those of the Golding type or those that have Golding parentage. However, some strains of *Hop mosaic virus* appear to cause infections that may be almost symptomless on Golding hops. The three carlaviruses reduce growth, which is particularly critical in establishing new plantings. Yield can be reduced by approximately 15%, but varieties sensitive to *Hop mosaic virus* can suffer losses as great as 62% as a result of infection. Changes in brewing characteristics induced by these viruses are minor and appear to be analogous to over maturity of the hop cones at harvest.

Figure 44. Yellow mosaic pattern on Chinook due to *Hop mosaic virus*. (K. C. Eastwell)

Disease Cycle

Carlaviruses are transmitted mechanically and in a non-persistent manner by aphids.

All three are transmitted by the hop aphid, *Phorodon humuli,* and *Hop mosaic virus* and *Hop latent virus* are also transmitted by the potato aphid, *Macrosiphum euphorbiae*, and green peach aphid, *Myzus persicae*. Transmission by aphids is thought to be quite inefficient, however. Propagation and distribution of virus-infected plants is the primary mode through which carlaviruses are spread long distances. Root grafting and mechanical transmission are thought to contribute to localized spread. Carlaviruses typically have narrow host ranges and for practical purposes the only hosts for these pathogens likely to be near hop yards are other hop plants. Over the life of a hop planting, a high percentage of plants in a particular hop yard may become infected.

Management

Since vegetative propagation of virus-infected plants is the principal factor in virus spread, the use of certified virus-free planting stock is the most practical method of limiting any virus disease, particularly during the early stages of plant growth and development. Application of insecticides to control aphids is inefficient for limiting the introduction of virus since the virus will be transmitted before the viruliferous aphids are killed. However, reducing aphid populations can reduce the rate of secondary transmission within a hop yard.

Apple mosaic virus

Kenneth C. Eastwell and Dez J. Barbara

Apple mosaic virus is considered the most important virus disease of hop around the world. Originally, it was believed that the disease was caused by either *Apple mosaic virus* or the closely related virus *Prunus necrotic ringspot virus*. Recent data indicate that all natural infections of hop are by *Apple mosaic virus* and that previously described isolates of *Prunus necrotic ringspot virus* in hop plants were genetic variants of *Apple mosaic virus.*

Symptoms

Apple mosaic virus induces chlorotic rings or arcs that can become necrotic. Frequently, these merge to create oak-leaf line patterns on leaves (Figs. 45-47). The severity of symptoms is dramatically affected by environmental conditions. Symptoms are usually most severe when a period of cool weather with temperatures below 80° F is followed by higher temperatures. Plants can be infected for several seasons without disease expression until appropriate environmental conditions occur. Under conditions where severe symptoms are expressed, cone and alpha acid yield can be reduced up to 50%. A mixed infection of *Apple mosaic virus* and *Hop mosaic virus* may result in enhanced disease severity and crop loss.

Figure 45. Necrotic ringspots and oak-leaf line pattern on Nugget due to *Apple mosaic virus*. (D. H. Gent)

Figure 46. Oak-leaf line pattern caused by *Apple mosaic virus*, without the development of ringspot symptoms. (D. H. Gent)

Figure 47. Necrotic ringspot due to *Apple mosaic virus*. Development of this symptom is temperature dependent; necrotic ringspots may not be apparent in all seasons. (D. H. Gent)

Disease Cycle

Propagation of *Apple mosaic virus*-infected plants is the primary mode of transmission, although mechanical transmission in the hop yard and root grafting appear to be significant factors in the local spread of the virus. Since *Apple mosaic virus* is not expressed every growing season, infected plants may be selected inadvertently for propagation and spread the virus to other hop yards.

Apple mosaic virus belongs to a genus of viruses that includes some pollen- and/or seed-transmitted viruses, but these routes of spread do not appear to be significant for *Apple mosaic virus*. The rate of spread is dependent on hop variety, climatic conditions, and farm management practices. No known insect or mite vectors transmit *Apple mosaic virus*. *Apple mosaic virus* has a host range that bridges several major plant groups that include apple, pear, and rose but there is no evidence to suggest that the virus is naturally transmitted from one host species to another.

Management

Selection and propagation of planting materials free of *Apple mosaic virus* are essential for disease management. The use of contact herbicides rather than mechanical pruning to control basal growth may reduce mechanical transmission of *Apple mosaic virus* to adjacent plants.

At-A-Glance
Apple mosaic virus

- Use only certified virus-free planting stock when establishing new yards.
- Use contact herbicides rather than mechanical pruning to control basal growth to reduce mechanical transmission of *Apple mosaic virus* to adjacent plants.

At-A-Glance
Hop stunt viroid

◆ Use only certified viroid-free planting stock when establishing new yards.

◆ If a small number of plants are infected, promptly remove to minimize spread.

◆ Thoroughly kill all volunteer plants when replanting hop yards.

◆ Use contact herbicides rather than mechanical pruning to control basal growth to reduce mechanical transmission to adjacent plants.

◆ Thoroughly wash farm equipment to remove plant residue and sap.

◆ Disinfecting knives and cutting tools with an appropriate disinfectant solution for 10 minutes may reduce transmission.

Hop stunt viroid

Kenneth C. Eastwell

Hop stunt viroid is a sub-viral pathogen that causes a serious disease of cultivated hop. It spread throughout Japan in the 1950s and 1960s. Presence of the viroid in North American-grown hops was confirmed in 2004. The disease has not been widely reported in hop growing regions of the world other than Japan and North America. *Hop stunt viroid* can reduce alpha acid yield by as much as 60% to 80% per acre.

Symptoms

The severity of symptoms caused by *Hop stunt viroid* is dependent on the hop variety and the weather. Visible symptoms of infection may take three to five growing seasons to appear after initial infection of mature plants. This long latent period before the appearance of discernible symptoms frequently leads to the propagation and distribution of infected root pieces. Early-season growth of infected bines is delayed and foliage is generally pale relative to healthy bines (Fig. 48). During active growth, the length of the internodes of infected bines is reduced by as much as two-thirds compared to healthy bines (Fig. 49). The degree of stunting is temperature-dependent, with more severe stunting occurring in warmer growing regions or seasons. As bines mature, the development of lateral branches is inhibited (Fig. 49). The cones borne on the sparse and shortened lateral branches are smaller and development is delayed compared to cones on healthy plants. The development of yellow-green foliage continues to appear at the base of infected bines throughout the season. The response of different varieties to infection is not well known but on some sensitive varieties yellow speckling appears along the major leaf veins (Fig. 50). This may be the result of a mixed infection of *Hop stunt viroid* and a carlavirus.

Disease Cycle

The only known mechanisms of transmission are through propagation of infected plants and mechanical transmission. There is no evidence that *Hop stunt viroid* is transmitted through hop seeds or via an insect or mite vector. *Hop stunt viroid* has a greater tendency to move along rows rather than across rows, suggesting that transmission by bines rubbing together on a wire is inefficient. Observation suggests that agricultural operations are the primary mode of viroid transmission once an infection has become established in a planting. *Hop stunt viroid* is readily transmitted mechanically by workers, cutting tools, and equipment during cultural activities such as pruning, thinning, and mechanical leaf stripping. Mechanical transmission is most likely to occur when sap pressure is high and abundant contaminated sap is forced from cut or wounded surfaces, contaminating wound sites on other plants. *Hop stunt viroid* can remain infectious in dry plant debris in the field for three months, but it is unknown if this contributes significantly to transmission of the viroid in the field.

Figure 48. Pale green and yellow leaves on Willamette associated with *Hop stunt viroid*. (K. C. Eastwell)

Management

Since propagation is the major route of *Hop stunt viroid* spread, the use of planting material certified free of this pathogen is the best means of limiting its distribution. *Hop stunt viroid* spreads by mechanical means and presumably also by root grafting. If a small number of plants are infected, they should be removed promptly, with care to remove as much root tissue as possible. Because of the latent period, removal of only symptomatic plants may allow nearby infected plants to remain in the hop yard. Several plants adjacent to symptomatic plants should also be removed. If possible, plants to be removed should be treated in late summer with a systemic herbicide, such as glyphosate, to kill roots. Sites should be allowed to lay fallow for one season so that remaining living roots will produce shoots that can be treated with herbicide. Soil fumigation may also be helpful in killing infected root pieces that remain after roguing if larger areas are affected.

Precautions should be employed to limit spread within a hop yard and between yards. The use of contact herbicide for spring pruning is preferable to the use of mechanical mowers that may transmit the viroid. Similarly, removing basal vegetation later in the season by chemical rather than mechanical means also reduces the risk of transmission. Thorough washing of farm equipment to remove plant residue and sap may help reduce the likelihood of transmission to new fields. Treating knives and cutting tools with a disinfectant solution for 10 minutes may reduce transmission. Many products including bleach (sodium hypochlorite), calcium hypochlorite, and hydrogen peroxide have been suggested but results are inconsistent.

ABOVE RIGHT: Figure 49. Reduced growth and sidearm development of Willamette due to *Hop stunt viroid*. (D. H. Gent)

AT RIGHT: Figure 50. Prominent yellow speckling along and between leaf veins associated with infection by *Hop stunt viroid*. (D. H. Gent)

Other Viruses, Viroids, and Virus-like Agents

Kenneth C. Eastwell and Dez J. Barbara

At-A-Glance
Other Viruses, Viroids, and Virus-like Agents

◆ These viruses and viroids do not merit control at this time, but growers should be aware of symptoms.

◆ Use of virus- and viroid-free planting stock is a first line of defense.

◆ Some of these viruses are problematic in Europe and/or other countries, but are not currently an issue in the U.S.

Several virus and viroids are known to occur in hops that are not addressed by current management practices in the western United States. However, growers should continue to be vigilant for the appearance of symptoms that may indicate the presence of one of these agents.

Hop latent viroid

The group of sub-viral hop pathogens that contains *Hop stunt viroid* also includes *Hop latent viroid*. The presence of *Hop latent viroid* has been confirmed in most hop-producing regions of the world including the United States; wherever it is known to occur, it is widely distributed. *Hop latent viroid* has a very limited natural host range so the primary source of new infections is the use of infected propagation material or mechanical transmission from other hop plants. Infection by *Hop latent viroid* does not cause overt symptoms on most varieties, but it can reduce alpha acid production up to 20% in the limited number of symptomless varieties that have been studied. The variety Omega is sensitive to *Hop latent viroid* (Fig. 51) and infected plants of this variety express obvious symptoms including general chlorosis, poor growth, and retarded development of lateral branches. Total alpha acid production in infected Omega plants can be reduced by 50 to 60%. The epidemiology of *Hop latent viroid* is still not totally clear but control measures adopted elsewhere have centered on producing viroid-free hops and planting away from sources of infection such as older plantings.

Figure 51. Yellowing of leaves and weak growth of Omega variety caused by *Hop latent viroid*. The pathogen is widespread in hop yards in the U.S. but symptoms are rarely produced on varieties currently grown in the U.S. (D. Barbara)

Apple fruit crinkle viroid

Another sub-virus pathogen, *Apple fruit crinkle viroid* (AFCVd) was first reported to occur in hops in Japan in 2004. This viroid is not known to occur in North America in either its hop or fruit tree hosts. Very little additional information is available about this viroid in hops. Symptoms are reported to be very similar to those induced by *Hop stunt viroid* and appropriate control measures are similar (see *Hop stunt viroid,* preceding two pages).

Arabis mosaic virus

Reports of the hop strain of *Arabis mosaic virus* appeared in early literature of the U.S. hop industry. However, recent attempts to identify infected plants failed to detect the presence of this virus in contemporary hop production in the United States. *Arabis mosaic virus* is transmitted by a nematode, *Xiphinema diversicaudatum*, which has a very limited distribution in the United States. The absence of the nematode vector and the adoption of new varieties bred in the United States have contributed to the apparent elimination of *Arabis mosaic virus* from current U.S. production areas. In the United Kingdom, where the nematode vector is indigenous, infection by *Arabis mosaic virus* is reported to reduce yield by 23% to 50%. *Arabis mosaic virus* is also transmitted by introducing sap from infected plants into mechanical wounds, but this is thought to be an insignificant route of virus spread. Plants infected with *Arabis mosaic virus* can display a diversity of symptoms depending on variety, weather, and season. Early-season symptoms include short, erect shoots with shortened internodes that fail to climb or cling to strings (Fig. 52). The sparse appearance of bines early in the growing season ("bare-bine disease") is the most common symptom (Fig. 53). Leaves may roll upward and develop outgrowths occasionally on the underside. With the onset of warm weather, symptoms are absent on newly formed shoots. In other cases, infected plants develop "nettlehead disease," or severe distortion of leaves with deep divisions between lobes and short internodes leading to a rosette appearance (Fig. 54). Development and maturation of cones is significantly delayed on affected bines. The limited presence of the vector for *Arabis mosaic virus* in North America suggests adequate control can be achieved by the use of virus-free plants for propagation.

Strawberry latent ringspot virus

Strawberry latent ringspot virus infects hop plants in Eastern Europe, but no clear symptoms have been described. This virus is related to *Arabis mosaic virus* and is transmitted by the same nematode vector that has a very limited distribution in North America. The impact on hop production is unknown.

Tobacco necrosis virus

Tobacco necrosis virus is transmitted by the soil-borne fungus *Olipidium brassicae,* which infects a wide range of plant species. Sporadic infection of hop has been reported in Europe, but no specific symptoms or reduction in yields have been ascribed to this virus. *Tobacco necrosis virus* is occasionally associated with field crops near major hop production areas in North America but infection of hop has not been confirmed on this continent.

Humulus japonicus latent virus

Humulus japonicus latent virus was first isolated from *Humulus japonicus* (Japanese hop) seedlings grown from seed imported into the United Kingdom from China. The infected plants were destroyed and the virus was not detected by subsequent testing conducted in the U.K. or by limited testing in North America. This virus seems to have been common in both wild *H. japonicus* and commercial hops in China but is little studied and its current status is unknown. No symptoms have been described on current commercial hop plants experimentally inoculated with this virus, and the virus did not move beyond the inoculated leaves. In China, the virus was widely spread within plants that were naturally infected. Symptomless infection of commercial hop plants is of concern because production losses from this virus are unknown. No control measures are required at this time beyond enforcement of quarantine measures to prevent the introduction of foreign plant material.

Other Viruses and a Phytoplasma of Minor Importance

Several different viruses have been associated with mottling and chlorotic rings on infected hop plants. *Alfalfa mosaic virus* and *Cucumber mosaic virus* have wide host ranges and are transmitted by several aphid species, mechanical inoculation, and seed. These viruses occur frequently in field crops grown in North America, but confirmed reports of infection of hop plants are absent. Most reports of disease caused by these viruses have originated in Eastern Europe. The impact of infection beyond the appearance of foliar symptoms is unknown. In addition to producing leaf chlorosis and mottling, *Petunia asteroid mosaic virus* induces leaves that are deformed and rugose (i.e., rough, wrinkled). There are no known natural vectors for *Petunia asteroid mosaic virus*. It is likely transmitted through mechanical means although details of the mechanism of natural spread remain unclear.

In 2004, a phytoplasma was reported to naturally infect hops in Poland; some of the infected hop plants exhibited severe shoot proliferation accompanied by severe dwarfing. Further characterization of DNA sequences obtained from the infected plants indicated that the phytoplasma is similar to Aster yellows phytoplasma (*Candidatus* Phytoplasma asteris). Aster yellows and related phytoplasmas are frequently detected in hop production regions of North America but no natural infections of hop plants have been reported on this continent.

Figure 52. Stunted shoots and leaf curling caused by *Arabis mosaic virus*. (A. Eppler, Justus-Liebig Universität, Bugwood.org)

Figure 53. Severe stunting of plants caused by *Arabis mosaic virus*. (A. Eppler, Justus-Liebig Universität, Bugwood.org)

Figure 54. "Nettlehead" disease caused by *Arabis mosaic virus* resulting in severe distortion. (A. Eppler, Justus-Liebig Universität, Bugwood.org)

At-A-Glance
Hop Cyst Nematode

◆ In most cases the effect of hop cyst nematodes is not sufficient to warrant control measures.

◆ Nematicide is unlikely to be economic or effective.

Nematodes

Hop Cyst Nematode

Frank S. Hay

Several species of nematodes (a.k.a. "eelworms") feed on hop roots but are generally considered of minor importance to hop production. The perennial nature of hop, the size of its root system, and its rapid growth rate during spring suggest that hop plants have a great capacity to tolerate nematode feeding. The most common species associated with hop is the hop cyst nematode, *Heterodera humuli*.

Symptoms

The symptoms of nematode feeding injury on hop have not been well documented. Symptoms are likely to be similar to water stress and/or nutritional deficiencies, and could include a general reduction in growth. Where such symptoms cannot be attributed to other factors, then nematodes might need to be considered as a possible cause.

Hop cyst nematodes are visible in spring; the cream-colored, pear-shaped females are approximately 1/50-inch long and they appear on the roots of hop plants. As they mature, the females harden and darken to form egg-containing cysts. Cysts can be found attached to the root surface or in the soil.

Disease Cycle

Hop cyst nematodes survive as eggs within cysts. Eggs hatch into microscopic, worm-like juveniles as hop plants emerge from dormancy in spring. Juveniles penetrate the root and form a feeding site. Females mature on the surface of the root. Up to several hundred eggs are laid internally within the female, which darkens, hardens, and dies, forming a protective cyst around the egg mass. Hop cyst nematode undergoes one to two generations per year. Hop cyst nematode is also known to interact synergistically with the soil-borne fungus *Verticillium albo-atrum* (Verticillium wilt) to reduce hop growth and increase the severity of wilt symptoms.

Management

In most cases the effect of hop cyst nematode is not sufficient to warrant control measures. One study in Australia suggested some 38% loss in yield between plants with high numbers (5040 per 200 ml soil) and those with lower numbers (924 per 200 ml soil) in spring. Despite this, control of nematodes with nematicide is unlikely to be economic or effective due to the perennial nature of the hop, rapid multiplication rate of *H. humuli*, and difficulty of applying an effective dose of a nematicide to the depths that hop roots and nematodes can penetrate. At present little is known about the differences in the resistance to or tolerance of hop varieties to nematodes.

Abiotic Diseases

Heptachlor Wilt

Mark E. Nelson and David H. Gent

Heptachlor is an insecticide that was used on several crops in the Pacific Northwest, including potato, strawberry, and sugar beet. It was used extensively in 1955 and 1956 for control of strawberry root weevil on hop and this led to severe die-out in treated hop yards. Heptachlor was removed from the U.S market in 1972, but residues of the pesticide are extremely persistent and still can cause injury to hop plants planted in soil with levels below current detection thresholds (i.e., 1 to 10 ng/g soil). Fields treated with chlordane can also lead to wilting since this closely related pesticide also contained heptachlor. Chlordane was banned in 1983.

Figure 56. Wilting of young hop plants due to heptachlor wilt. (D. H. Gent)

Symptoms

Young hop plants initially grow normally, but often cannot establish a root system and wilt and die during the summer or following season. Affected plants have a rough and corky bark that cracks and bleeds sap (Fig. 55). The bases of bines may swell and become brittle, causing them to break off from the crown. Leaves become yellow and die as bines begin to wilt (Fig. 56). Stems of affected plants develop a characteristic brown spotting that develops into a rot. Eventually entire crowns may rot, leading to plant death. The pattern of affected plants is influenced by where heptachlor was applied in the past, and often there is a distinct boundary between healthy and affected plants. Heptachlor residues also may increase the susceptibility of hop plants to Verticillium wilt.

Figure 55. Rough and corky bark on a stem of a plant with heptachlor wilt. (M. E. Nelson)

Management

Economic production of hop often is impossible in fields that were treated with heptachlor. Varieties vary in their sensitivity to heptachlor, although specific information on variety sensitivity is limited. Willamette is sensitive to heptachlor, while Late Cluster and some super alpha varieties appear less sensitive. Hops should not be planted to fields with a history of heptachlor wilt.

Although soil tests can be used to detect heptachlor residues, some varieties are susceptible to heptachlor damage at levels below current detection limits. Therefore, a negative soil test may not be a reliable indicator of the risk of heptachlor wilt. In suspect fields, plants of the desired variety should be planted and observed for heptachlor wilt symptoms for at least one year before planting the entire yard.

***At-A-Glance* Heptachlor Wilt**

- ◆ Do not establish hop yards where heptachlor has been applied in the past.
- ◆ Avoid planting highly susceptible varieties such as Willamette in fields that may contain heptachlor residues.
- ◆ Soil tests for heptachlor are available, but some varieties are susceptible to heptachlor damage at levels below current detection limits.
- ◆ A negative soil test may not be a reliable indicator of the risk of heptachlor wilt.

Arthropod and Slug Pest Management

At-A-Glance
California Prionus Beetle

- Identify, remove and destroy crowns of infested plants.
- Fumigate or fallow fields two to three years before replanting.
- Treat post-harvest with labeled soil-applied insecticides.

California Prionus Beetle

Jim D. Barbour

Pest Description and Crop Damage

Adult California prionus (*Prionus californicus*) are large red-brown to black beetles 1 to 2 inches in length with long antennae characteristic of the longhorned beetle family, to which this beetle belongs (Fig. 57). The larvae are cream-colored, legless, from 1/8 to 3 inches long (Fig. 58), and have strong, dark mandibles that are used to chew plant roots. California prionus larvae do not curl into a c-shape when disturbed as do the larvae (grubs) of other soil-inhabiting beetles such black vine weevils and June beetles. Adults do not feed, but larva feed on plant roots, resulting in decreased nutrient uptake, water stress, and reduced plant growth. Severe infestations can completely destroy crowns and kill plants (Fig. 59). Less severe infestations cause wilting, yellowing, and death of one or more bines (Fig. 60). Feeding damage is likely to be associated with the occurrence of secondary pathogens that can rot crowns.

Biology and Life History

Adults in the Pacific Northwestern United States emerge from pupation sites in the soil in late June and early July. Adults are active at night and not frequently encountered during the day. Males locate females for mating using a pheromone released by females. Eggs are laid on or in the soil near the base of plants. A single female can lay 150 to 200 eggs in her two- to three-week lifetime. Larvae hatching from eggs move to plant roots, where they feed for three to five years. Mature larvae pupate during the early spring in cells constructed from soil and lined with root material.

Monitoring and Thresholds

Larvae can be quantified only by destructively sampling the crown and roots of plants suspected of being infested. Adults fly to light traps, but light trapping is expensive. Light traps capture largely males and there is no information indicating that capture of adults at light traps is correlated to the severity of infestation of hop crowns and roots. Economic thresholds based on economic injury levels have not been established.

Figure 57. Adult California prionus beetles (left, female; right, male). Adult beetles are 1 to 2 inches long with prominent antennae. (D. H. Gent)

Management

Management of California prionus consists of identifying, removing, and destroying (e.g., burning) roots and crowns of infested hop plants. It may be necessary to dig up and remove all plants in severely infested fields. If all plants have been removed and destroyed, the field can be fumigated and replanted to hop, or planted to a non-host crop for two to three years to further reduce California prionus populations prior to replanting. The potential for use of the volatile mating pheromone produced by females for managing California prionus via mating disruption or adult trapping techniques is currently being investigated. Ethoprop (Mocap EC) is labeled for control of California prionus in hop. The long pre-harvest interval of this pesticide (90 days) combined with summer emergence of adults may limit use of ethoprop for California prionus management to post-harvest applications. See the Pacific Northwest Insect Management Handbook at http://pnwpest.org/pnw/insects for a current list of registered insecticides.

PHOTOS AT RIGHT, FROM TOP:

Figure 58. Cream-colored, legless larva of the California prionus beetle. Larvae range in size from 1/8 to 3 inches long. (D. H. Gent)

Figure 59. California prionus larva feeding in a hop crown. Severe infestations can destroy crowns and kill hop plants. (Courtesy J. D. Barbour. Reproduced with permission from *Compendium of Hop Diseases and Pests*, 2009, W. Mahaffee, S. Pethybridge, and D. H. Gent, eds., American Phytopathological Society, St. Paul, MN)

Figure 60. Wilting, yellowing, and death of bines caused by California prionus feeding damage. (J. D. Barbour)

At-A-Glance
Hop Aphid

◆ Begin monitoring in May when daytime temperatures exceed 58 °F.

◆ Avoid excessive application of nitrogen.

◆ Intervene early to prevent aphid establishment in hop cones.

◆ Rotate chemical classes to avoid resistance.

◆ Use selective pesticides that preserve natural enemies.

Hop Aphid

Amy J. Dreves

Pest Description and Crop Damage

Hop aphids (*Phorodon humuli*) are small (1/20 to 1/10 inch long), pear-shaped, soft-bodied insects that occur in winged and wingless forms on hop. Wingless forms are pale white (nymphs) to yellowish-green (adults) and found mostly on the underside of hop leaves (Fig. 61). Winged forms are darker green to brown with black markings on the head and abdomen (Fig. 62). Both forms have long slender antenna and two "tailpipes" (cornicles) at the end of the abdomen. Adults and nymphs have piercing-sucking mouthparts that they use to remove water and nutrients from the vascular tissue of hop leaves and cones. Leaf feeding can cause leaves to curl and wilt and, when populations are large, defoliation can occur. Most economic damage occurs when aphids feed on developing cones, causing cones to turn limp and brown. Hop aphids also secrete large amounts of sugary honeydew that supports the growth of sooty mold fungi on leaves and cones (see Sooty Mold in Disease Management section). Sooty mold on leaves reduces plant productivity and severe infestations render cones unmarketable. Hop aphids also can transmit plant viruses including *Hop mosaic virus* and *American hop latent virus* that can reduce yield, both of which are discussed under the Virus and Viroid Diseases subsection of this volume's Disease Management section.

Figure 61. Wingless hop aphid nymphs (pale white) and adults (yellowish-green) on the underside of an infested leaf. (D. G. James)

Biology and Life History

Hop aphids overwinter as eggs on ornamental and agricultural species of the genus *Prunus,* including plum, cherry plum, sloe, and damson (Fig. 63). Eggs hatch in early spring and one or two generations of wingless aphids are produced asexually on the overwintering host before winged aphids are produced that migrate to developing hop plants in early May. After arriving on hop, wingless asexual females are produced. Each female can give birth to 30 to 50 nymphs in its two- to four-week lifetime and more than 10 overlapping generations occur during a season. In late August, winged adult females are produced that migrate back to the winter host and produce wingless sexual females. Winged males are produced on hop plants approximately two weeks after winged females are produced, and disperse to an overwintering host and mate with the females. Eggs are laid near buds on the winter host.

Monitoring and Thresholds

Yellow pan traps and suction traps (Figs. 64 and 65) are useful for monitoring the start of spring aphid flight from winter hosts into hop yards. Monitoring should begin when daytime minimum temperatures exceed 58 to 60° F. A comprehensive economic threshold does not exist for hop aphid. Most growers apply a pesticide when an average five to 10 aphids per leaf are observed before flowering. Generally, aphids are not tolerated after flowering; control with pesticides is difficult once aphids infest cones.

Management

Growers should apply sufficient but not excessive nitrogen, as large flushes of new growth favor outbreaks of hop aphids. Many aphid predators and parasitoids (e.g., lady beetles, lacewings, predatory bugs, fly larvae, and parasitic wasps: see Beneficial

Arthropods section) occur in hop yards. Since these natural enemies often do not establish until after aphids arrive on hop plants and begin reproducing, however, they frequently are unable to regulate hop aphid below levels that growers will tolerate, particularly after flowering. Attractants (e.g., methyl salicylate) are available that can increase populations of natural enemies in hop yards. Methyl salicylate has also been shown to repel hop aphids.

Unless climatic conditions are unfavorable to reproduction and development (e.g., hot dry weather), hop aphid numbers often exceed the regulating capacity of their natural enemies and pesticides must be applied to limit early-season population growth. A number of insecticides are available for control of hop aphid. It is important to rotate aphicide classes to avoid resistance. When possible, growers should use selective pesticides such as pymetrozine (Fulfill) that control aphid populations while preserving natural enemies of aphids and other hop pests. A Superior-type oil applied to winter hosts during the dormant or delayed-dormant period may reduce the number of spring migrants into hop yards. See the Pacific Northwest Insect Control Handbook at http://pnwpest.org/pnw/insects for a current list of registered insecticides.

Figure 62. Winged form of the hop aphid. Notice the dark green to brown color and black markings on the head and abdomen. (L. C. Wright)

Figure 63. Wingless hop aphids on an overwintering *Prunus* sp. (L. C. Wright)

Figure 64. Yellow pan trap for hop aphid. (J. D. Barbour)

Figure 65. Suction trap for hop aphid. (J. D. Barbour)

At-A-Glance
Garden Symphylan

◆ Monitor fields for symphylans prior to planting or during plant establishment.

◆ Cultivate if necessary to kill symphylans and disrupt their movement.

◆ Treat with soil-applied insecticides in early spring (preferred) or fall.

Figure 66. The centipede-like garden symphylan. Adults are 1/8 to 1/4 inch long. (Ken Gray Image Collection, Oregon State University)

Garden Symphylan

Amy J. Dreves

Pest Description and Crop Damage

Garden symphylans (*Scutigerella immaculata*) are small (1/8 to ¼ inch long), white, centipede-like animals; their long antennae have a "beaded" appearance (Fig. 66). Adults have 12 pairs of legs. Newly hatched nymphs resemble adults but have six pairs of legs with a new pair added at each of six subsequent molts. The eggs are pearly white, spherical with ridges, and found in clusters in the soil.

Garden symphylans feed below ground on fine roots and aboveground on growing plant parts in contact with soil. Root feeding can reduce vigor (Fig. 67), stunt plants, cause poor plant establishment in newly planted yards (Fig. 68), and contribute to the decline of established plantings. Root damage also may increase plant susceptibility to soil-borne pathogens. Garden symphylans are pests of hop in the cool, moist growing regions of western Oregon, and are not known to cause damage to hop in Washington or Idaho.

Biology and Life History

The garden symphylan spends its entire life in the soil or in plant material and debris in contact with the soil surface. Nymphs and adults become active in the spring and can be found aggregating in the upper surface of soil during moist, warm weather. They move deeper in soil as it becomes dry and cool. Eggs hatch in 12 to 40 days, depending on temperature. It takes approximately three months to complete development from egg to adult. Eggs, immature nymphs, and adults can be found together throughout the year. One to two generations occur per year.

Monitoring and Thresholds

Garden symphylans often occur in patches in hop yards and can be monitored by one of several methods. The simplest method is to scout hop yards for garden symphylan damage during warm, moist conditions. Field personnel can search the soil surface and plant parts in contact with the soil for garden symphylans. They can also bait for symphylans prior to planting by placing a cut, moistened potato half face-down on the soil surface of a hop hill. The potato should be covered with a protective material (e.g., tarp segment), then checked two to three days later for presence of symphylans. Alternatively, soil samples can be taken during early spring or fall to determine the presence of symphylans below the soil surface. Samples should be taken by shovel to a depth of 6 to 12 inches from 10 to 20 different sites in the hop yard. The soil can then be placed on a piece of dark plastic or cloth, broken apart, and symphylans observed and counted. More samples should be taken in larger fields. Although no threshold based on economic injury level has been established, an average of five to 10 symphylans per potato or soil sample often is considered a damaging level.

Management

Established plantings can tolerate moderate symphylan damage, however, management is critical in new plantings and during plant establishment in early spring. No single management method has been found completely reliable. Cultivating fields immediately prior to planting or during early spring in established fields directly kills symphylans, exposes them to desiccation and predators, and disrupts their movement. Symphylan mortality increases with the severity and depth of cultivation, but care must be taken to avoid cultivating too close to and damaging perennial hop crowns. Natural predators, such as staphylinid and cucujid beetles, centipedes, and predaceous mites exist, but are not known to provide economic levels of control. No varieties are considered resistant.

Insecticides often are needed to manage symphylans. Insecticides should be broadcast and incorporated as close to hop crowns as possible to ensure penetration into the soil layer where symphylans live. Spring applications (April through late May) tend to be more effective than fall applications (September to October), since symphylans live deeper in the soil in the fall. Advance planning is necessary, as insecticides registered for garden symphylan management in hop have long pre-harvest intervals (65 to 90 days).

ABOVE: Figure 67. Stunting, weak growth, and yellowing of leaves caused by garden symphylan feeding injury. (W. F. Mahaffee)

AT RIGHT: Figure 68. Severe stunting and plant death caused by garden symphylan feeding injury in a newly established hop yard. Notice the aggregated pattern of affected plants. (D. H. Gent)

See the Pacific Northwest Insect Management Handbook at http://pnwpest.org/pnw/insects for a current list of registered insecticides.

Hop Looper and Bertha Armyworm

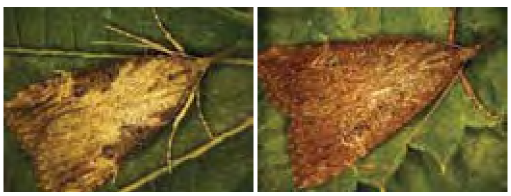
Jim D. Barbour

At-A-Glance
Hop Looper and Bertha Armyworm

- ◆ Monitor plants prior to flowering for presence of caterpillars in hop foliage.
- ◆ Treat to prevent establishment in the upper plant canopy after flowering.
- ◆ Choose compounds selective for caterpillar larvae (e.g., certain Bt formulations) to preserve natural enemies and reduce the number of treatments required for control.

Pest Description and Crop Damage

The larvae (caterpillars) of several moths and butterflies attack hop, however, only the hop looper *(Hypera humuli)* and the bertha armyworm *(Mamestra configurata)* commonly reach damaging levels. The adults of both species are indistinctly mottled gray to gray-brown moths approximately 1 inch long. Female hop looper moths have a distinct W-shaped dark patch along the front edge of each forewing (Fig. 69). This line is present but less distinct in males (Fig. 70). Both sexes have an elongated "snout" that distinguishes them from bertha armyworm moths, which have a large spot on each forewing and a white band near the rear edge of the forewing (Fig. 71).



Figures 69 and 70. Left, female hop looper. Right, male hop looper. Notice the distinct W-shaped dark patch along the front edge of each forewing of the female. (D. G. James)

Figure 71. Adult bertha armyworm. Notice the large spot on each forewing and the white band near the rear edge of the forewing. (Ken Gray Image Collection, Oregon State University)

Hop looper larvae are pale green with two narrow white lines on each side of the back and one on each side (Fig. 72). They have four pairs of prolegs: one each on abdominal segments 4 to 6, and one on the last abdominal segment. They move with a characteristic looping motion and are active largely at night. Larvae rest during the day on the undersides of leaves, often lying along the veins or petiole (leaf stem), making them difficult to see. When disturbed, younger instars drop to the ground on a silken thread, while larger larvae may thrash violently from side to side. Bertha armyworms are dark-backed caterpillars with a yellow to orange stripe on each side and a tan to light brown head (Fig. 73) that lacks the "Y" marking present on the head of other armyworm larvae. The first-instar larvae can be distinguished from hop looper larvae by their black head, their occurrence in groups on leaves, and by having five rather than four pairs of prolegs: four on abdominal segments 3 to 6, plus one on the terminal segment.

Figure 72. Hop looper larva. Notice the pale green color and two narrow white lines on each side of the back and on each side. (D. G. James)

Figure 73. Larva of the bertha armyworm. Note the dark back and yellow to orange stripe on each side. (D. G. James)

When present in large numbers, hop looper larvae can defoliate hop plants, giving them a characteristic lacey appearance (Fig. 74). Although eggs are distributed equally across the surface of the plant, leaf feeding often is more severe near the base of the plant. Later in the season, larvae feeding on hop cones can cause severe losses. Bertha armyworm larvae also defoliate hop plants, but yield loss is caused when caterpillars chewing on the stems cause cones to fall on the ground.

Biology and Life History

Hop loopers overwinter as adults in protected areas such as cracks and crevices in tree trunks and fallen logs, sometimes at considerable distances from hop yards. The adults fly back to hop yards in spring (April) and begin laying slightly flattened, circular eggs (Fig. 75), usually on the underside of hop leaves. Few other plants serve as hosts for hop loopers. Eggs are approximately 1/50 inch in diameter and, although several eggs may be laid on a leaf, all are laid singly, not in masses. Eggs hatch in approximately three days and the larvae feed for two to three weeks, developing through five or six instars before pupating (Fig. 76). Adults emerge in 10 to 12 days. Three generations occur per year; however, after the first generation all life stages can be present in the field at the same time, making it difficult to determine the best time for pesticide treatments.

Bertha armyworms overwinter as pupae in the soil. Moths emerge in late June through July and lay eggs in masses of 50 to more than 100 eggs (Fig. 77) on a wide variety of host plants in addition to hop. Eggs hatch in three to five days and larvae grow through six instars in five to six weeks before pupating in the soil. Larvae often move from weed hosts to hop plants as weeds are consumed. Two generations per year typically occur in the Pacific Northwest.

Monitoring and Thresholds

No economic threshold has been established for hop loopers or bertha armyworms in hops. The presence of large larvae in the upper canopy after flowering generally is not tolerated. The presence of caterpillars in the hop canopy can be monitored by placing a plastic or cloth tarp along a three-foot section of hop row, grasping a bine at or just above head-height, and shaking vigorously for 10 to 15 seconds, dislodging large caterpillars to the tarp where they can be observed and counted.

Management

Hop yards contain many predators (e.g., big-eyed bugs, damsel bugs) and parasitic wasps and flies of hop looper and bertha armyworms (see Beneficial Arthropods section). Hop looper parasitism rates can reach 70%. Several pesticides are labeled for control of hop loopers and bertha armyworms and even the larger instars are readily controlled by these insecticides. *Bacillus thuringiensis* subsp. *aizawai* is effective and is highly specific to caterpillars. Use of Bt products will avoid disrupting biological control of hop loopers and bertha armyworms, as well as biological control agents of spider mites and hop aphid. See the Pacific Northwest Insect Management Handbook at http://pnwpest.org/pnw/insects for a current list of registered insecticides.

AT LEFT, TOP ROW, LEFT TO RIGHT:

Figure 74. Hop looper feeding results in a characteristic lacey appearance. (D. G. James)

Figure 75. A slightly flattened, circular egg of the hop looper. Notice that eggs are laid singly. (D. G. James)

AT LEFT, BOTTOM ROW, LEFT TO RIGHT:

Figure 76. Pupating hop looper. (D. G. James)

Figure 77. Egg mass of the bertha armyworm. Eggs are laid in groups of 50 to 100 or more. (D. G. James)

ABOVE: Figure 78. Adult black vine weevil with characteristic bowed antennae and mouthparts at the end of a long snout. (D. G. James)

BELOW: Figure 79. Root weevil larvae are white, legless, c-shaped grubs with tan to dark-brown head capsules. Actual length is approximately ¼ inch. (P. Greb, USDA Agricultural Research Service, Bugwood.org)

Root Weevils

Jim D. Barbour

Pest Description and Crop Damage

Root weevils are beetles characterized by elbowed antennae and mouthparts at the end of a long snout (Fig. 78). Several root weevil species, including the strawberry root weevil (*Otiorhynchus ovatus*), the rough strawberry root weevil (*O. rugosotriatus*), and the black vine weevil (*O. sulcatus*) attack hop. The black vine weevil is the largest and most common of these in hop. The life cycle, appearance, and damage caused by these species are similar. Adults are oblong gray to black beetles approximately ½ inch long, although the strawberry root weevil is approximately ¼ inch long. The wing covers (elytra) are fused and marked with rows of round punctures. Larvae are white, legless, c-shaped grubs with tan to dark-brown head capsules (Fig. 79).

Adult weevils feed on leaves, creating rough notches on the edges of leaves, but this feeding is not known to cause economic loss (Fig. 80). Economic losses can result from larvae feeding on the roots of hop plants (Fig. 81). Root damage by larvae reduces nutrient uptake and plant growth and increases water stress. The most severe damage results from late-instar larvae feeding on roots prior to pupating in the spring. Premature leaf drop and plant death have been associated with severe feeding damage caused by black vine weevil larvae. Heavy infestations may require that individual plants or even whole hop yards be removed from production.

Biology and Life History

Adult root weevils begin feeding on leaves within 24 hours after emerging from overwintering sites beginning in late April. All adult weevils are females; males are not known to occur. They cannot fly and are active largely at night. Females must feed for 25 to 30 days before they can begin laying eggs. Eggs are deposited on the soil surface, in soil crevices, and on leaves near the base of plants. Egg-laying continues through late September and early October, with each female laying an average of 300 eggs. Larvae emerge from eggs in approximately 21 days, move through soil, and begin feeding on plant roots. Most root weevils overwinter as late-instar larvae that pupate in the spring, but overwintering as adults can occur.

Monitoring and Thresholds

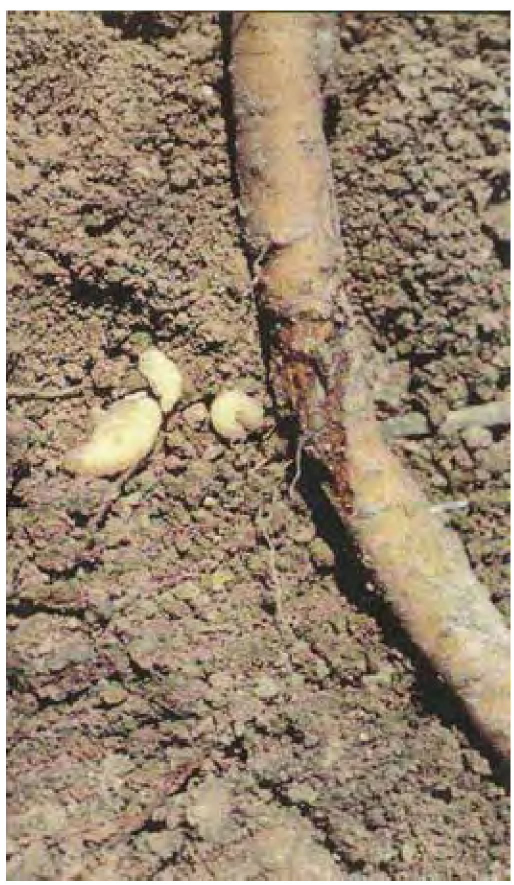
Populations of adult weevils can be monitored with the use of grooved boards and pitfall traps to determine when adults are active in the spring. Scouting for leaf notching caused by adult feeding is also useful. Economic thresholds have not been established for root weevils in hop.

Management

Biological control of root weevil in hop has been achieved using heterorhabditid and steinernematid nematodes. Nematode applications should be timed to coincide with the presence of late-instar larvae, soil temperatures above 50 °F, and adequate soil moisture. Nematodes and foliar insecticides are best applied in late summer or fall to reduce the abundance of large larvae feeding on hop roots in the spring. Foliar insecticides should be applied approximately three weeks after adult emergence but before egg-laying begins. They are more effective applied at night when adult weevils are most active. See the Pacific Northwest Insect Management Handbook at http://pnwpest.org/pnw/insects for a current list of registered insecticides.

BELOW LEFT: Figure 80. Notched edge of a leaf caused by adult weevil feeding. This feeding injury is not known to cause economic loss. (Ken Gray Image Collection, Oregon State University)

BELOW: Figure 81. Root weevil larvae and associated feeding injury on a root. (C. Baird)



At-A-Glance
Root Weevils

- Monitor for vine weevil adults beginning in April.
- Treat for adults with foliar insecticides approximately three weeks after adults are detected in hop yards.
- Treat for late-instar larvae in the late summer or fall using soil-applied insecticides.
- Biological control of root weevil in hop can been achieved using heterorhabditid and steinernematid nematodes.

Figure 82. Adult female spider mite with prominent black spots on each side of the abdomen. Adults are approximately 1/50 inch long. (D. G. James)

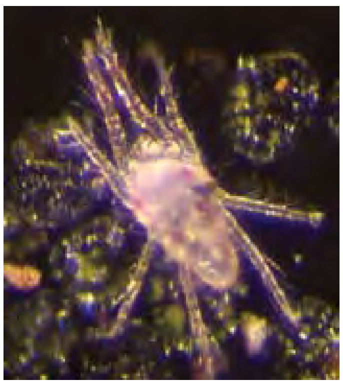


Figure 83. Adult male spider mite. Males are approximately 3/4 the size of females and have a more pointed abdomen. (D. H. Gent)

Figure 84. Spider mite adult, nymphs, and eggs. The eggs are clear to pearly-white spheres approximately 1/200 inches in diameter. (S. Broughton, Department of Agriculture & Food Western Australia, Bugwood.org)

Twospotted Spider Mite

Jim D. Barbour

Pest Description and Crop Damage

Twospotted spider mites (*Tetranychus urticae*) are closely related to spiders and ticks and get their name from their spider-like ability to spin webs. Adult females are small, oval, yellow to yellow-green animals, approximately 1/50 inch long, with a large black spot on each side of the abdomen (Fig. 82). Newly hatched spider mites (larvae) have three pairs of legs, whereas all other life stages (nymphs, adults) have four. Overwintering females turn orange-red in the fall and lose the paired black spots. As they begin feeding in the spring, females turn green and regain the spots. Adult males are approximately 3/4 the size of females and have a more pointed abdomen (Fig. 83). Spider mite eggs are clear to pearly-white spheres approximately 1/200 inch in diameter (Fig. 84).

Spider mites damage hop plants by feeding on leaves and cones, sucking plant juices from the cells. Leaf feeding causes bronzing of leaves and reduces plant vigor (Figs. 85 and 86). Severe infestation can cause defoliation and is accompanied by heavy production of webbing (Fig. 87). Most economic damage is caused by spider mites feeding on cones, which results in dry, brittle, discolored (red) cones (Figs. 88 and 89) that tend to shatter, reducing both quality and quantity of yield. Spider mites in hop cones are also considered contaminants that lower cone quality. When infestations are severe, brewer rejection or total crop loss can occur.

Figures 85 (ABOVE) and 86 (AT RIGHT). Bronzing of leaves and defoliation caused by spider mite feeding. (D. G. James)

Biology and Life History

Twospotted spider mites have a wide host range, feeding and reproducing on more than 180 plant species, and are important pests of many field, forage, ornamental, and horticultural crops. They overwinter as dormant or diapausing females in hop crowns, cracks and crevices in poles, and other protected areas in fields and adjacent areas. Males do not overwinter. Females emerge from overwintering sites in early spring and immediately begin feeding on young shoots beneath bracts. Egg-laying can begin as early as two days after emergence. Eggs hatch in two to five days with females produced from fertilized eggs and males from unfertilized eggs. The sex of immature stages, however, cannot be accurately determined. The larvae develop through two additional molts, the second instar (protonymph) and the third instar (deutonymph), before becoming adult mites. Development from egg to adult takes one to three weeks depending on temperature. As many as five to eight overlapping mite generations per season may occur on hop. Except when populations are high, eggs and motile stages are usually found on the undersides of leaves. Orange, diapausing females appear in late August and September in response to shorter days and cooling temperatures, at which time mites begin moving down plants to overwintering sites.

Monitoring and Thresholds

Samples should be taken weekly beginning in mid- to late May by removing leaves and examining the undersides for the presence of spider mites, mite eggs, and webbing, as well as stippling and yellowing of leaves associated with spider mite feeding. Leaves can be taken at the three- to six-foot level early in the season, however, after approximately mid-June, higher leaves near the trellis wires should be sampled. Several leaves from each of 10 to 30 plants should be sampled depending on field size and the amount of time available. A 10X to 20X hand lens and a pole pruner are useful mite sampling tools.

A comprehensive economic threshold based on spider mite economic injury levels has not been developed for hop. Most growers treat when there is an average of one to two female spider mites per leaf in June and early July, or five to 10 mites per leaf after mid-July. However, research in the United States and Germany indicates that hop plants can tolerate much higher twospotted spider mite populations without suffering economic loss if cones are not infested. Low to moderate numbers of mites on hop foliage may be tolerated if the weather is mild and sufficient biological control agents are present. However, spider mite populations can build rapidly, especially in hot, dry conditions, therefore monitoring is important.

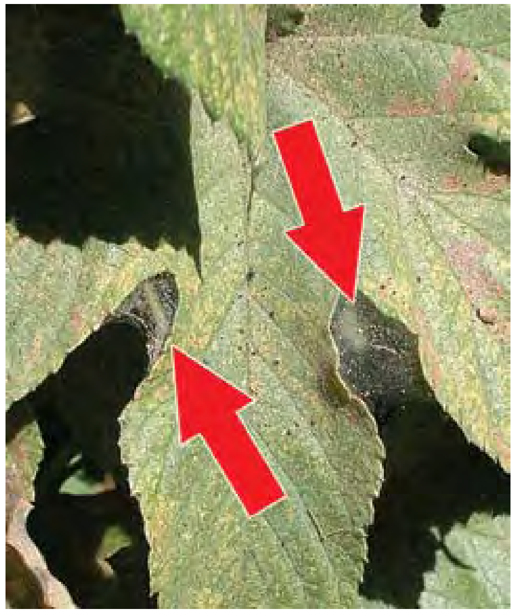


Figure 87. Spider mite webbing is associated with severe infestations. (D. G. James)

Figure 88 (ABOVE). Close-up of dry, brittle, and red discolored cones resulting from spider mite feeding. (D. H. Gent)

Figure 89 (AT LEFT). Hop yard exhibits dry, brittle, and red discolored cones resulting from spider mite feeding. (D. R. Smith)

At-A-Glance Twospotted Spider Mite

- ◆ Monitor weekly beginning in mid- to late May.
- ◆ Provide plants with adequate but not excessive nitrogen fertility and water.
- ◆ Reduce dust, especially in hot dry weather.
- ◆ Treat to prevent cone infestations using foliar-applied miticides.
- ◆ Rely on selective miticides to reduce impact on natural enemies and the number of required miticide applications.
- ◆ Avoid the use of pyrethroid, organo-phosphate, carbamate, and neonicotinoid insecticides, and late-season sulfur applications.
- ◆ Rotate chemical miticide classes to avoid resistance development.

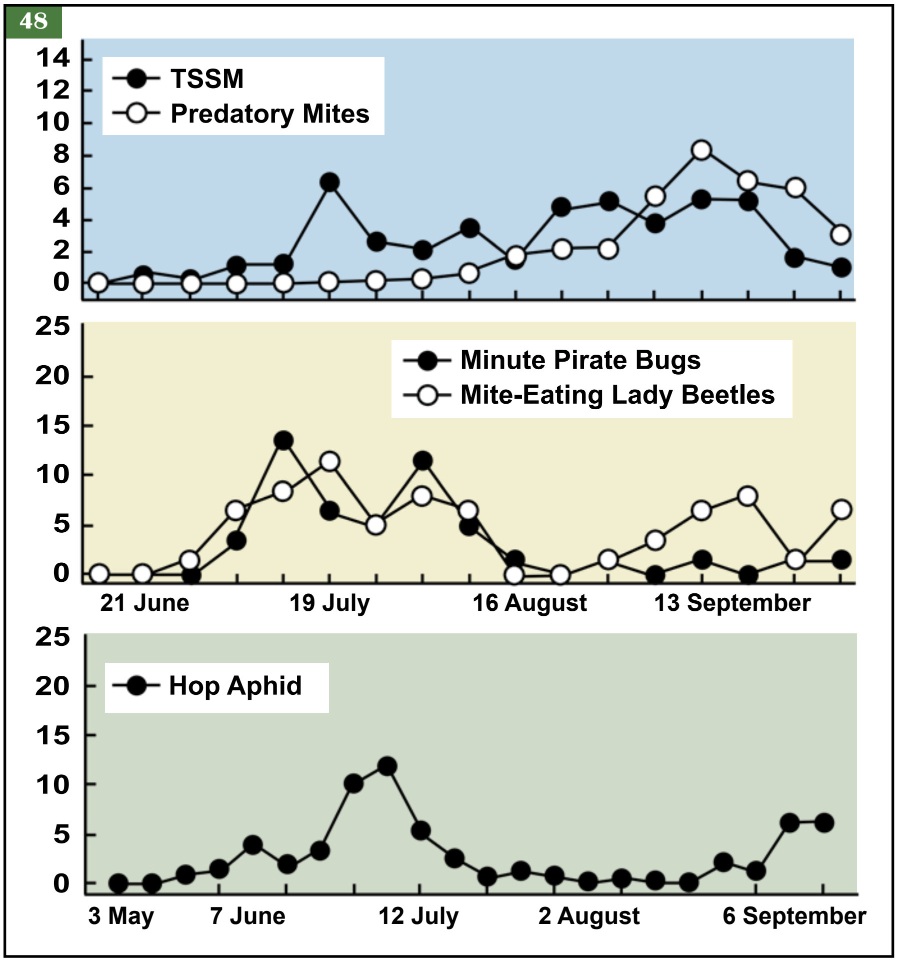
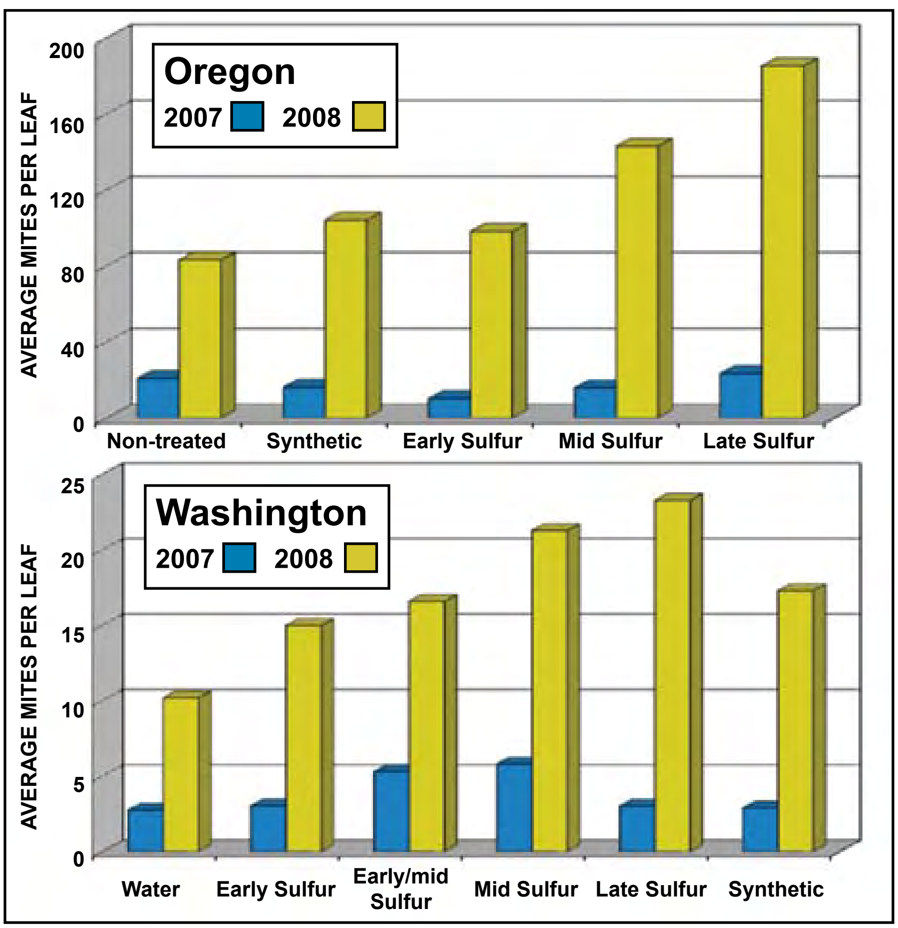


Figure 90 (ABOVE): Examples of successful biological control of twospotted spider mites (TSSM) and hop aphid when natural enemies were present and not disrupted by non-selective pesticides or cultural practices.



Management

Plant stress can be reduced by providing adequate but not excessive fertilizer and irrigation. Spider mite problems are often exacerbated by excessive nitrogen fertility and the presence of dust on plants. Covering dirt roads with gravel, straw, or crop debris, watering or oiling roads, reducing driving speed, and planting ground covers can minimize dust. The use of ground covers also can provide habitat favorable for spider mite natural enemies.

A complex of natural enemies (e.g., predatory mites, big-eyed bugs, minute pirate bugs, lady beetles, spiders, and lacewings; see Beneficial Arthropods section) occurs in hop yards when not disturbed by non-selective pesticides or certain cultural practices. Preserving endemic spider mite natural enemies and maintaining basal foliage on plants can enhance biological control, potentially reducing the need for chemical controls (Fig. 90). Recruitment of predators to hop yards using volatile attractants (e.g., methyl salicylate) also may improve biological control of twospotted spider mite.

A number of foliar-applied miticides are available for control of twospotted spider mites in hop. See the Pacific Northwest Insect Management Handbook at http://pnwpest.org/pnw/insects for a current list of registered insecticides. Several of these are reported to be relatively safe to predatory insects and mites (see Table 1, page 5). Using these selective miticides can enhance biological control. Non-selective miticides should only be used as a last resort when other control tactics fail. Spider mite populations can be exacerbated by the use of pyrethroid, organophosphate, carbamate, and neonicotinoid insecticides used to control spider mites or other arthropod pests, or by multiple applications of sulfur to control hop powdery mildew. Sulfur applications made later in the season (i.e., in June and July) tend to exacerbate mite outbreaks most severely (Fig. 91).

Figure 91 (AT LEFT): Effect of sulfur timing on the severity of spider mite outbreaks in Oregon and Washington. Sulfur was applied three times at 7- to 14-day intervals in each of the plots receiving sulfur treatments. A rotation of synthetic fungicides (Flint, Accure, and Quintec) were applied to plots receiving the synthetic treatment.

Hop Flea Beetle

Amy J. Dreves

Pest Description and Crop Damage

Hop flea beetle (*Psylliodes punctulatus*) adults are small (1/12 inch long), bronze to black metallic beetles (Fig. 92) with strongly developed hind legs that allow the beetle to jump like a flea when disturbed. The eggs are whitish-yellow, oval, less than 1/60 inch in diameter, and deposited singly or in groups of three or four near the roots of hop plants. Mature larvae are approximately 1/5 inch long and off-white with a brown head.

Adult beetle feeding in spring causes shothole damage on leaves on young bines (Fig. 93). Adults emerging in the fall may feed on young cones. Larval feeding on hop roots causes surface tracking and small tunnels. Infestations resulting in economic damage are uncommon and occur primarily in Oregon.

Figure 92. Adult hop flea beetles feeding on a hop leaf. Adults are approximately 1/12 inch long and bronze to metallic black in color. (F. Weihrauch)

Biology and Life History

Hop flea beetles overwinter as adults in plant debris, in cracks in poles, under bark, and around the margins of hop yards. Adults become active March to May and begin feeding on growing hop bines and weeds. The beetles mate and lay eggs during May and June with most eggs deposited in the upper 1/4 inch to 1 inch of soil around hop plants. Larvae hatch in June and feed on hop roots for approximately four to five weeks before pupating in the soil. Adults emerge in three to five weeks and feed on low-growing foliage around hills before migrating to overwintering sites. One generation occurs each year.

Monitoring and Thresholds

Growers should scout fields in early spring, looking for shothole damage on leaves and for the presence of jumping beetles. Beetles are easier to observe if the leaves are not disturbed during scouting. White or yellow sticky traps can be placed at the bases of bines to detect spring-emerging black beetles. No thresholds are established for flea beetles on hop. Healthy, rapidly growing hop plants usually quickly outgrow feeding damage. Larger plants can withstand more feeding injury.

Management

Trap crops (crops more attractive to the pest than hop) such as Chinese mustard or radish can be used to intercept beetles before they enter hop yards. Beetles should be treated in the trap crop to prevent migration into hops. Plowing or tilling weeds and hop residue in the fall to destroy overwintering sites may be beneficial. Biological control using commercial formulations of entomopathogenic nematodes may help to reduce populations of overwintering beetles and consequently reduce flea beetle damage to plant roots. Nematodes should be applied to moist soil during the summer before most larvae pupate. No insecticides are labeled for control of hop flea beetle in hop, but foliar- or soil-applied systemic pesticides used for control of hop aphid usually provide control. See the Pacific Northwest Insect Management Handbook at http://pnwpest.org/pnw/insects for a current list of registered insecticides. When flea beetles migrate from hosts outside a hop yard, most of the infestation will be localized on the borders and spot treatment of borders may be effective. Treat early in the season when plants are young and less than three feet tall.

At-A-Glance

Hop Flea Beetle

- Monitor hops for flea beetle adults and leaf damage in May and June, especially if alternative flea beetle hosts are present nearby.
- Need for treatment is unlikely.
- Certain insecticides applied for aphid control usually control flea beetles.

Figure 93. Severe feeding damage caused by hop flea beetle resulting in a “shothole” appearance. (F. Weihrauch)

Slugs

Amy J. Dreves

At-A-Glance Slugs

- Monitor for slug presence on hills in early spring.
- Cultivate between rows to directly kill slugs or expose them to weather and predators.
- Damage caused by other pests such as flea beetles or cucumber beetles can be mistaken for slug damage.
- Slime trails indicate the presence of slugs.
- Iron phosphate bait is available for slug management (Oregon only).
- Bait at planting time in an Oregon yard with a history of slug infestation.

Pest Description and Crop Damage

Slugs are a problem in Pacific Northwest hops primarily in Oregon. While several species can be found in hop yards, the most common is the gray field slug, *Deroceras reticulatum* (Fig. 94). These soft-bodied mollusks range in length from ¼ inch to 2 inches and are light gray to dark brown with a network of mottled colors. The underside of the foot is whitish with a darker zone. The mantle (i.e., area on top just behind the head) is rounded at both ends and generally lighter in color than the rest of the body. As in all slugs, there is a respiratory pore behind the mid-point and on the right side of the mantle. The body of the slug behind the keel (i.e., the foot) has a boat-like shape running down the top to the tail. When disturbed, the watery slime trail of this slug turns from clear to milky white.

Slugs are most active at night or early morning, especially when humidity is high and temperatures are cool. They retreat into cracks, soil crevices, and sheltered areas by day to protect themselves from predators and dehydration. Very little activity takes place in extremely cold or hot weather. Slugs feed on newly developing shoot tips and leaves of hop plants, resulting in ragged leaves with irregularly sized holes. Damage tends to be heaviest along the edges of hop yards where weedy or grassy borders serve as a habitat for slugs. When populations are high, slugs can destroy the growing tips of hop shoots.

Biology and Life History

The gray field slug completes one to two generations per year. Young adults or eggs overwinter under leaf residue, in soil cracks, and in sheltered areas under the soil surface. In the spring, mating and egg-laying usually follow within one to three weeks after slug activity is noticed. Eggs are laid in clutches of 10 to 40, totaling 200 to 400 eggs in a lifetime. The spherical eggs are laid in a gelatinous mass and are transparent when laid but become cloudy just before hatching. The immature slugs resemble adults but are smaller. The average life span of a slug is nine to 13 months. All slugs have both male and female reproductive organs, so that self-fertilization and egg-laying can occur in any individual.

Monitoring and Thresholds

In areas where slugs may be present, growers can monitor for slugs by carefully observing hop shoots during the pest's critical stage of emergence in the early spring. Open bait traps (in Oregon, where bait is registered, see below) or slug blankets/boards can be placed on the ground near hop hills to monitor for slugs. After several nights, the traps should be turned over and checked for the presence of slugs. Treatment should be considered if the field has a history of slug damage or if excessive damage to foliage or growing tips is observed and slugs are determined to be present.

Management

The most effective control of slugs can be achieved in early spring when temperatures begin to warm and hop plants start to grow. The hop plant is at its greatest risk of slug damage when plants are young. Where baits are registered, it is best to bait at planting time or just before shoots emerge in spring if a yard has a history of slug damage. Managing hop yards so that plants emerge quickly in the spring can help to escape the worst period of slug damage.

Increased use of irrigation and moist warm springs favor slugs in hop yards. Soil cultivation in early spring between hop plants can kill slugs and also expose them to predators and desiccation. Birds, frogs, snakes, Sciomyzid flies, harvestmen (daddy long-leg spiders), and carabid ground beetles prey on slugs. Parasitic nematodes and naturally occurring ciliates (protozoans that move by means of small hairs or cilia) can infect the bodies of slugs.

No chemical treatments/baits for control of slugs are labeled for use on hops in Washington or Idaho; Oregon has a 24c "Special Local Needs" registration for iron phosphate (Sluggo). Iron phosphate baits must be ingested by slugs, and slug death takes three to six days. Feeding activity, however, is stopped almost immediately. Iron phosphate baits works at most temperatures and slugs will not recover after ingesting the bait.

See photo opposite page.

Western Spotted Cucumber Beetle

Jim D. Barbour

Pest Description and Crop Damage

Adult western spotted cucumber beetles (*Diabrotica undecimpunctata undecimpunctata*) are small (1/4 to 1/3 inch long), yellowish-green beetles with 11 distinct black spots on the wing covers (Fig. 95). Eggs are yellow, oblong, and approximately 1/50 inch long. Larvae are 1/20 to ¾ inch long and have one very short pair of legs on each of the three body segments immediately behind the head. Large larvae are white except for the head and the last abdominal segment, which are brown. Adults feed on pollen, flowers, and foliage of many plants. Adult feeding is not generally of economic importance in hop except when beetles attack the growing tips of newly planted hops or developing hop flowers. Larvae feed on the roots of many plants but have not been reported as an economic pest of hop.

Biology and Life History

Western spotted cucumber beetles overwinter as fertilized females on vegetation within field borders and on plant debris. They may be active on warm winter days. Eggs are deposited in the soil near the base of host plants in early spring and hatch in seven to 10 days. A single female can lay between 200 and 1200 eggs. Larvae complete development and pupate in the soil by late spring, and adults emerge in early July in western Oregon. The complete life cycle requires 30 to 60 days. Two generations per year occur in the Pacific Northwest.

Figure 94. Gray field slug. Slugs range in size from ¼ to 2 inches in length. (J. Berger, Bugwood.org)

Monitoring and Thresholds

Hop is not a favored host of western cucumber beetle and is seldom attacked in numbers warranting management. Ground beetles (Carabidae) prey on eggs and a parasitic fly attacks adult cucumber beetles. Avoiding unnecessary use of broad-spectrum pesticides may help to preserve natural enemies. No insecticides are registered for control of western spotted cucumber beetle on hop.

Management

Preventing establishment of weed hosts in fields and field borders may reduce risk of attack. Hop yards near favored larval hosts such as cucurbits and corn may have a higher risk of attack by adult beetles. Certain insecticides applied for control of hop aphid likely provide some control of western spotted cumber beetles.

Figure 95. Adult western spotted cucumber beetle. (J. N. Dell, Bugwood.org)

At-A-Glance Western Spotted Cucumber Beetle

- ◆ Monitor for adults prior to flowering of hop plants.
- ◆ Need for treatment is unlikely.
- ◆ Certain foliar insecticides applied for hop aphid are likely to control this insect.

At-A-Glance
Predatory Mites

◆ Predatory mites are important biocontrol agents of spider mites.

◆ Some predatory mites feed on aphids and on hop looper eggs.

◆ Always monitor for predatory mites as well as spider mites.

◆ Predatory mites move faster than pest mites.

◆ Adults can eat three to 10 spider mites and/or eggs a day.

◆ Consider population density of predatory mites (1 predator to 20 pests) before applying miticides.

◆ Always use miticides and insecticides that are nontoxic or partially toxic to predatory mites.

Beneficial Arthropods

David G. James and Amy J. Dreves

Conservation biological control seeks to preserve and enhance populations of resident beneficial organisms in cropping systems. When a crop environment is "friendly" to beneficial arthropods, biological control provided by endemic populations of predators and parasitoids can contribute substantially to pest management. In hops, beneficial arthropods can provide partial or complete control of spider mites and aphids, depending on the population densities of pest and prey, environmental conditions, and grower cultural practices. The foundations of reliable conservation biological control include: 1) proper identification of beneficial organisms; 2) preservation of beneficial arthropods through use of selective pesticides that have low toxicity to beneficial insects and mites (see Table 1, page 5; see also http:www.koppert.nl./Side_effects.html and http://ipmnet.org/phosure/database/selctv/selctv.htm); and 3) modification of cultural practices to provide refuge and extra-floral nectar and pollen resources for beneficial organisms (e.g., border plantings, hedgerows, ground covers). A generalized summary of the seasonal development and activity of several key beneficial (predatory) arthropods is illustrated in Figure 124, page 61. For more information on IPM and conservation biological control, see the Pacific Northwest Insect Management Handbook at http://pnwpest.org/pnw/insects.

Predatory Mites

A number of predatory mites occur on hop in the Pacific Northwest including the phytoseiids *Galendromus occidentalis* (western predatory mite) and *Neoseiulus fallacis*, and the anystid, *Anystis* spp. (whirligig mite). All feed on spider mites and *Anystis* spp. also feed on aphids and on hop looper eggs. *G. occidentalis* and *N. fallacis* are generally pale tan colored, pear-shaped, shiny and more active than spider mites (Figs. 96-98). Predatory mites move faster than pest mites. They range in size from 1/50 to 1/25 inch in length and have needle-like mouthparts, which they use to puncture spider mites and suck out body contents. Predatory mites feeding on spider mites change color, temporarily reflecting their meal. Eggs of phytoseiid mites are oblong and slightly larger than the spherical eggs of spider mites (Fig. 98). Nymphs are smaller and lighter in color but otherwise are miniature versions of the adult. Anystid mites are velvety red and up to 1/10 inch long (Fig. 99).

Biology and Life History

Predatory mites (Phytoseiids) pass through four stages before becoming adults: egg, larva, protonymph, and deutonymph. Eggs generally require high humidity for survival and hatching, a condition provided by the hop leaf surface. Larvae and nymphs are active predators, consuming spider mite eggs and motiles. Phytoseiids develop faster than spider mites, with *G. occidentalis* and *N. fallacis* completing development within a week during the summer. Mating is required for reproduction and females (66 to 75% of the population) lay 1 to 5 eggs per day for up to six weeks. Adults can eat three to 10 spider mites and/or eggs a day, depending on temperature. Up to 12 generations of predatory mites may occur on hop during the growing season and very large populations can develop by mid-summer.

Figures 96 and 97. Adult predatory mite, *Neoseiulus fallacis*. Notice shiny appearance and distinctive pear shape. (D. G. James)

Figure 98. Adult predatory mite, *Galendromus occidentalis*, lower right, with its opaque, oblong egg. Above left is a twospotted spider mite adult. Predatory mites range in size from 1/50 to 1/25 inch in length. (D. G. James)

Most hop yards in Washington have both *G. occidentalis* and *N. fallacis* present in proportions that vary with location and year. *Galendromus occidentalis* is better adapted to hot, dry conditions, while *N. fallacis* flourishes under cool, moist conditions, thus dominating the phytoseiid fauna in Oregon hop yards. *Neoseiulus fallacis* is shinier and faster than *G. occidentalis* and is able to feed on pollen as well as spider mites, enabling persistence in hop yards even when spider mite numbers are low. Mature females of both species overwinter in hop yard leaf litter, debris, soil, or pole fissures. Activity resumes in March to April when spider mites colonize new hop growth.

Little is known about the biology of *Anystis* mites (Fig. 99), which are becoming more frequent in hop yards as pesticide inputs lessen. They are active predators of mites, aphids, and small insects like thrips. They are very rapid movers and are long-lived as adults. Development from egg to adult takes more than a month, but adults eat large numbers of mites, up to 40 per day. Two generations occur per year. *Anystis* mites' biology complements the rapid developmental biology of phytoseiids and it is expected that they will become an important component of IPM as use of broad-spectrum pesticides decreases.

Predatory Mites

Monitoring, Importance in IPM and Compatibility with Pesticides

Predatory mites are readily monitored by sampling and examining leaves with a hand lens or microscope. Their rapid movement easily distinguishes them from slower-moving spider mites. A definitive guide to determining the number of predatory mites needed to give good biological control of spider mites on hop has not been developed. Generally, early-season populations of predatory mites in hop yards are too small (fewer than one per leaf) to control a rapidly expanding mite population. However, by July predatory mite numbers are often large enough (1 to 5 per leaf) to provide control of spider mites. A predator:prey ratio of 1:20 or lower often will result in acceptable biological control

Although predatory mites, particularly *G. occidentalis* and *N. fallacis,* are very important in the biological control of spider mites during July and August, acceptable biological control only occurs when insect predators of spider mites, such as mite-feeding lady beetles also are present.

Predatory mites are extremely sensitive to broad-spectrum pesticides. However, many new generation insecticides, miticides, and fungicides are non-toxic to predatory mites and should be used in preference to those that are not. Predatory mites also can be conserved by providing in-yard and adjacent refugia that harbor overwintering populations.

A generalized summary of the seasonal development and activity of key predatory arthropods is illustrated in Figure 124, page 61.

Figure 99. An anystid mite, *Anystis* spp. Notice the velvety red color. These mites are relatively large (1/10 inch) compared to other predatory mites. (A. J. Dreves)

Predatory Lady Beetles

Washington, Oregon, and Idaho hop yards are readily colonized by several species of lady beetles (Coccinellidae), which play a major role in suppressing spider mite and aphid populations. Four species of primarily aphid-feeding lady beetles and two species of mite-feeding lady beetles are most frequently seen and are discussed separately below.

At-A-Glance
Aphid-Feeding
Lady Beetles

◆ Lady beetle adults and larvae help control spider mites, thrips, aphids and other small insects.

◆ Monitor for aphid-feeding lady beetles; one adult every second or third plant can help suppress aphids.

◆ Always use lady beetle-compatible insecticides to control aphids.

Aphid Feeders

Transverse Lady Beetle
Coccinella transversoguttata

Description

The adult is approximately ¼ inch long and rounded. The wing covers (elytra) are orange with distinct, narrow transverse black markings (Fig. 100). The body and pronotum (area between the head and wing cases) are black with small white or yellow patches. The yellowish-orange, spindle-shaped eggs are laid in batches. The alligator-shaped larva is purple-blue with orange markings.

Biology and Life History

Transverse lady beetles are native to North America but declining in abundance throughout much of Canada and the eastern United States. However, they are still relatively common in eastern Washington and are frequently found in hop yards. Overwintered beetles fly into hop yards during April and May and feed on newly established colonies of hop aphids. In some years, *C. transversoguttata* is very common, but in others it can be scarce; the cause of these population fluctuations is unknown. Transverse lady beetles are also found in other aphid-affected crops such as tree fruit. Adults may consume up to 100 aphids a day depending on temperature. Larvae are also voracious feeders. When prey is scarce adults can survive (but not reproduce) on nectar, honeydew, and pollen. Larvae molt through four instars before pupating. The life cycle from egg to adult takes approximately three weeks during summer.

Figure 100. Adult stage of the transverse lady beetle is approximately ¼ inch long and rounded with distinct narrow black markings on the wing covers. (D. G. James)

Convergent Lady Beetle
Hippodamia convergens

Description

The adult is approximately 1/4 inch in length and more oval-shaped than round (Fig. 101). The wing covers are orange to red, typically with 12 to 13 black spots. However, the number of spots is variable and some individuals have none. The first section between the head and thorax (pronotum) is black with two converging white stripes and white edges. The small head is almost covered by the front of the thorax. Legs and antennae are short. The egg is approximately 1/20 inch, bright yellow, elongated, and pointed at one end. Eggs are laid in clusters. The alligator-shaped larva is dark gray to blackish blue with two small, indistinct orange spots on the pronotum and four larger ones on the back (Fig. 102). The pupa is orange and black and often attached to the upper surface of a leaf.

Biology and Life History

Convergent lady beetles are native and common in hop yards. They also are available commercially. Females lay 200 to 500 eggs, which hatch in five to seven days. Development through larval and pupal stages takes three to six weeks depending on temperature and food availability, with one to two generations a season. The largest populations in hop yards occur during spring; convergent lady beetles tend to disappear when weather becomes hot. Field evidence suggests that populations migrate to cooler, high-elevation areas in summer and aestivate (enter summer dormancy). Congregations of millions of inactive convergent lady beetles may be found during July to August in the Blue Mountains of northeastern Oregon and southeastern Washington states (Fig. 103). Most of these beetles overwinter in the mountains before migrating back to valley areas in spring.

Multicolored Asian Lady Beetle
Harmonia axyridis

Description

Adults are strongly oval and convex, approximately ¼ inch long (Fig. 104). They are highly variable in color and pattern, but most commonly are orange to red with many to no black spots. Some individuals are black with several large orange spots. The first section between the head and thorax is straw-yellow with up to five black spots or with lateral spots usually joined to form two curved lines, an M-shaped mark, or a solid trapezoid. Eggs are bright yellow and laid in clusters of approximately 20 on the undersides of leaves. Larvae are elongate, somewhat flattened, and adorned with strong round nodules (tubercles) and spines (Fig. 105). The mature larva (fourth instar) is strikingly colored: the overall color is black to dark bluish-gray, with a prominent bright yellow-orange patch on the sides of abdominal segments 1 to 5.

Biology and Life History

This exotic species is considered to be primarily forest-dwelling, but it appears to be well adapted to living in hop yards and is often the most common lady beetle species present.

Unmated females overwinter in large congregations, often in buildings or caves (Fig. 106). Mating occurs in spring and eggs hatch in five to seven days. In summer, the larval stage is completed in 12 to 14 days and the pupal stage requires an additional five to six days. In cool conditions development may take up to 36 days. Adults may live for two to three years. *H. axyridis* is a voracious predator, feeding on scale insects, insect eggs, small caterpillars, and spider mites, as well as aphids. Adults consume 100 to 300 aphids a day and up to 1200 aphids may be consumed during larval development.

Convergent Lady Beetle. ABOVE LEFT: Figure 101. Adult is approximately 1/4 inch long, more oval than round, typically with 12 to 13 black spots on the wing cases. (R. Ottens, Bugwood.org) ABOVE RIGHT: Figure 102. Alligator-shaped larvae are gray to blackish-blue with six orange spots. (D. G. James) BELOW: Figure 103. Congregating adults during aestivation. (D. G. James)

Multicolored Asian Lady Beetle.

TOP: Figure 104. Adult is oval, convex, and approximately ¼ inch long. They are highly variable in color and pattern, but most commonly orange to red with many to no black spots.

MIDDLE: Figure 105. Larvae are elongate and somewhat flat with round nodules and spines. Mature larvae are black to dark bluish-gray, with prominent bright yellow-orange patches on the sides.

BOTTOM: Figure 106. Overwintering *H. axyridis* congregated under a rock.

(3 photos, D. G. James)

A generalized summary of the seasonal development and activity of key predatory arthropods including lady beetles is illustrated in Figure 124, page 61.

Seven-Spot Lady Beetle
Coccinella septempunctata

Description

This species is comparatively large (approximately 3/8 inch), with a white or pale spot on either side of the first section between the head and thorax (Fig. 107). The body is oval and domed. The spot pattern is usually 1-4-2, black on the orange or red wing cases. Eggs are spindle-shaped and small, approximately 1/25 inch long. Larvae are alligator-like, dark gray with orange spots on segments 1 and 4 (Fig. 108), and grow to the same length as adults before they pupate (Fig 109).

Biology and Life History

This exotic species is a newcomer to hop yards, unknown before approximately 2000. Currently, it is well established and often as common and important as *H. axyridis* in controlling hop aphids. Adults overwinter in protected sites near fields where they fed and reproduced the previous season. In spring, emerging beetles feed on aphids before laying eggs. Females may lay 200 to 1,000+ eggs during a period of one to three months commencing in spring or early summer. The spindle-shaped eggs are usually deposited near prey, in small clusters of 10 to 50 in protected sites on leaves and stems. Larvae grow from 1/25 to 3/8 inch in 10 to 30 days depending on the supply of aphids. Older larvae may travel up to 36 feet in search of prey. The pupal stage lasts from three to 12 days depending on temperature. Adults are most abundant in mid- to late summer and live for weeks or months, depending on availability of prey and time of year. One to two generations occur before adults enter winter hibernation.

Seven-Spot Lady Beetle.

AT RIGHT: Figure 107. Adult is relatively large (approximately 3/8 inch) and has a distinctive “1-4-2” pattern of black spots on the wing cases. (D. G. James)

FAR RIGHT, TOP: Figure 108. Larvae are dark gray with orange spots. (R. Otten, Bugwood.org)

FAR RIGHT, BOTTOM: Figure 109. Pupal stage lasts 3 to 12 days. (D. G. James)

Aphid-Feeding Lady Beetles
Monitoring, Importance in IPM and Compatibility with Pesticides

Aphid-eating lady beetles are extremely important to natural suppression of hop aphids. Growers should encourage the species described here to colonize and reside in hop yards. Attraction and conservation of lady beetles is more effective and sustainable than the purchase and introduction of *H. convergens*, which tend to rapidly leave hop yards after released. Despite feeding primarily on aphids, these lady beetles also can feed on spider mites, thrips, and other small insects, and thus contribute generally to biological control. Lady beetles can be monitored by simply walking through yards and conducting timed counts. Alternatively, they can be sampled by shaking foliage over a tray. A mean of one adult lady beetle every second or third plant represents a significant population capable of responding to aphid population increases. Lady beetles are compatible with many new, selective insecticides and miticides but are negatively affected by older, broad-spectrum pesticides.

Mite Feeders
Mite-Eating Lady Beetles
Stethorus picipes, S. punctillum

Description

Mite-eating lady beetles are black, tiny (1/25 to 1/16 inch), oval, convex, and shiny, covered with sparse, fine, yellowish-to-white hairs (Fig. 110). Emerging adults are reddish-orange for a few hours before turning black. The white, oval eggs are less than 1/50 inch long, and turn dark just before the larvae emerge (Fig. 111). Eggs are laid singly, usually on the underside of leaves near the primary vein, and adhere tightly to the leaf. The newly hatched larva is gray to blackish and has many long-branched hairs and black patches (Fig. 112). The larvae grow from 1/25 to 1/16 inch long, becoming reddish as they mature, at first on the edges of the body. Just prior to pupation the entire larva turns reddish. The pupae are black and flattened, somewhat pointed on the posterior end, with the entire body covered with yellow hairs (Fig. 113).

Mite-Feeding Lady Beetles
Monitoring, Importance in IPM and Compatibility with Pesticides

Mite-eating lady beetles are critical to good biological control of spider mites. One or two *Stethorus* beetles are usually sufficient to control an early-season mite "hot spot," preventing it from spreading into a larger outbreak. In combination with predatory mites, *Stethorus* may maintain non-damaging levels of spider mites during July and August. Monitoring can be conducted by examining leaves in the field or a laboratory by looking for tiny alligator-like larvae or mobile pinhead-sized black dots. The beetles also can be shaken from bines and collected onto a tray. *Stethorus* spp. are susceptible to broad-spectrum insecticides and miticides such as abamectin. However, many narrow-spectrum pesticides are compatible with the survival of these important predators.

TOP: Figure 110. Adult mite-eating lady beetles are 1/25 to 1/16 inch long. MIDDLE: Figure 111. White, oval eggs are less than 1/50 inch long. BOTTOM: Figure 112. Newly hatched *S. picipes* larva is dark and hairy, with black patches. (3 photos, D. G. James)

Biology and Life History

Stethorus picipes (a native species) is most commonly found in hop yards but *S. punctillum* (exotic) also occurs. Both species are found in hop yards not exposed to broad-spectrum pesticides and are voracious spider mite feeders, consuming 50 to 75 mites per day. Overwintering occurs as non-reproductive adults in protected habitats (e.g., in ground debris, under bark) away from hop yards. Adults emerge from hibernation sites in late March and April, and seek out spider mite colonies in hop yards, which they are able to do extraordinarily well. Once prey is found, female *Stethorus* feed and lay eggs (approximately 15 eggs per day), rapidly exterminating small colonies of mites. Larvae develop through four instars, pupating after 12 days. Development from egg to adult takes approximately three weeks and three to four generations are produced during spring-summer. Adults live for four to eight weeks during summer and thrive at temperatures between 68 and 95 °F.

At-A-Glance
Mite-Feeding Lady Beetles

- ◆ Monitor for mite-eating lady beetles.
- ◆ Learn to recognize "black dot" adults and alligator-type black larvae.
- ◆ These voracious spider mite feeders consume 50 to 75 mites per day.
- ◆ Spider mite "hot spots" can be suppressed by 1 or 2 mite-eating lady beetles.
- ◆ Use only insecticides and miticides safe to mite-eating lady beetles.

Figure 113. Pupa of the mite-eating lady beetle *S. picipes*. Notice the pointed posterior end and yellow hairs covering the body (D. G. James)

At-A-Glance
Predatory Bugs

- Recognize and identify predatory bugs.
- Predatory bugs are important in early season suppression of mites and aphids.
- Predatory bugs also feed on eggs, immature and adult thrips, loopers and other soft-bodied arthropods.
- Monitor predatory bugs by shake sampling or direct counts on foliage.
- Always use insecticides and miticides safe to predatory bugs.

Predatory Bugs

The predatory bugs described here are true bugs, belonging to the insect order Hemiptera. Predatory bugs have shield-like, thickened forewings and suck out the body contents of their prey through tubular, stylet-like mouthparts. All of the predatory bugs found on hop feed on more than one type of prey, consuming the eggs, immatures, and adults of a wide variety of prey including mites, aphids, caterpillars, and thrips.

Minute Pirate Bug
Orius tristicolor

Description

Adults are 1/12 to 1/5 inch long, oval, and black or purplish with white markings on the forewings (Fig. 114). The wings extend beyond the tip of the body. The tiny (1/100 inch) eggs are embedded in plant tissue with the "lid" exposed, through which the nymph emerges (Fig. 115). Newly hatched nymphs are transparent with a slight yellow tinge, turning yellow-orange to brown with maturity (Fig. 116). They are fast-moving, wingless, and teardrop-shaped.

Figure 114. Adult minute pirate bug (*Orius tristicolor*). Adults are 1/12 to 1/5 inch in length. (D. G. James)

Figure 115. First-instar nymph and egg of the minute pirate bug (*Orius tristicolor*). Eggs are extremely small (1/100 inch) and embedded within leaves. (D. G. James)

Biology and Life History

Minute pirate bugs overwinter as adults in leaf litter or under bark and usually emerge from hibernation in late March or early April. They feed on mites, aphids, thrips, hop loopers, and other soft-bodied insects. Eggs take three to five days to hatch and development from egg to adult through five nymphal stages takes a minimum of 20 days. Females lay an average of approximately 130 eggs over a 35-day period and several generations are produced during spring and summer. When prey is not available, minute pirate bugs are able to survive feeding on pollen and plant juices. Adults and immatures can consume 30 to 40 spider mites or aphids per day. Minute pirate bugs are efficient at locating prey and are voracious feeders. They aggregate in areas of high prey density and increase their numbers more rapidly when there is an abundance of prey. Minute pirate bugs are common predators in low-input hop yards and contribute significantly to control of spider mites, aphids, and hop loopers.

Figure 116. Minute pirate bug (*Orius tristicolor*) nymph. Notice that nymphs are wingless and teardrop-shaped, and older ones are yellow-orange to brown in color. (D. G. James)

Big-Eyed Bug
Geocoris pallens

Description

Big-eyed bugs are oval, somewhat flattened, and 1/10 to 1/5 inch in length. They are usually gray-brown to blackish and have a wide head with prominent, bulging eyes (Fig. 117). Antennae are short and enlarged at the tip. Big-eyed bugs walk with a distinctive "waggle" and emit an unpleasant odor when handled. Eggs are cylindrical, ribbed, and pink or yellowish-white with a distinctive red spot. Eggs hatch into nymphs that resemble adults except they are smaller and lack wings.

Figure 117. Adult big-eyed bug (*Geocoris pallens*) is 1/10 to 1/5 inch long, gray-brown to blackish in color, and has a wide head with prominent bulging eyes. (D. G. James)

Biology and Life History

Eggs are deposited singly or in clusters on leaves near potential prey and hatch in approximately a week. Development from egg to adult through five nymphal stages takes approximately 30 days under summer conditions. Both adults and nymphs are predatory, but can survive on nectar and honeydew when prey is scarce. Nymphs may consume up to 1600 spider mites during development and adults feed on 80 to 100 mites a day. Big-eyed bugs prey on a wide variety of insects and mites smaller than themselves. They feed on eggs and small larvae of hop loopers and other caterpillar pests, as well as all stages of thrips, aphids, and mites. Two to three generations a year occur between April and September. Adults overwinter in leaf litter or debris, or under bark. The relative abundance of *Geocoris pallens* in Oregon is low compared to other natural enemies.

Predatory Mirid
Deraeocoris brevis

Description

Adult predatory mirids (*Deraeocoris brevis)* are oval, shiny black with paler markings, 1/10 to 1/5 inch long and approximately 1/12 inch wide (Fig. 118). Eggs are elongate, approximately 1/25 inch long, and inserted into plant tissue, often at the mid rib of a leaf, with only the "lid" and a respiratory horn visible (Fig. 119). Nymphs are mottled pale gray with long gray hairs on the thorax and abdomen (Fig. 120). A cottony secretion covers most of the body. Dark areas on the thorax and abdomen give it a spotted appearance. The eyes are dull red.

Biology and Life History

Deraeocoris overwinters as an adult in protected places such as under bark or in leaf litter. Overwintered adults emerge from hibernation during March to April and feed on nectar of willow catkins and other early spring flowers. They seek out prey and begin laying eggs in late April or May. Nymphs of the first generation occur two to three weeks later. Nymphs develop through five stages in approximately 25 days at 70 °F. Females lay up to 250 eggs during their lifetime and adults consume 10 to 20 aphids or mites a day. Nymphs can eat 400 mite eggs a day. *Deraeocoris* adults and nymphs are important predators that prey on a wide variety of small insects and mites including aphids, thrips, leafhoppers, scale insects, small caterpillars, and spider mites. Two or three generations are produced between May and September. *Deraeocoris* is abundant in many agricultural and non-agricultural habitats in the Pacific Northwest.

TOP: Figure 118. Oval, shiny black adult predatory mirids.

ABOVE: Figure 119. Elongated predatory mirid eggs are inserted into plant tissue.

AT LEFT: Figure 120. Predatory mirid (*Deraeocoris brevis*) nymph. Nymphs are mottled pale gray with long gray hairs on the thorax and abdomen.

(3 photos, D. G. James)

Figure 121. An adult assassin bug feeding on a beetle larva. Adult assassin bugs are relatively large (2/5 to 4/5 inch), blackish, brown, or reddish in color, and have a long, narrow head and beak. (D. G. James)

Figure 122. A raft of eggs laid by an assassin bug. Notice the reddish-brown color, distinctive skittle shape, and clustering of eggs. (D. G. James)

Predatory Bugs

Monitoring, Importance in IPM and Compatibility with Pesticides

Predatory bugs are an important component of IPM, providing control and suppression of spider mites, aphids, loopers, and thrips. They are particularly important early in the season, when predatory mites have not fully established, helping to suppress spider mite populations. They also exert significant control on aphid populations. The abundance of predatory bugs in hop yards is likely to increase as broad-spectrum pesticide use decreases and greater use is made of ground covers. Monitoring of predatory bugs is best done by visual scanning of foliage or by taking canopy shake samples.

Assassin Bugs

Reduviidae

Description

Adults are blackish, brown, or reddish with a long, narrow head; round, beady eyes; and an extended, three-segmented, needle-like beak (Fig. 121). They are larger (2/5 to 4/5 inch) than other predatory bugs. Eggs are reddish-brown, skittle-shaped, laid in a raft of 10 to 25 or more, and coated with a sticky substance for protection (Fig. 122). Nymphs are small versions of adults, although early instars are often ant-like.

Biology and Life History

Assassin bugs are long-lived and consume large numbers of insects and mites during their lifetime. Adults may live for more than one season and nymphs are slow to develop. Population densities of assassin bugs are usually low but they provide useful, consistent, and long-term feeding on aphids and caterpillars in hop yards. They are most frequently found in yards with a ground cover. Populations of assassin bugs in hop yards in Oregon tend to be relatively low.

Damsel Bugs

Nabis spp.

Description

Damsel bugs are mostly yellowish, gray, or dull brown, slender insects up to ½ inch long with an elongated head and long antennae (Fig. 123). The front legs are enlarged for grasping prey. Cylindrical white eggs are deposited on leaf surfaces near potential prey. Nymphs look like small adults but are wingless.

Biology and Life History

Adult damsel bugs overwinter in ground cover, debris, and protected sites. They emerge from hibernation in April and soon begin laying eggs. Numerous overlapping generations occur during the season. Both adults and nymphs feed on soft-bodied insects and mites including aphids, loopers, spider mites, leafhoppers, small caterpillars, and thrips. A number of damsel bug species are seen in hop yards, particularly those with a ground cover.

Figure 123. Adult damsel bug. Note that damsel bugs are mostly yellowish, gray, or dull brown, slender insects up to ½ inch long with an elongated head and long antennae. (D. G. James)

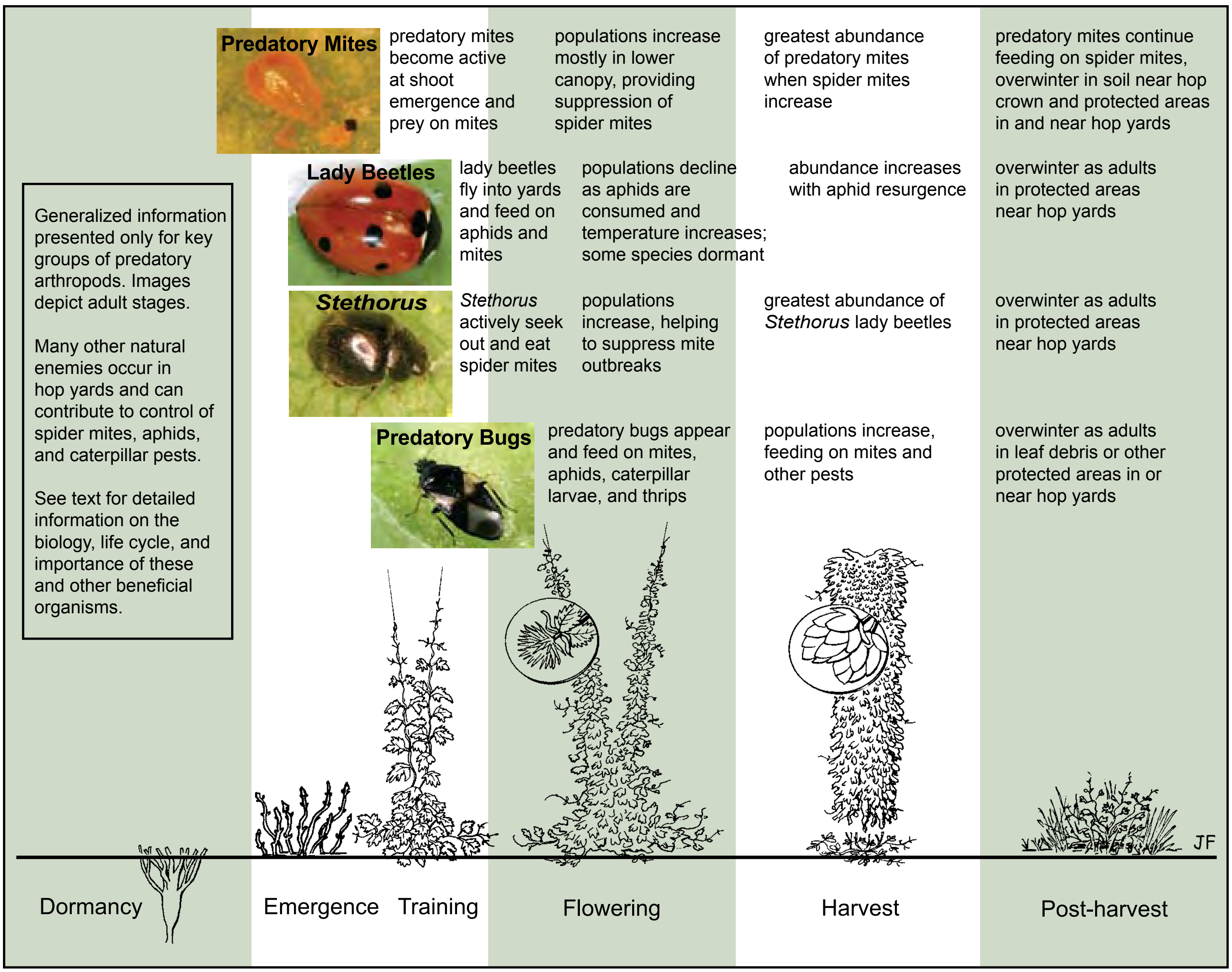


Figure 124. Seasonal development and activity of four key groups of predatory arthropods that occur on hop: predatory mites, aphid-eating lady beetles, mite-eating *(Stethorus)* lady beetles, and predatory bugs. Information is generalized; multiple factors influence the presence and abundance of beneficial arthropods in hop yards. Detailed sections for each of these predator groups appear on the preceding pages, beginning p. 52; other beneficial arthropods are detailed in the pages following. (Illustrations by Joel Floyd)

At-A-Glance Parasitic Wasps

◆ Wasps are important parasitoids of eggs, larvae, or pupae of hop loopers and other caterpillar pests.

◆ Predatory wasps such as yellow jackets and hornets can remove caterpillars and aphids.

◆ Encourage flowering ground covers that provide nectar for wasps.

◆ Use insecticides and miticides safe to wasps.

Parasitic Wasps (Parasitoids)

Description

Parasitic insects that attack and kill other insects are termed parasitoids. Many species of wasp parasitoids attack eggs, larvae, or pupae of hop pests such as loopers, cutworms, leafrollers, and aphids. There are several families of parasitic wasps; some have a noticeable stinger/ovipositor specialized for piercing their hosts. Each family is distinguished primarily by differences in wing venation. Adults are usually small, varying from less than 1/12 inch to 1 inch long, with two pairs of membranous wings folded over their backs. They are black-brown to metallic blue in color and have medium to long segmented antennae. Some are slender with long bodies (Ichneumonidae) (Fig. 125); others smaller (<1/3 inch) with fewer veins on wings (Braconidae and Trichogrammidae); and some parasitic wasps are tiny (<1/5 inch) and stout with reduced wing venation (Chalcidae). The larvae of most wasp parasitoids are white, legless, and maggot-like. Some examples of wasp species found in hop yards include *Lysiphlebus testaceipes*, *Praon* spp., *Trichogramma* spp., *Bracon* spp., *Aphelenid* spp., *Aphidius* spp., and *Aphelinus* spp. In addition to the aforementioned hop pest arthropods, predatory wasps like yellow jackets, hornets, paper wasps, and sand wasps will also attack and consume larger prey such as sizeable caterpillars.

Biology and Life History

One to numerous generations of parasitoids can occur in a year, depending on species and temperature. A parasitic wasp's life history is closely synchronized with the presence of its host. Most wasp parasitoids overwinter as pupae or prepupae in soil, under debris, within the host, or in other protected areas in the hop yard. Female parasitoids lay eggs within the eggs, larvae, or pupae of hosts, and the wasp larvae develop on or within the host body as they consume the pest's organs and tissues. When the larva matures, it pupates then emerges from the prey's body as a wasp.

At least nine species of parasitoids are associated with the various life stages of the hop looper. Looper pupae are attacked by two ichneumonid wasps in Washington, *Pimpla sanguinipes* and *Vulgichneumon brevicinctor*. These species can be very abundant in hop yards after harvest and can help reduce the number of overwintering adult loopers. Two species of *Trichogramma* wasps attack looper eggs, with as many as three adult wasps emerging from a single egg. When not disrupted by pesticides, these minute wasps are capable of season-long parasitism rates of approximately 20%, with occasional peaks of up to 70%.

In addition to prey, extra-floral nectar and pollen produced by plants in and around hop yards are important water and nutrition sources for adult parasitoids. Survival and egg-laying can be enhanced by providing these resources.

Figure 125. Adult ichneumonid wasps (*Pampla sanguinipes*) are up to 1 inch in length. (D. G. James)

Parasitic Wasps
Monitoring, Importance in IPM and Compatibility with Pesticides

Parasitic wasps can be monitored by placing a light-colored tray or cloth directly under a bine and shaking the bine vigorously for four seconds to dislodge pests and wasps out of the canopy and onto the tray. Close observation can reveal the tiny parasitoids. Yellow sticky traps may also be used to monitor wasp parasitoids. Wasp parasitoids are important in the biological control of hop looper and other caterpillar pests of hop. They also play a role in controlling hop aphid but usually only on the overwintering *Prunus* spp. host of this pest.

Figure 126. Adult banded thrips. (W. Cranshaw, Colorado State University, Bugwood.org)

Figure 127. Adult black hunter thrips. Thrips are less than 1/5 inch in length. (D. G. James)

Predatory Thrips

Description

Thrips are fast-moving, tiny (<1/5 inch) insects with slender splinter-like bodies, short antennae, and piercing-sucking mouthparts. The adults have indistinguishable fringed narrow wings that lie together and flat over the body. Three common species of predatory thrips found in hop yards include the six-spotted thrips (*Scolothrips sexmaculatus)*, banded thrips (*Aeolothrips fasciatus*), and black hunter thrips (*Leptothrips mali*). The six-spotted thrips has three dark spots on each forewing; the banded thrips has three darker bands across each forewing (Fig. 126); and the black hunter thrips is brown-black with opaque, narrow wings (Fig. 127). Larvae are almost colorless to yellow but become darker as they mature. The pupal stage is dark-colored with yellowish-white appendages.

Biology and Life History

Predatory thrips feed on spider mites, aphids, moth eggs, and pest thrips, producing eight or more generations per year depending on species, prey availability, and seasonal conditions. Adults overwinter in aggregated groups in sheltered locations in and outside hop yards. Adults become active in early spring and search for prey among the developing hop bines. The life cycle may be completed in two to three weeks, and consists of egg, two larval stages, a non-feeding pre-pupa, and a pupa stage. Females lay eggs on the underside of leaves, usually near the mid-vein. Pre-pupae leave the plant and drop to the soil or leaf litter below to pupate.

Predatory thrips can reduce high mite populations, but usually occur too late to prevent damage by themselves. In combination with key predatory insects and mites, predatory thrips can help maintain spider mites at low population densities during spring and summer.

Predatory Thrips
Monitoring, Importance in IPM and Compatibility with Pesticides

Predatory thrips can be counted with a hand lens along with other insects using a beating tray under hop bines. Blue or yellow sticky traps can also be used to monitor pest and beneficial thrips activity. Populations can build rapidly in early to mid-summer and contribute to suppression of spider mites when spider mite populations are high. Predatory thrips are generally sensitive to broad-spectrum pesticides.

At-A-Glance Predatory Thrips

- ◆ Recognize and identify predatory thrips.
- ◆ Adults become active among the bines in early spring.
- ◆ Predatory thrips can help maintain low populations of spider mites, aphids, moth eggs, and pest thrips during mid summer.
- ◆ Use insecticides and miticides safe to predatory thrips.

Predatory and Parasitic Flies

A number of fly species from at least five families are known as predators or parasitoids of hop pests in the Pacific Northwest.

At-A-Glance
Predatory & Parasitic Flies

◆ Identify and monitor adult and larval predatory flies.

◆ Predatory flies feed on aphids, spider mites, thrips, and the eggs and adults of small insects.

◆ Use insecticides and miticides safe to predatory flies.

◆ Encourage flowering ground covers that provide nectar for predatory flies.

Hover Flies

The yellow-and-black-banded adult hover fly resembles a stinging bee or wasp, but only has one pair of wings (Fig. 128). Hover flies lay single white, oblong eggs near aphid infestations. The adult is not predaceous but feeds on flower nectar. The larvae are approximately ¼ to ½ inch long, green to light brown, with a wrinkled-looking body that is blunt at the rear and pointed at the mouth end (Fig. 129). The pupae are pear-shaped and greenish to dark brown (Fig. 130). A number of species occur in hop yards and may be black and yellow or black-and-white banded.

Hover flies overwinter as pupae in the soil or above ground in leaves and plant material. The adult flies become active during spring (April and May), laying eggs on leaves and stems of hop plants harboring aphids. Hover flies are good fliers, disperse widely, and seek out aphid infestations very effectively. Larvae feed on aphids for approximately 7 to 10 days and then pupate. The larvae are voracious feeders: as many as 300 to 400 aphids may be consumed by one larva during development.

Adult hover flies may be monitored using yellow sticky traps; the maggot-like larvae can be found amongst aphid colonies. Hover flies are an important component of biologically based hop aphid management. In combination with lady beetles and predatory bugs, they can provide rapid control of aphid infestations. Hover flies are generally sensitive to broad-spectrum pesticides.

Figure 128. Adult hover fly. The adult hover fly resembles a stinging bee or wasp, but only has one pair of wings. (D. G. James)

Figure 129. Hover fly larva attacking hop aphid. Larvae are ¼ to ½ inch long. (D. G. James

Figure 130. Hover fly pupa. (D. G. James)

Dance Flies

The adults are small to medium-sized (< ¼ inch), dark-colored flies with a humpbacked thorax, long tapering abdomen, and slender legs. Dance flies are predators as adults and larvae, consuming smaller insects like aphids. Adults fly and use their front legs to grasp small insects on the wing and pierce them with their sharp snout. The larvae are pale and cylindrical and live in the soil or decaying vegetation, preying on small insects and mites. Adults also visit flowers and swarm for mating. The larvae are generally found on moist terrestrial soil or rotten wood and are predacious on various arthropods.

Adult dance flies may be monitored using yellow sticky traps. Their value in hop yards is undetermined but they may contribute to suppression of hop aphids.

Long-legged Flies

These small to medium-sized (¼ to 3/8 inch), slender flies have metallic green, blue, to bronze coloration, long legs, and large, prominent eyes. The wings are clear with some darker markings, depending on species. The larva is maggot-like. Both larvae and adults prey on small insects such as aphids, thrips, and spider mites.

Adult long-legged flies commonly sit on hop leaves and may be monitored using timed counts or yellow sticky traps. Their value in hop yards is undetermined but they likely contribute to some degree to suppression of aphids and spider mites.

Tachinid Flies

These parasitic flies are gray-black, robust, and have stout bristles on their body similar to house flies (Fig. 131). Tachinids parasitize the caterpillars of moth pests of hop including armyworms, cutworms, leafrollers, and hop loopers (Fig. 132). Tachinids typically deposit a single egg directly on or inside the body of a caterpillar, and the developing maggot feeds inside the host, eating away non-essential organs first, then emerging from the moribund caterpillar or pupa. The adult fly emerges after two weeks. There are two to three generations a year in Washington. Five species of tachinid fly attack larvae of the hop looper in Washington, with levels of parasitism later in the season up to 30%. Tachinid flies tend to be less common in hop yards in Oregon as compared to those in Washington.

Tachinid flies can be monitored using yellow sticky traps. The value of tachinid flies in hop yards has not been fully investigated but recent research shows that they do have an impact on hop looper populations, particularly in Washington. They are susceptible to pesticides, therefore should become more frequent in hop yards as broad-spectrum chemical inputs decrease.

Figure 131. Adult tachinid fly. (D. G. James)

Figure 132. Top, hop looper larva killed by a tachinid fly larva, which has now pupated. Bottom, a tachinid fly larva exiting a hop looper larva. (D. G. James)

Predatory Midges

Predatory midges are fragile-looking and gnat-like (less than 1/8 inch long) with antennae that curl back over their heads. The tiny larvae are yellowish to red-orange (Fig. 133) and are easily seen using a 10X hand lens. Predatory midges are most often found feeding amongst aphids, spider mites, thrips, and the eggs of other insects and mites. Predatory midges are most frequently seen during pest outbreaks. In some parts of the Pacific Northwest, a predatory midge species (*Feltiella* sp.) specialized for feeding on spider mites has been observed, however the occurrence of this species in Oregon is rare. Other species may occur, including *Aphidoletes* spp., which specialize on aphids. Adult predatory midges feed on nectar and honeydew and lay 70 to 200 eggs near aphid or mite colonies. A larva during development consumes 40 to 100 mites or aphids. Pupation occurs on the ground and pupae overwinter. The life cycle occupies three to six weeks with three to six generations per year.

Predatory midge adults can be monitored using yellow sticky traps. The value of predatory midges to biological control of spider mite and aphid is significant, particularly when there is an outbreak of these pests. Mid-summer colonies of spider mites in low-input hop yards can be suppressed by predatory midge larvae in combination with other predatory insects and mites. Most broad-spectrum insecticides and miticides used in hop yards are toxic to predatory midges.

Figure 133. Larva of a predatory midge. Larvae are less than 1/8 inch long. (D. G. James)

Other Beneficial Arthropods and Pathogens

Lacewings
Chrysopa, Chrysoperla, and *Hemerobius* spp.

At-A-Glance
Lacewings and Snakeflies

◆ Monitor for lacewings and snakeflies by shaking bines or using yellow sticky traps.

◆ Consider lacewing presence in combination with lady beetles and predatory bugs for delaying or omitting aphicide sprays.

◆ The presence of lacewings in hops is a clear sign of low pesticide input.

◆ Use insecticides and miticides safe to lacewings and snakeflies.

Description

Green and brown lacewings are common predators in hop yards, primarily feeding on mites and aphids. Adults are soft-bodied, approximately 3/5 to 9/10 inch long, and green or light brown in color (Fig. 134). They have long, hair-like antennae and two pairs of transparent, lacy wings netted with fine veins. The wings fold over the body when at rest. The eyes of green lacewings are golden and their eggs are small, white, and oblong, each supported on a hair-like stalk approximately 3/4 inch in length (Fig. 135). They are laid singly or in groups. The larvae resemble small caterpillars or lady beetle larvae (Fig. 136). They are fast-moving, up to 1 inch long, and spindle-shaped with prominent jaws that project forward. After feeding for a few weeks, pupation occurs within a spherical, parchment-like silken cocoon. Overwintering occurs as pre-pupae, pupae, or adults. Brown lacewings are generally smaller and more active in spring and fall. Superficially, the larvae are similar to those of green lacewings, but the jaws are not so prominently developed. The stalkless eggs are deposited on leaf surfaces.

Figure 134. Adult green lacewings are 3/5 to 9/10 inch long. (D. G. James)

Figure 135. Lacewing egg laid singly on a stalk. (D. G. James)

Biology and Life History

Lacewing larvae feed on aphids, thrips, spider mites, and small caterpillars in hop yards. They are frequently found on hop plants and on low-growing vegetation. Green lacewings tend to specialize in feeding on aphids and usually the adults lay their distinctive eggs near aphid colonies. Adult lacewings in the genus *Chrysopa* are also predatory but adults in other genera require carbohydrate-rich foods such as aphid honeydew or flower nectar or pollen. One to five generations occur per year with the life cycle occupying four to eight weeks. Adults live for up to three months, producing 100 to 500 eggs.

Figure 136. Larva of the green lacewing. Notice the prominent jaws that project forward. (D. G. James)

Snakeflies

Description

Related to lacewings (Order: Neuroptera), snakeflies are voracious feeders of a wide variety of small insects. Adult snakeflies are weak flyers with long, transparent wings. The common name, snakefly, derives from the superficially snake-like appearance that is suggested by the unusually long "neck" (frontal thorax) and long, tapering head (Fig. 137 A-B).

Biology and Life History

Snakeflies have four stages in their life cycle: egg, larva, pupa, and adult. Both larvae and adults are predatory, feeding on aphids, thrips, hop looper eggs, small caterpillars, spider mites, and other small prey. The larvae usually live under tree bark or on the ground in decaying organic material. Snakeflies are arboreal; hop yards provide a good temporary habitat during spring and summer. They can be monitored using yellow sticky traps or by shaking hop bines over a tray. Snakeflies are susceptible to many broad-spectrum pesticides.

Figure 137 A and B. Adult snakefly. Notice the unusually long "neck" that is a characteristic of these insects. (D. G. James)

Lacewings and Snakeflies

Monitoring, Importance in IPM and Compatibility with Pesticides

Lacewings and snakeflies can be monitored by shaking bines over a tray or by using yellow sticky traps. In conjunction with key predators, their importance in biocontrol is considerable, contributing to suppression of aphids, mites, and hop loopers. Broad-spectrum pesticides are harmful to lacewings and snakeflies, but some newer selective materials appear safer to these closely related arthropods.

Insect Pathogens

Naturally occurring diseases sometimes contribute to management of hop pests. In particular, outbreaks of *Bacillus thuringiensis,* a bacterial infection, and viruses occasionally result in population crashes of hop looper. Once pathogens take hold, they can almost eliminate hop looper populations. Diseased caterpillars are easy to spot; they are dark brown to black and hang from one pair of claspers or are draped over leaves (Fig. 138). They emit a foul-smelling odor and basically become liquefied, releasing endospores of *Bacillus thuringiensis* to infect other caterpillars. Mites and aphids may also succumb to pathogens but the incidence of this is generally low in the Pacific Northwest, unless the season is unusually cool and wet.

Figure 138. A hop looper larva infected with a bacterium. Diseased caterpillars are dark brown to black and hang from or are draped over leaves. (D. G. James)

At-A-Glance Insect Pathogens

- Watch for diseased caterpillars.
- Diseased caterpillars are dark in color, smell bad, and hang loosely.
- Disease usually leads to epidemic and looper population crash.

Spiders

Description

Spiders are common residents in most low-chemical-input hop yards and can reach high densities on the ground floor and in the hop canopy. Some of the common spiders found in hop yards include jumping spiders (Figs. 139 and 140), crab spiders (Fig. 141), sheet web weavers, and sac spiders. Spiders are one of the most abundant predators in hop yards.

Biology and Life History

Spiders often serve as buffers that limit the initial exponential growth of prey populations. However, the specific role of spiders as effective predators has received little attention and is difficult to demonstrate. There is evidence in many ecosystems that spiders reduce prey populations. They are generalists that accept most arthropods as prey in their webs or in their paths. They eat the eggs and larvae of all the insects and mites that infest hops. Spiders disperse easily to new areas in hop yards and colonize rapidly by aerial ballooning and walking between bines. They are also blown around with the wind and debris. The abundance and diversity of spiders in hop yards is linked to the large-scale landscape complexity (hop yard margins, overwintering habitat, weediness) and local management practices (pesticide use, tillage practices).

Figure 139. A jumping spider (*Phidippia* sp.) feeding on a beetle larva. (D. G. James)

Figure 140. A jumping spider. (D. G. James)

Figure 141. A crab spider feeding on a wasp. (D. G. James)

At-A-Glance Spiders

- ◆ Spider presence in hops is a good sign of low pesticide input.
- ◆ Spiders often serve as buffers that limit initial exponential growth of prey populations.
- ◆ Spiders may help regulate aphids and caterpillars.
- ◆ Use insecticides and miticides safe to spiders.

Spiders Monitoring, Importance in IPM and Compatibility with Pesticides

Spiders can be monitored by shaking bines over a tray. The value of spiders to biocontrol is thought to be considerable, but has yet to be evaluated. Most pesticides harm spiders, but populations tend to recover rapidly.

Weed Management

Robert Parker

Weeds have many definitions. In hop yards they are plants that interfere in some way with production, whether directly impacting the growth and yield of the plants themselves or indirectly inhibiting production by interfering with field operations.

Weeds compete with hop plants for nutrients, water, and—to some extent—light. Hop by nature grows tall, therefore competition for light is usually not as great a problem as it can be with most row crops. Some weeds also provide an environment for certain pathogens to survive when hop plants are not actively growing. Generally speaking, as weed density increases in the hop yard, yields decrease. Therefore weed management must be considered in an overall integrated pest management program in hops.

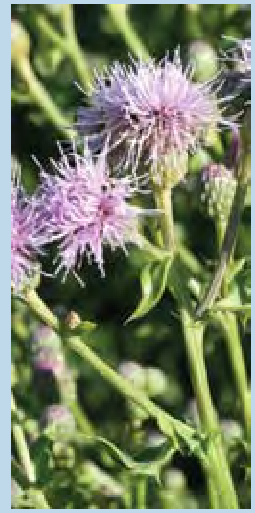
Hop is a perennial crop and weeds can be a problem year around. Summer annual weeds, those germinating in the spring or summer, are found in the growing crop. They can interfere with spraying operations, distort sprinkler patterns in sprinkler-irrigated yards, and interfere with harvest. However, winter annual weeds, those germinating in the late summer or fall, usually do not have much direct impact on hop growth. Winter annual weeds can, however, cause indirect problems in hop yards by depleting stored soil moisture, interfering with hop yard maintenance during the off season, and slowing spring field operations. Perennial weeds, those plants that live more than two years, can create problems similar to those posed by annual weeds. Perennials are much more difficult to control and are frequently spread with tillage operations.

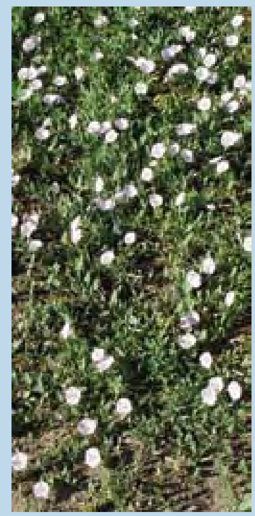
A few representative annual and perennial weeds are pictured in Figures 142 to 148. The pages following contain basic information on planning and executing an integrated weed management program in hops as well as photos of many of the weeds that can be problematic in hop yards.

Representative Annual Weeds

TOP ROW, LEFT TO RIGHT: Figure 142. Prickly lettuce. Figure 143. Common lambsquarter.
BOTTOM ROW, LEFT TO RIGHT: Figure 144. Kochia. Figure 145: Puncturevine. (R. Parker)

Representative Perennial Weeds





FROM TOP:
Figure 146: Canada thistle.
Figure 147: Field bindweed.
Figure 148: Blackberry.
(R. Parker)

Figure 149. Canada thistle seedling. (R. Parker)

Figure 152. Kochia seedling. (R. Parker)

Figure 150. Common lambsquarter seedling. (R. Parker)

Figure 153. Shepherd's purse seedling. (R. Parker)

Figure 151. Common lambsquarter seedling. (R. Parker)

Figure 154. Common groundsel seedlings. (R. Parker)

Planning a Weed Management Program

Several factors should be considered when planning a weed management program in the hop yard. Factors such as weed species, tillage, row spacing, irrigation, and herbicides all need to be integrated to develop an effective weed control strategy. (See "Identification" sidebar, opposite.) The photos presented in this section are intended to aid in the identification of weeds at various stages. Weed seedlings are shown first, with other stages on the pages following.

Prevention

The first line of defense in hop yard weed control is to prevent weeds from becoming established. It is very difficult to prevent weed seed from infesting a hop yard, as weed seed and reproductive propagules are easily transported from outside areas into a yard via animals, birds, wind, equipment, irrigation water, and many other means. However, cleaning equipment before moving it from one field to another and controlling weeds around the field borders will lessen the establishment of weeds within the yard. Cultivating or mowing weed growth around the field border not only reduces the potential for weed seed movement into the field, but also improves air circulation and helps eliminates refuge areas for insect pests.

As weeds arise, further spread can be discouraged through diligence and immediate control of new weeds before they are allowed to produce seed.

Weed seed germination is triggered by optimum temperature, adequate moisture, and field operations that expose seed to light. Not all weed seeds located in the soil will emerge each year because most weed seeds have an inherent dormancy factor. For example, approximately 26% of kochia and 3% of common lambsquarter seed will germinate each year. With certain summer annual weeds, secondary dormancy will occur and seed germination stops when temperature increases to a critical point. Winter annual weeds generally will not germinate until soil temperatures and/or day length begins to decrease. Perennial herbaceous weeds begin to grow when soil temperatures reach a certain point and will continue to grow until they either set seed or temperatures drop to a critical point.

Figure 155. Blue mustard seedlings. (R. Parker)

Figure 158. Sunflower seedling. (P. Westra, Colorado State University, Bugwood.org)

Figure 156. Pigweed seedling. (R. Parker)

Figure 159. Flixweed seedling. (R. Parker)

Figure 157. Puncturevine seedlings. (R. Parker)

Figure 160. Common purslane seedlings. (Utah State University Archive, Bugwood.org)

Weed Seedling Identification

◆ Accurate weed identification should be the first step in any weed management program.

◆ Many weeds (e.g., hairy nightshade, common lambsquarter, and pigweed) look similar in the seedling stage, however their susceptibility to control measures can be quite different.

◆ To aid in proper seedling identification, a series of common weed seedlings affecting hops are presented in Figures 149 to 160.

◆ Proper weed identification is important for selecting the most effective and economical treatment in the hop yard.


Figure 161. Redroot pigweed plant. (R. Parker)

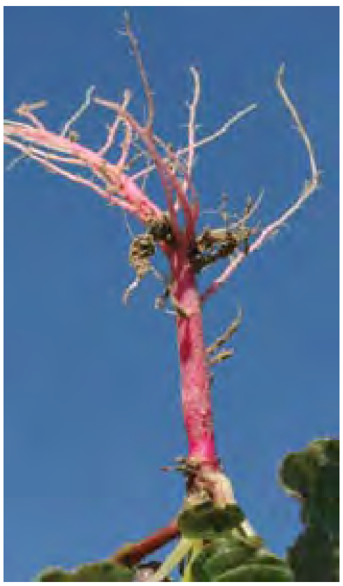


Figure 162. Aptly named red-root pigweed root. (R. Parker)


Figure 163. Powell amaranth inflorescence. (R. Parker)

Cultural (Non-chemical) Tactics

Tillage has a major impact on weed spectrum and population. Weed seed response to burial and exposure to light varies with the species. Disking in the spring stimulates certain seeds to break seed dormancy and allow germination.

The use of a fall-planted cover crop can reduce weed emergence the following spring. Fall tillage may stimulate germination of certain summer annual weed seeds, which are then killed by freezing fall temperatures. Summer annual weed populations will be lower in fall-tilled areas planted to a fall-planted cover crop. Fall-planted cover crops and weeds can then be killed with glyphosate before hop shoots emerge.


Figures 164, 165, and 166. Prickly lettuce. From Top: Plants at various stages of growth; close-up of leaves; mature plants. See also Figure 142. (3 photos, R. Parker)

Herbicides

The number of herbicides available in hop production is limited; however, herbicides are becoming more widely used for controlling weeds. Herbicide selection should be based on the weed spectrum in each yard. It is extremely helpful for hop producers to keep records of previous weed infestations. Perennial weeds such as Canada thistle, field bindweed (wild morning glory), and Bermudagrass usually occur in patches initially. Scattered patches and individual weeds can be spot-treated with an herbicide, rogued, or cultivated. Soil-active herbicides applied during the dormant period may not provide adequate weed control because of inadequate moisture or mechanical incorporation after application. Tools such as disking and post-emergence herbicide application can be utilized to control weed escapes. One disadvantage to disking is that soil disturbance can stimulate weed seed germination in the growing season and also disking can deposit dust on hop foliage which could enhance the buildup of spider mites. Field scouting immediately after weeds emerge is important to identify weeds and provide the information needed to choose a post-emergence herbicide that matches the weed spectrum.


Figure 167. Puncturevine fruit. (R. Parker)


Figure 168. Puncturevine plant. See also Figure 145. (R. Parker)

Several herbicides are registered for use in hop production: trifluralin (Treflan and several other trade names), norflurazon (trade name Solicam), clopyralid (trade name Stinger), 2,4-D amine (various trade names), glyphosate (various trade names), clethodim (trade names Select and others), carfentrazone (trade name Aim), flumioxazin (trade name Chateau), paraquat (trade names Gramoxone, Firestorm, Parazone, and Paraquat), and pelargonic acid (trade name Scythe).

Trifluralin and norflurazon are primarily soil-applied and are applied prior to annual weed emergence. Trifluralin must be mechanically incorporated into the soil, whereas norflurazon may be mechanically incorporated or incorporated into the soil by sufficient overhead moisture. Clopyralid, glyphosate, and 2,4-D are post-emergence herbicides applied to actively growing weeds. Clopyralid is selective on some broadleaf weeds, particularly those in the sunflower, nightshade, pea, and smartweed families. Clopyralid will control many perennial weeds in those plant families. 2,4-D controls a broader spectrum of annual broadleaf weeds and suppresses or controls many perennial broadleaf weeds found in hop yards. Glyphosate is non-selective and will control both annual and perennial broadleaf and grass weeds. However, glyphosate will kill or seriously injure hop plants if the allowed to contact hop foliage. Clethodim is selective in controlling most annual and perennial grass weeds found in hop yards. Pelargonic acid, while registered, is not widely used.

Paraquat effectively controls emerged weeds before hop emergence and is sometimes tank-mixed with norflurazon. The two herbicides used as desiccants are carfentrazone and paraquat; these are utilized to "burn back" basal leaves and suckers, aiding in air circulation and the removal of inoculum of the powdery and downy mildew pathogens. Carfentrazone is the most active product in burning back or desiccating hop foliage and will also control some annual broadleaf weeds. Paraquat, although not as active as a desiccant, will control both annual grass and broadleaf weeds and provide top kill of some perennial weeds. Paraquat can be used to control broadleaf weeds prior to bine training.

Specific herbicide use guidelines can be found in the annually updated Pacific Northwest Weed Management Handbook available from the Idaho, Oregon, and Washington Extension Services and on-line at http://pnwpest/pnw/weeds. Table 3 presents a summary of the effectiveness of herbicides and cultural control practices for several common weeds in hop yards.

Figure 169. Henbit plant. (R. Parker)

Figure 170. Kochia plant. See also mature plant, Figure 144. (R. Parker)

Figure 171. Henbit flower. (R. Parker)

Figure 172. Field bindweed flowers. See also plant, Figure 147. (R. Parker)

Figure 173. Horseweed plant. (R. Parker)

Figure 174. Mature horseweed plants. (R. Parker)

Figure 175. Horseweed inflorescence. (R. Parker)

Figure 176. Horseweed buds. (R. Parker)

Figure 177. Common mallow. (R. Parker)

Figure 178. Common purslane plants. (R. Parker)

Figure 179. Common purslane flowers. (R. Parker)

Figure 180. Individual purslane plant.
(S. Dewey, Utah State University, Bugwood.org)

Figure 181. Blue mustard plant. (R. Parker)

Figure 182. Blue mustard seed pods. (R. Parker)

Figure 183. Severe blue mustard infestation. (R. Parker)

Figure 184. Common sunflower plants. (J. D. Byrd,
Mississippi State University, Bugwood.org)

Table 3. Efficacy Ratings for Weed Management Tools in Hops

RATING SCALE: E = Excellent (90-100% control); G = Good (80-90% control); F = Fair (70-80% control); P = Poor (<70% control); ? = Efficacy unknown, more research needed; - = Not used for this pest; U = Used but not a standalone management tool, NU = Not Used.

TYPE: Pre = Soil-active against pre-emerged weeds, Post = Foliar-active against emerged weeds. Note that weed size or stage of growth is an important consideration with most post-emergence herbicides.

		ANNUAL BROADLEAVES							PERENNIAL BROADLEAVES				GRASSES		
MANAGEMENT TOOLS	**Type**	**Kochia**	**Lambsquarters**	**Prickly Lettuce**	**Mallow**	**Mustards**	**Pigweed**	**Puncturevine**	**Bindweed**	**Blackberry**	**Curly Dock**	**Canada Thistle**	**Quackgrass**	**Bermudagrass**	**COMMENTS**
REGISTERED CHEMISTRIES															
2,4-D (Weedar & others)	Post	F-G	E	G-E	P	E	E	E	F-G	F	G	F-G	- -	- -	
carfentrazone (Aim)	Post	G	F	G	P	F	G	G	P	P	P	P	- -	- -	Broadleaf weeds need to be small and spray coverage good
clethodim (Select Max)	Post	-	-	-	-	-	-	-	-	-	-	-	G*	G*	Grass control only
clopyralid (Stinger)	Post	P	P	E	P	P	P	P	P	P	?	G-E	- -	- -	
flumioxazin (Chateau)**	Pre	E	E	E	F	G	G	P	P	P	P	P	P	P	If small weeds are emerged, use in combination with a post-emergence herbicide
glyphosate (Roundup & others)	Post	E	E	E	P	E	E	E	F	E	?	E*	E*	F*	Rating based on weeds not being dusty. Correct timing important when used on perennials
norflurazon (Solicam)	Pre	G	P	E	F	G	G	E	P	P	P	P	F	F	
paraquat (Gramoxone & others)	Post	E	E	E	F	E	E	E	P	P	P	P	P	P	Rating based on weeds not being dusty and small
trifluralin (Treflan & others)	Pre	G	E	F	P	F	E	G-E	P	P	P	P	P	P	
CULTURAL (NON-CHEMICAL)															
Cover crop between rows		U	U	U	U	U	U	U	F	F	F	F	P	P	Efficacy depends on cover type and stand quality
Crowning (mechanical)		F	F	F	F	F	F	F	P	P	P	P	P	P	
Cultivation between rows		E	E	E	E	E	E	E	see comments				P-E	P	Can be good to excellent on perennials if very persistent and done correctly
Equipment sanitation		Not a standalone management tool, but cleaning equipment before moving from infested to uninfested fields is always a good practice													
Hand hoeing/pulling		G-E	G-E	G-E	G-E	NU	G-E	G-E	P	P	P	P	P	P	Can be good to excellent if very persistent in efforts

*Repeat applications may be needed. Timing and glyphosate rates are critical.
**Registered in Oregon and Idaho, but not Washington, as of 4-20-10.

weed photographs continue next page...

Calculating Treated Acres versus Sprayed Acres

Herbicide rates given on an herbicide label are usually given in pounds, pints, or quarts per acre. An acre is equal to 43,560 square feet. Herbicides in hop yards, particularly foliage desiccant control products, frequently are applied in bands over the row. Confusion commonly occurs in interpreting how much herbicide should be applied when the herbicide is used to treat only a portion of each field. To illustrate this, if a 4-foot band is applied only over the row, 10,890 feet or 3,630 yards of row would have to be treated to equal one treated or broadcast sprayed acre. Assuming hops are planted in rows spaced 14 feet apart and the herbicide label indicates the herbicide is to be applied at 2 pints per acre, it would mean that 2 pints of herbicide is enough to treat 3.5 field acres of hops. Since 2 pints equal 32 fluid ounces, each planted acre of hops will receive only 9.14 fluid ounces of herbicide.

Figure 185. Flixweed inflorescence. (R. Parker)

Figure 186. Flixweed plant in flower. (R. Parker)

Figure 187. Quackgrass. (S. Dewey, Utah State University, Bugwood.org)

Figure 188. Common groundsel. (R. Parker)

Figure 189. Mature inflorescence of Canada thistle. See also Figure 146. (R. Parker)

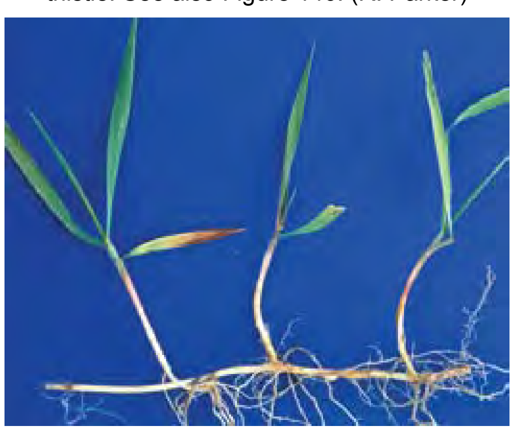


Figure 190. Quackgrass plant and rhizome. (S. Dewey, USU, Bugwood.org)

Figure 191. Bermudagrass plants. (R. Parker)

Figure 192. Bermudagrass inflorescence. (R. Parker)

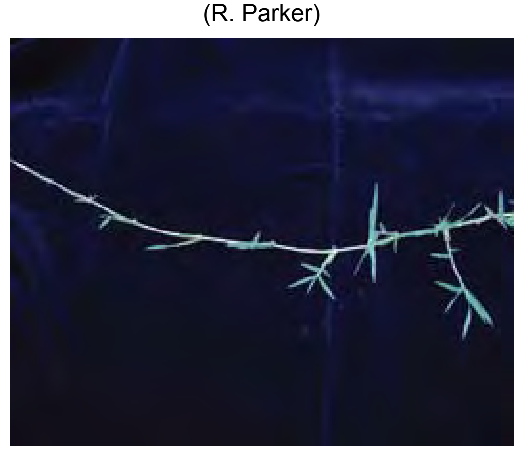


Figure 193. Bermudagrass stolon. (R. Parker)

Table 4. Common Symptoms of Herbicide Injury on Hop

Herbicide use carries an inherent risk of crop damage. When using herbicides, read and carefully follow label instructions to minimize crop injury and maximize weed control. Table 4 presents herbicide injury symptoms commonly observed on hop. Figures 194 to 204 display typical symptoms associated with herbicides commonly used in hop yards.

Herbicide	Symptoms
2,4-D	Leaf cupping usually will be exhibited on sprayed foliage and developing leaves may be malformed. Some stem twisting may be observed. Symptoms seldom occur above the zone of spray contact (Figs. 194, 195).
carfentrazone	Sprayed foliage will exhibit chlorotic (yellow) and necrotic (brown) stem tissue, with stem cracking reported on some hop varieties. Sprayed growing points are killed. Chlorotic and/or necrotic spotting will be observed on leaves (Fig. 196) and stems (Fig 197) if the herbicide drifts.
clethodim	No symptoms have been observed on hops even at extremely high rates. The young growth of treated grasses will eventually turn yellow or brown and the leaves in the leaf whorl can be easily separated from the rest of the plant.
clopyralid	Upward leaf cupping (Fig. 198) and some stem twisting sometimes will be exhibited, particularly on sprayed foliage. Leaf cupping is seldom observed above the zone of spray contact (Fig. 199).
glyphosate	Leaves may be chlorotic, necrotic, and malformed (Figs. 200, 201). Leaf veins will often remain green while the areas between the leaf veins are chlorotic. Developing stems have shortened stem internodes (Fig. 201). Cones may be malformed. Plants are often severely injured or killed. Symptoms may persist into the next growing season.
norflurazon	Leaf veins may be chlorotic to complete white (Fig. 202). The symptoms are usually temporary.
paraquat	Sprayed foliage will exhibit chlorotic and necrotic leaf tissue (Fig. 203). Stem cracking may be observed on some varieties. Sprayed growing points are killed. Chlorotic and/or necrotic spotting will be observed on leaves and stems if herbicide drifts (Fig. 204).
trifluralin	Root tips may be club-shaped and stems may emerge slowly if herbicide-treated soil is thrown over the root crowns when incorporating the herbicide. Occasionally stems are thickened where they emerge from the soil.

Figure 194. Leaf cupping and stem twisting due to 2,4-D. Notice that upper leaves above the zone of herbicide contact appear healthy. (R. Parker)

Figure 195. Injury caused by direct exposure of leaves to 2,4-D. Leaves above the zone of herbicide contact appear healthy. (R. Parker)

Figure 196. Yellowing and spotting of leaves caused by carfentrazone. (D. H. Gent)

Figure 197. Necrotic spotting on stems due to carfentrazone. (D. H. Gent)

Figure 198. Severe cupping of leaves due to high rate of clopyralid applied to control Canada thistle. (D. H. Gent)

Figure 199. Slight cupping of leaves due to clopyralid. Notice that leaf cupping is not apparent on leaves above the zone of herbicide contact. (R. Parker)

Figure 200. Severe yellowing, bleaching, and malformation of leaves on newly emerged shoots caused by a fall application of glyphosate on Willamette. (D. H. Gent)

Figure 201. Yellowing and stunting of leaves and shoots caused by a fall application of glyphosate on Columbus. (M. E. Nelson)

Figure 202. Yellowing of leaves caused by norflurazon. Affected plants generally recover. (R. Parker)

Figure 203. Yellowing and death of leaves caused by paraquat applied for spring pruning during cold weather. (D. H. Gent)

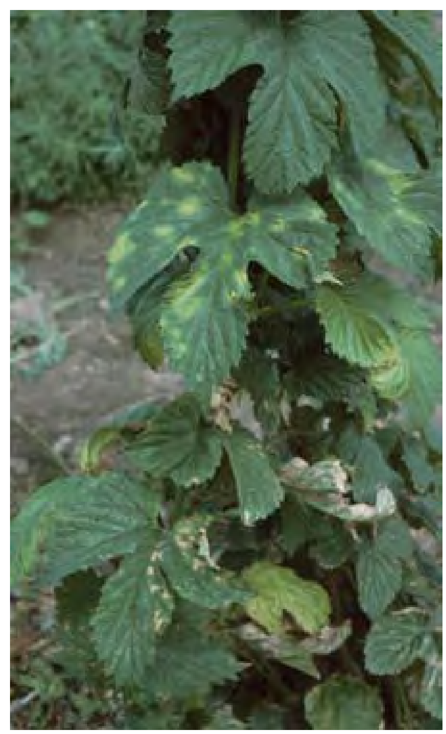


Figure 204. Yellow spots on leaves caused by paraquat drift. (R. Parker)

Nutrient Management and Imbalances

David H. Gent

Several nutrients can occur at deficient or toxic levels in Pacific Northwest soils, and the situation can be difficult to diagnose. Symptoms may be similar among various conditions or may vary with the same condition, depending on variety and the environment. General symptoms associated with nutrient imbalances are described in this section, as well as known nutrient interactions with diseases and arthropod pests. Fertilization recommendations vary widely in published literature, differing among production regions, varieties, irrigation methods, soil pH, and seasons, therefore fertility recommendations are not provided. Local experts should be consulted for specific recommendations appropriate for your hop yard.

Boron

Boron deficiency can result in delayed emergence of shoots, stunting, distortion and crinkling of young leaves (Fig. 205), and yellowing and death of shoot tips (Fig. 206). Leaves of affected plants may be small, brittle, and develop a fluffy-tipped appearance due to impaired development of lobes (Fig. 207). Deficiencies are most common in acid soils. Boron deficiency has been suggested as a contributing factor for red crown rot.

Figure 205. Stunting, distortion, and crinkling of young leaves associated with boron deficiency. (J. Portner)

Figures 206 and 207. Misshapen shoot tip and misshapen, "fluffy-tipped" leaf, both due to boron deficiency. (J. Portner, P. McGee)

Calcium

Symptoms of calcium deficiency develop first in young tissues and at growing points. Symptoms can be similar to boron deficiency, and may include yellowing of growing points, reduced development of leaves, and yellowing and death of leaf margins. Excessive calcium can interfere with uptake of other nutrients and induce deficiencies in other positively charged ions (e.g., ammonium, magnesium, potassium).

Iron

Iron deficiency is first observed on young leaves as yellowing between veins, while veins remain green (Figs. 208 and 209). Iron deficiency is most common in alkaline soils, although it can be induced in highly acid soils (approximately pH 5.7 or less) because of enhanced solubility and uptake of manganese.

ABOVE: Figure 208. Close-up of yellowed leaf due to iron deficiency. (D. H. Gent)

AT RIGHT: Figure 209. Yellowing of the youngest leaves resulting from iron deficiency. Notice that symptoms are less pronounced on older leaves. (J. Portner)

Figure 210. Yellowing and death of tissue between leaf veins caused by magnesium deficiency. (C. B. Skotland)

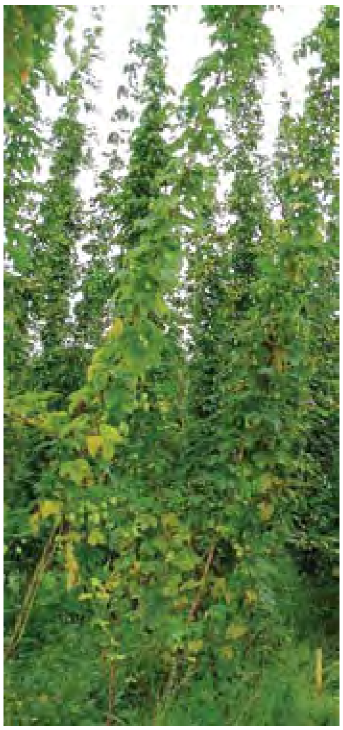


Figure 211. Weak growth and yellowing of lower leaves associated with nitrogen deficiency. (J. Portner)

Figure 212. Weak growth and reduced side arm development associated with zinc deficiency. (C. B. Skotland)

Magnesium

Symptoms appear first on older leaves as yellowing between leaf veins, followed by death of these areas and defoliation (Fig. 210). Magnesium deficiencies are most common in acid soils or where excessive potassium was applied.

Manganese

Manganese becomes limited in high-pH (alkaline) soils and can be present at toxic levels under low-pH (acidic) conditions. Symptoms of manganese deficiency are yellowing of young leaves and white speckling. Manganese accumulation in plant tissues increases at pH below 5.7, which interferes with iron uptake and can induce an iron deficiency.

Molybdenum

Molybdenum deficiencies appear first in older leaves as yellowing and white speckling. Deficiencies have been reported on hops grown in acidic soils (pH 5.7 or less). In some plants, molybdenum deficiency can be misdiagnosed as a nitrogen deficiency since affected plants can have a general yellowing.

Nitrogen

Symptoms of nitrogen deficiency include poor growth, stunting, and a general yellowing of plants that is most pronounced on older leaves (Fig. 211). Cones of nitrogen-deficient plants are smaller than cones on plants receiving adequate nitrogen. Excessive nitrogen fertilization can increase incidence of several diseases and arthropod pests, including powdery mildew, Verticillium wilt, spider mites, and hop aphid. Excessive nitrogen can also reduce alpha acid levels of cones. Efforts should be taken to balance crop demands with nitrogen inputs and to avoid over-application of nitrogen.

The form of nitrogen can also affect certain diseases. Fusarium canker appears to be favored by ammonium-based nitrogen fertilizers, whereas nitrate-based fertilizers favor Verticillium wilt. These interactions probably involve complex relationships between the fertilizer components, the soil pH, and the availability of other nutrients (i.e., manganese and zinc).

Phosphorus

Symptoms of deficiency first appear on lower leaves as down-curved, dark-green leaves with a dull appearance. Bines are thin and weak. Affected cones may have a brown discoloration. Studies in England indicate that although symptoms may not be apparent, yield can decrease significantly when hop plants are deficient in phosphorous.

Excessive phosphorous fertilization may induce zinc deficiencies, particularly in alkaline soils or soils otherwise marginally deficient in zinc. Phosphorous acid compounds often are applied as foliar fertilizers and can suppress downy mildew, black root rot, and, to a lesser extent, powdery mildew.

Potassium

Potassium deficiency results in weak bine growth and reduced burr formation. Symptoms develop first on older leaves, appearing as a bronzing between veins. These bronze areas become an ashy gray, and leaves may be shed prematurely. Excessive potassium fertilization also may induce magnesium deficiencies.

Sulfur

Deficient plants have stunted growth, spindly stems, and yellowing of younger leaves. Sulfur is commonly deficient in the acidic, coarse-textured soils of western Oregon.

Zinc

Plants deficient in zinc have weak growth, short lateral branches, and poor cone production (Fig. 212). Leaves are small, misshapen, yellow, curl upward, and can become brittle (Fig. 213). In severe cases affected plants may die. Zinc deficiencies occur frequently when soil pH is greater than 7.5, which is common in central Washington. Zinc applications also can cause remission of symptoms associated with *Apple mosaic virus.*

Figure 213. Cupped, brittle leaves caused by zinc deficiency. (J. Portner)

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