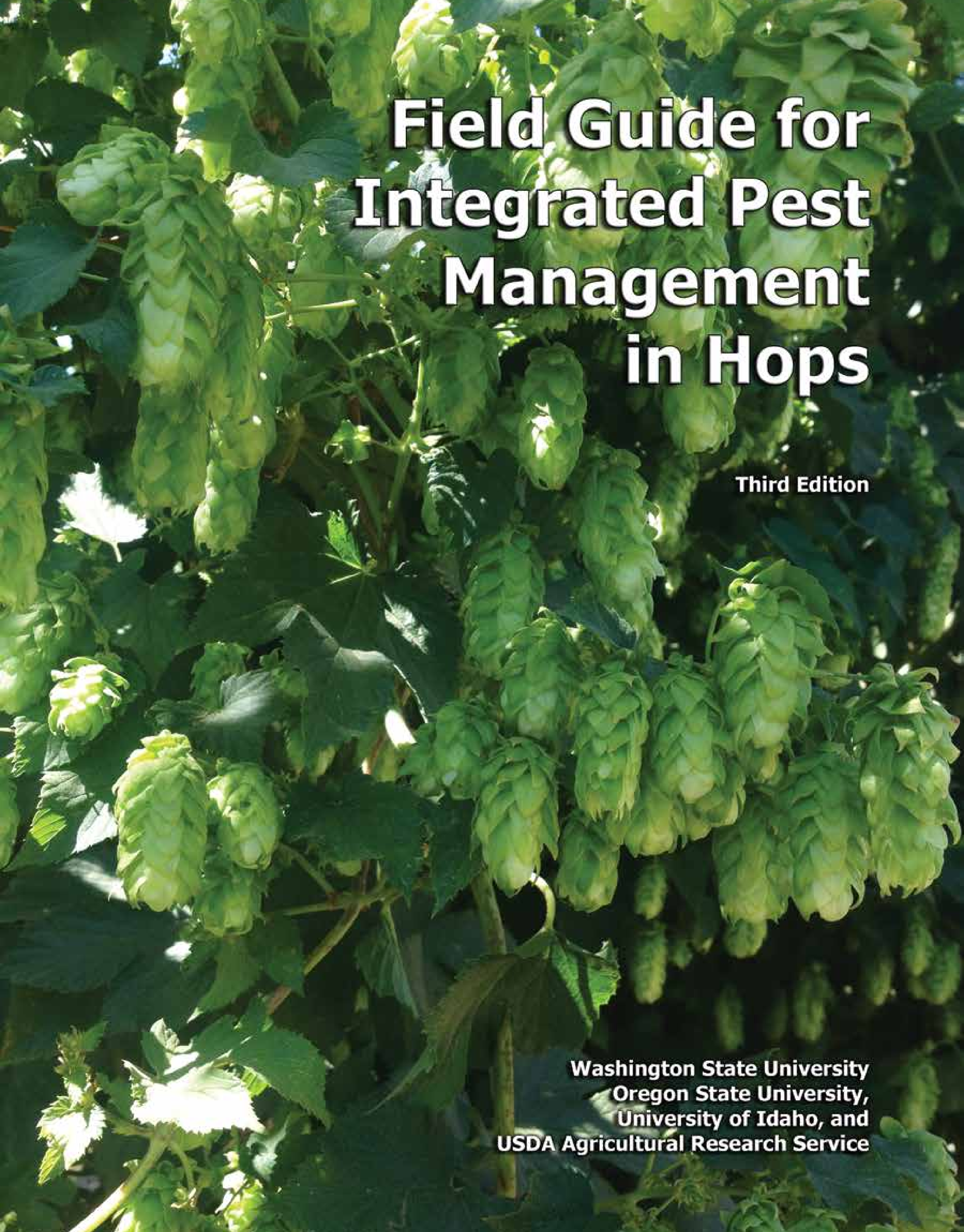

Field Guide for Integrated Pest Management in Hops

Third Edition

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

Field Guide for Integrated Pest Management in Hops

Third Edition • 2015

A Cooperative Publication Produced by Washington State University, Oregon State University, University of Idaho, and U.S. Department of Agriculture in cooperation with Michigan State University and Cornell University

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Abbreviations:
IAREC = Irrigated Agriculture Research and Extension Center
MSU = Michigan State University
OSU = Oregon State University
SIREC = Southwest Idaho Research and Extension Center
SROC = Southern Research and Outreach Center
USDA-ARS = United States Department of Agriculture, Agricultural Research Service
UI = University of Idaho
WSU = Washington State University

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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

Background, Purpose, and Use of This Guide

Douglas B. Walsh, David H. Gent, and Sally D. O’Neal

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, and many plants common to hop-producing regions can become weeds in hop yards in certain circumstances. The damage pests and diseases cause ranges from insignificant to complete economic loss due to direct reduction in yield or diminished cone quality.

The goal of the first edition of *Field Guide for Integrated Pest Management in Hops* in 2009 (as well as the slightly revised second edition in 2010) was to provide growers, consultants, extension personnel, and other pest managers with what was then the most current science-based information on identification and management of arthropod pests, beneficial organisms, diseases, and weeds affecting hop, specifically hop plants grown in the dominant hop-producing states of the Pacific Northwest. In this third edition, we have expanded our scope beyond the Pacific Northwest to encompass several regions where hop production is increasing, making the scope of this book national and attempting to address the needs of both large and small hop producers in established, emerging, and reemerging hop-producing regions. Regional craft brewers are seeking local sources of hops to appeal to their consumers. In expanding the scope of this handbook, we hope to assist new hop growers in their efforts to control pests as they learn to produce hops in the microclimates associated with their geographic locations.

In this third edition, we continue the emphasis set forth in the previous editions in promoting the adoption of integrated pest management (IPM) strategies including whole-farm IPM planning, consideration of pesticide toxicology, and nutrient management (to the extent that it impacts the pest complex and its management). Our aim is to educate and assist the grower and pest manager so they can better utilize the latest pest management information in the context of an entire farming system. Correct identification of pest problems is the first step in IPM, therefore color images and graphics have been included as diagnostic aids wherever possible. Information is presented on the life cycle and biology of the primary pests of hop to provide key concepts underlying management recommendations.

This book is not intended to prescribe which products to use in specific instances, nor is it intended to replace university-based extension guidelines for pest management in the various states in which hop plants are grown. Products mentioned in this field guide have been registered by the U.S. Environmental Protection Agency, but users should check with their own state or local pesticide regulatory authority to determine whether use is approved in their location. A partial list of resources on current pesticide registrations for hop is provided on Page 101.

In many cases, when a specific pesticide is listed in this field guide, it will be listed as the name of its primary active ingredient (e.g., glyphosate), followed in parentheses by one or more of the most common trade names (e.g., Roundup). Use of a particular trade name in this instance is not intended to exclude other trade names under which the product may be marketed. Trade names are provided as a frame of reference only.

The first edition of the *Field Guide for Integrated Pest Management in Hops* was followed with a pocket-sized English/Spanish companion guide that many found useful. Our intent is to follow suit and produce pocket companions to this comprehensive third edition that will be specific to the various geographic regions in which hops are now being produced.

The editors acknowledge the significant contributions of numerous general and pest-specific references that provided the foundation and scaffolding for this handbook and its previous editions. A few of the general publications used are provided on page 101, Resources.

At a Glance:

Main Sections of This Field Guide

Principles of Integrated Pest Management

James D. Barbour

PHOTOS ABOVE:
D.P. Groenendale
PHOTOS BELOW:
D.G. James

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 has assumed a broader role and meaning over the last 60 years, 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, 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. 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.

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 their 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 their growth and reproduction, provide valuable information for pest management. Knowing which development stage of a particular pest causes damage; knowing when and where the damaging stage of a pest is located within or near the crop; 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 buildup. In IPM, acceptable pest levels are defined in terms of economic injury levels (EILs): 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 tactics 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 methods. 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 in an IPM program. The principle of EILs and economic (action) thresholds are illustrated graphically in Figure 1.

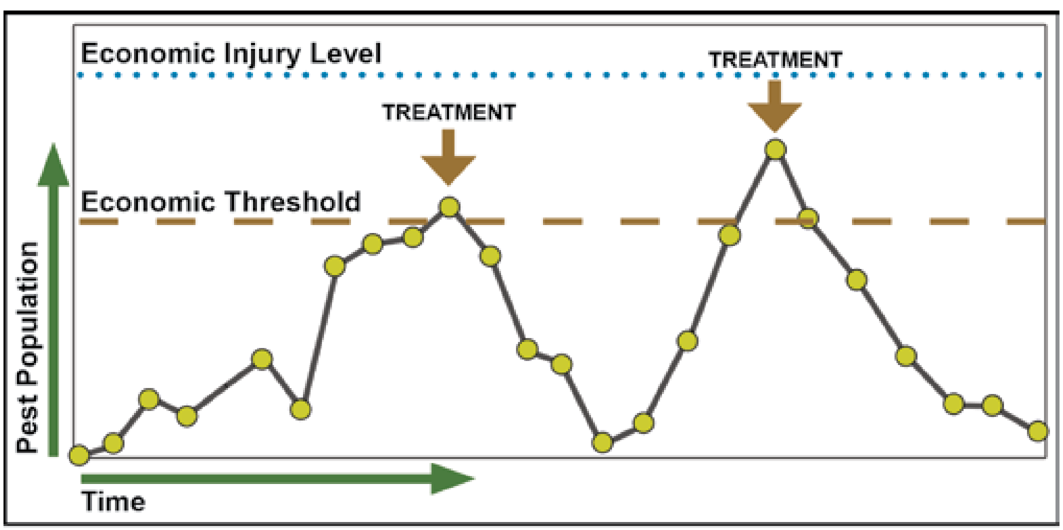


Figure 1. Graphic illustration of the use of an economic injury level and economic threshold for pest management decision making. The economic injury level is the break-even point where management costs equal the damage caused by a pest. The economic threshold is the pest density at which control efforts 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.

At a Glance:
Integrated Pest Management

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.

Key concepts include:

- Systems-level management
- Pest biology
- Beneficial organism ID
- EILs and economic (action) thresholds
- Scouting
- Monitoring treatment success
- Forecasting
- Recordkeeping
- Multi-tactic management

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 field 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, from simply noting the presence or absence of a particular pest to counting the number of pests present. Pest counts can take place through visual inspection of plants (with or without aid of a magnifying lens); dislodging pests through shaking them onto surfaces; gathering pests with a sweep net or other tool; or deploying traps (e.g., sticky traps, pheromone traps, spore traps) in or around a hop yard and counting the captured pests. 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.

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.

Consult with local experts about the availability, potential uses, and limitations of pest forecast models to support hop IPM in your area.

PHOTOS ABOVE: A.J. Dreves, B. Price, A.J. Dreves
AT RIGHT: B. Price

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.

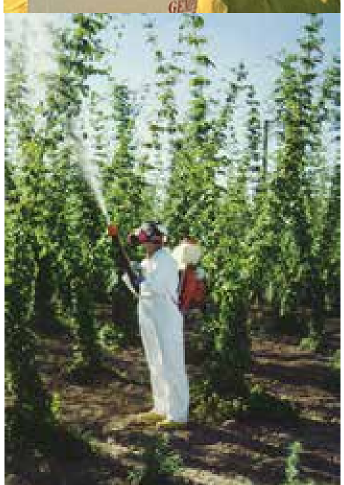
Mechanical controls include simple handpicking, erecting barriers, using traps, vacuuming, and tillage to disrupt pest growth and reproduction. Tillage is commonly used to manage weeds in hop, and can be important in managing arthropod pests such as the garden symphylan.

Biological control agents 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 biological control agents to the ecosystem is referred to as augmentative biocontrol; an example would be the purchase and release of predatory mites *Galendromus occidentalis* and/or *Neoseiulus fallacis* for management of twospotted spider mites. Natural enemy populations also can be augmented using commercially available chemical attractants, such as methyl salicylate. In addition, biological control 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 pyrethrins and spinosyns 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 when other management tactics fail to maintain pests at acceptable levels.

PHOTOS ABOVE: D.H. Gent, D.G. James, D.P. Gronendale
AT LEFT: D.H. Gent

Pesticide Toxicology and Selectivity



FROM TOP: D.H. Gent, M.J. Weaver (courtesy Virginia Tech Pesticide Programs, PesticidePics.org), J.D. Barbour, D.G. James

Pesticide Toxicity Ratings

Douglas B. Walsh

Pesticides are applied in hop yard IPM programs when pest abundance or disease incidence and severity exceed established or perceived action thresholds. Approximately 250 to 300 pesticide active ingredients have national registrations that permit their use on hop in the United States if the lead state agency permits the application of that pesticide on hop in its state. Inevitably pesticide use involves some degree of exposure and risk to humans, non-target organisms, and the environment. Table 1 lists selected pesticides along with their relative human health hazard rankings and their relative impacts on non-target beneficial arthropods.

In Table 1, Column 1 lists the active ingredient of fungicides, herbicides, and insecticide/miticides that are registered for use in the major hop-producing states. Column 2 provides a common trade name or products that contain the active ingredient in Column 1. Trade names vary by region, particularly between the East and West, with the Mississippi River being a common divide. As throughout this field guide, the listing of these trade names does not represent endorsement of that particular formulation; it simply provides a frame of reference.

The “signal word” in Column 3 indicates the hazard ranking assigned to each of these active ingredients by the U.S. Environmental Protection Agency with respect to potential human (i.e., mixer or applicator) exposure. The signal word “Danger” identifies a product as being a Category I restricted use pesticide, and includes products such as 2,4-D, ethoprop, and folpet. These products have toxicological profiles that could cause injury or irritation to individuals exposed to low concentrations and often require that the applicator has received specific training or licensing to apply the product. The signal word “Warning” identifies a product as a Category II pesticide, and includes products such as clethodim, cymoxanil, and beta-cyfluthrin. These materials typically require the use of fairly extensive personal protective equipment, but exposure levels required to cause injury or irritation are substantially greater than Category I pesticides. The signal word “Caution” identifies a Category III pesticide, and includes products such as the biocontrol bacterium *Bacillus pumilus*, carfentrazone, and various Bt formulations (e.g., *Bacillus thuringiensis* subsp. *kurstaki*). A Category III 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 IV pesticide. Simple safety rules should be followed with these products to avoid exposure. No Category IV pesticides are listed in the table.

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 between and among the various 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, whereas a smaller insect or mite will likely 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. Columns 4, 5, and 6 in Table 1 provide IOBC toxicity ratings, where available, on three key beneficial arthropods that occur on hop: predatory mites, lady beetles, and lacewing larvae. IOBC categories 1-4 should not be confused with EPA categories I-IV relating to human exposure and indicated by signal words “Danger,” “Warning,” and “Caution” as described previously.

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

Active Ingredient	Trade Name	Signal Word	Beneficial Arthropod IOBC Ranking*		
			Predatory Mites	Lady Beetles	Lacewing Larvae
Fungicides					
Bacillus pumilus	Sonata	Caution	1	ND	ND
Bacillus subtilis	Serenade	Caution	1	ND	ND
Boscalid	Pristine	Caution	1	ND	ND
Copper	Various formulations	Caution	1	ND	ND
Cyazofamid	Ranman	Caution	ND	ND	ND
Cymoxanil	Curzate 60DF	Warning	ND	ND	ND
Dimethomorph	Forum	Caution	ND	ND	ND
Famoxadone & cymoxanil	Tanos	Caution	ND	ND	ND
Fenarimol	Vintage SC	Caution	ND	ND	ND
Folpet	Folpan 80WDG	Danger	ND	ND	ND
Fosetyl-Al	Aliette WDG	Caution	ND	ND	ND
Kaolin	Surround	Caution	3	ND	ND
Mandipropamid	Revus	Caution	1	1	ND
Mefenoxam	Ridomil	Caution	ND	ND	ND
Metalaxyl	MetaStar	Warning	ND	ND	ND
Mineral oil/petroleum distillate	Various formulations	Caution	2	ND	ND
Myclobutanil	Rally 40W	Warning	2	1	ND
Phosphorous acid	Fosphite, other formulations	Caution	ND	ND	ND
Pyraclostrobin	Pristine	Caution	ND	ND	ND
Quinoxyfen	Quintec	Caution	1	ND	ND
Sodium borate	Prev-Am	Warning	2	ND	ND
Sulfur	Various formulations	Caution	2	ND	ND
Tebuconazole	Folicur 3.6F	Caution	1	ND	ND
Trifloxystrobin	Flint	Caution	1	ND	ND
Herbicides					
2,4-D	Weedar 64, other formulations	Danger	ND	ND	ND
Carfentrazone	Aim EC	Caution	1	ND	ND
Clethodim	Select Max	Warning	1	ND	ND
Clopyralid	Stinger	Caution	1	ND	ND
Flumioxazin	Chateau	Caution	1	1	ND
Glyphosate	Roundup, other formulations	Caution	1	ND	ND
Norflurazon	Solicam	Caution	ND	ND	ND
Paraquat	Gramoxone,other formulations	Danger	1	ND	ND
Pelargonic acid	Scythe	Warning	ND	ND	ND
Pendamethalin	Prowl H_2O	Caution	ND	ND	ND
Trifluralin	Treflan, other formulations	Caution	2	ND	ND
Insecticides/Miticides					
Abamectin	Agri-Mek, other formulations	Warning	3	3	ND
B. thuringiensis subsp. *aizawai*	XenTari, other formulations	Caution	1	2	ND
B. thuringiensis subsp. *kurstaki*	Dipel, other formulations	Caution	1	2	ND
Beta-cyfluthrin	Baythroid XL	Warning	4	4	4
Bifenazate	Acramite-50WS	Caution	1	2	ND
Bifenthrin	Brigade, other formulations	Warning	4	4	4
Cyfluthrin	Baythroid 2E	Danger	4	4	4
Dicofol	Dicofol	Caution	1	1	ND
Ethoprop	Mocap	Danger	4	4	ND
Etoxazole	Zeal	Caution	1	1	ND
Fenpyroximate	FujiMite	Warning	1	3	ND
Flonicamid	Beleaf 50SG	Caution	1	1	ND
Hexythiazox	Savey 50DF	Caution	1	1	ND
Imidacloprid	Admire Pro, other formulations	Caution	1	3	3
Malathion	Various formulations	Warning	2	4	3
Naled	Dibrom	Danger	2	4	3
Propargite	Omite 6E	Danger	1	1	ND
Pymetrozine	Fulfill	Caution	1	1	1
Pyrethrin	Pyganic, other formulations	Caution	2	2	2
Spinosad	Success, other formulations	Caution	2	2	1
Spirodiclofen	Envidor	Caution	2	2	1
Spirotetramat	Movento	Caution	1	1	1
Thiamethoxam	Platinum	Caution	1	1	ND

* International Organization for Biological Control rankings represent relative toxicity based on data from studies conducted with tree fruit, hop, mint, and grape. 1 = "harmless," less than 30% mortality following direct exposure to the pesticide; 2 = "slightly harmful," 30 to 79% mortality; 3 = "moderately harmful," 79 to 99% mortality; 4 = "harmful," greater than 99% mortality; and ND = no data / not determined.

Strategies to Minimize Development of Pesticide Resistance

◆ Utilize cultural practices to reduce pathogen, weed, and pest populations whenever possible.

EXAMPLE
Removing overwintering flag shoots and basal spikes mechanically or chemically helps reduce the inoculum level of powdery mildew and downy mildew.

EXAMPLE
Delay resistance development by hand weeding or cultivating annual weeds to prevent them from developing seed.

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

◆ Apply pesticides at rates specified on the label, especially for weed and arthropod pests.

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

Pesticide Resistance Management

Mark E. Nelson, David H. Gent, Robert Parker, Rick A. Boydston, and Douglas B. Walsh

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 (or, in some cases, a similar) mode of action, resulting in a lack of efficacy for a particular pesticide or pesticide group 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, abamectin and bifenazate resistance in twospotted spider mite, and mefanoxam 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 genetically 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 (e.g., 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. Weeds resistant to that herbicide will then dominate over time due to this selection pressure, and the previously effective herbicide 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 hop downy mildew pathogen. The registered label rate for Aliette of 2.5 lbs. per acre no longer effectively controls downy mildew in some regions. 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 mefenoxam (Ridomil) against the hop 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 mefenoxam can still be detected in the downy mildew pathogen in hop yards that have not been treated with this fungicide in over 10 years. Susceptibility to bifenazate

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

Twospotted spider mites. (D.G. James)

and bifenthrin is renewed more rapidly in field populations of spider mites than susceptibility to abamectin. This implies that the "cost" (from the mites' perspective) of maintaining resistance to bifenazate and bifenthrin is greater in a mite population than maintaining resistance to abamectin. Persistence of resistance in weeds depends in part on the longevity and dormancy of the weed seed in the soil. In addition, some resistance genes reduce the relative fitness of weeds in the absence of the herbicide, whereas others have no apparent effect on relative fitness.

The risk of resistance development is linked closely to the genetics and reproductive potential 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. The number of generations within a year also affects the rate of resistance development. Spider mites can produce multiple generations per growing season and are haplo-diploid. (Females emerge from eggs that have been fertilized by sperm and egg and consequently are diploid in having two sets of chromosomes. Males emerge parthenogenically from unfertilized eggs, consequently possessing only a single haploid set of chromosomes.) When acaricide resistance in a mite population is genetically based, male mites that lack the genes for resistance are killed when exposed to an acaricide, while male mites with the resistance gene survive to further contribute these resistant genes to subsequent generations. Haplodiploidy can contribute to rapid development of acaricide resistance. Most annual weeds produce only one generation a year, so the rate of resistance development tends to be slower in weeds than with many insect or plant pathogens. 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.

Few pesticides with novel modes of action are being brought forward to market and field use, and increased regulatory scrutiny of new pesticides limits the registration of new pesticides. Consequently, the hop industry must judiciously use pesticides to prevent or delay resistance development to available pesticides. 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

Symptoms of downy mildew. (D.H. Gent)

Strategies, cont.

◆ Include low-resistance-risk compounds in spray programs 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 eradicant 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 becomes a problem. Avoid making more than two consecutive applications of synthetic fungicides (e.g., DMI, quinoline [azanaphthalene], strobilurin [QoI], or carboxamide classes).

Strategies, cont.

- Alternate or tank mix products with diverse modes of action within and between seasons. Make sure the alternative mode of action chosen is also active on the target species.
- Avoid using broad-spectrum insecticides that are disruptive to the predators and parasites of pests, particularly early in the growing season.
- Choose miticides and insecticides with a high degree of selectivity for beneficial arthropods to allow biological control to reduce populations of resistant pest strains.

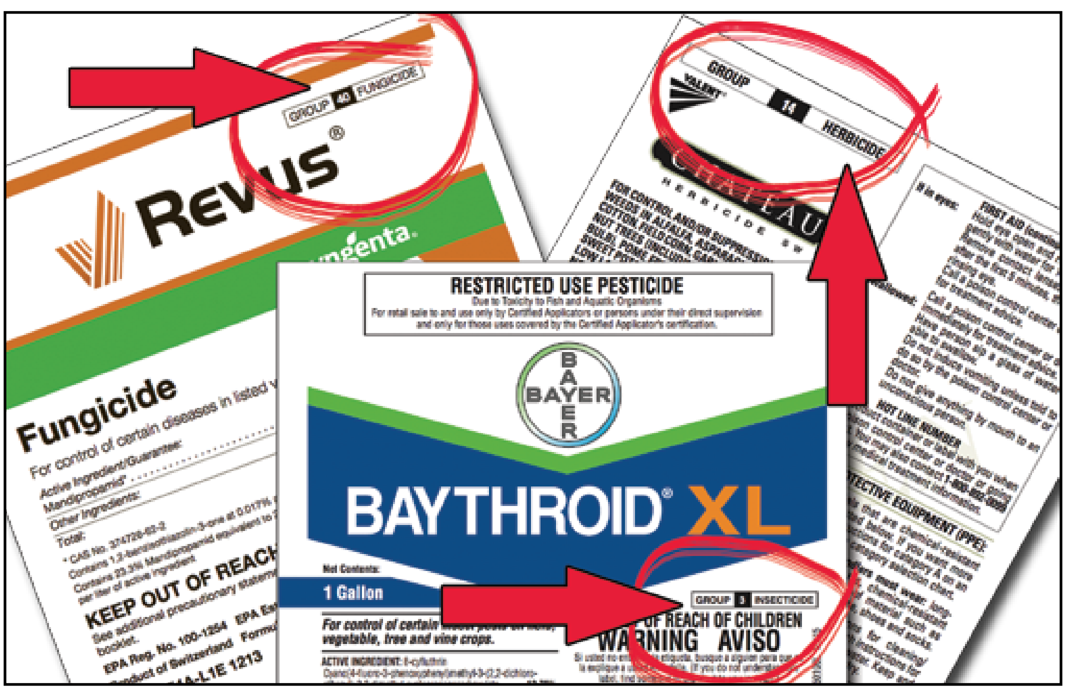
action serve to maintain a reservoir of the susceptible population, which is essential in proactive pesticide resistance management.

For downy mildew and powdery mildew, resistance generally can be 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, tank-mixing with fungicides with different modes of action, 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 demethylation inhibitor (DMI) and strobilurin fungicide classes. For example, a rotation of trifloxystrobin (Flint) and pyraclostrobin (Pristine) would not be effective since both fungicides have active ingredients with the same mode of action.

Similar principles apply to resistance management for spider mite and hop. 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 mode-of-action group, target applications against the most vulnerable life stage of the pest, and integrate non-chemical control measures before pests exceed economic thresholds. Use of products with a high degree of selectivity to the target pest (i.e., preserving beneficial arthropods) can allow biological control to reduce populations of resistant pest strains, and thus help to delay resistance.

The Fungicide Resistance Action Committee (FRAC, http://www.frac.info), Insecticide Resistance Action Committee (IRAC, http://www.irac-online.org), Herbicide Resistance Action Committee (HRAC, http://www.hracglobal.com), and Weed Science Society of America (WSSA, http://wssa.net) classify pesticides according to mechanism of action and resistance risk in their respective groups. These organizations assign numeric or alphanumeric codes to pesticides, signifying groupings with similar modes of action. For groups prone to resistance problems, development of resistance to any pesticide within a group generally means there will be a loss of efficacy by all members of the group. The appropriate website and pesticide label should be consulted for current use guidelines. The pesticide group designation is often indicated on the first page of the label, as illustrated below.

Table 2 provides a list of registered pesticides commonly used on hop, their modes of action, and their resistance codes.



The pesticide group designation is often indicated on the first page of the label.

Table 2. Modes of Action and Resistance Codes for Pesticides Used on Hop

Active Ingredient	Trade Name Example	Mode of Action*	Resistance Code
Fungicides			**FRAC Code**
Fenarimol	Vintage SC	G1: DMI (SBI class 1)	3
Myclobutanil	Rally 40W		
Tebuconazole	Folicur 3.6F		
Mefenoxam	Ridomil	A1: Phenylamide	4
Metalaxyl	MetaStar		
Boscalid	Pristine	C2: SDHI	7
Pyraclostrobin	Pristine	C3: QoI	11
Trifloxystrobin	Flint		
Famoxadone & cymoxanil	Tanos	C3: QoI & Unknown: Cyanoacetamideoxime	11 & 27
Quinoxyfen	Quintec	E1: Azanapthalene	13
Cyazofamid	Ranman	C4: QiI	21
Cymoxanil	Curzate 60DF	Unknown: Cyanoacetamideoxime	27
Fosetyl-Al	Aliette WDG	Unknown: Phosphonate	33
Phosphorous acid	Fosphite		
Dimethomorph	Forum	F5: CAA fungicide	40
Mandipropamid	Revus		
Bacillus pumilus	Sonata	F6: Microbial	44
Bacillus subtilis	Serenade		
Copper	Various	Multi-site	M1
Sulfur	Various		M2
Folpet	Folpan 80WDG	Multi-site: Phthalimide	M4
Kaolin	Surround	Physical barrier	n/a
Mineral oil/petroleum distillate	Various		
Sodium borate	Prev-Am		
Herbicides			**WSSA Group**
Clethodim	Select Max	Inhibition of acetyl CoA carboxylase (ACCase)	1
Pendimethalin	Prowl H_2O	Microtubule assembly inhibitor	3
Trifluralin	Treflan		
2,4-D	Weedar 64	Action like indole acetic acid	4
Clopyralid	Stinger		
Glyphosate	Roundup	EPSP synthase inhibitor	9
Norflurazon	Solicam	Phytoene desaturase step (PDS)	12
Carfentrazone	Aim EC	Protoporphyrinogen inhibitor	14
Flumioxazin	Chateau		
Paraquat	Gramoxone	Photosystem-I-electron diverter	22
Pelargonic acid	Scythe	Other	n/a
Insecticides/Miticides			**IRAC Code**
Ethoprop	Mocap	Acetylcholinesterase inhibitor	1B
Malathion	Various		
Naled	Dibrom		
Beta-cyfluthrin	Baythroid XL	Sodium channel modulator	3A
Bifenthrin	Brigade		
Cyfluthrin	Baythroid 2E		
Pyrethrin	Pyganic		
Imidacloprid	Admire Pro	Nicotinic acetylcholine receptor antagonist	4A
Thiamethoxam	Platinum		
Spinosad	Success	Nicotinic acetylcholine receptor allosteric antagonist	5
Abamectin	Agri-Mek	Chloride channel activator	6
Pymetrozine	Fulfill	Chordotonal organ modulator	9B
Flonicamid	Beleaf 50SG		9C
Hexythiazox	Savey 50DF	Mite growth inhibitor	10A
Etoxazole	Zeal		10B
B. thuringiensis subsp. *aizawai*	XenTari	Midgut membrane microbe disruptor	11A
B. thuringiensis subsp. *kurstaki*	Dipel		
Propargite	Omite 6E	Mitochondrial ATP synthase inhibitor	12C
Fenpyroximate	FujiMite	Mitochondrial complex I electron transport inhibitor	21A
Spirodiclofen	Envidor	Acetyl CoA carboxylase inhibitor	23
Spirotetramat	Movento		
Bifenazate	Acramite-50WS	Unknown	Unknown
Dicofol	Dicofol		

* Mode of action information is provided with guidance from FRAC, HRAC, and IRAC.

Disease Management
Fungal & Bacterial Diseases

At a Glance:
Alternaria Cone Disorder

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

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

◆ 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.

Alternaria Cone Disorder

David H. Gent

Alternaria cone disorder is reported to be caused by the fungus *Alternaria alternata*. This organism is widespread in hop yards and other agricultural systems worldwide. Strains of the fungus are known to attack apple, potato, sunflower, wheat, and many other hosts.

While the fungus is widespread, its disease is not known to be associated with direct hop yield losses in the United Kingdom or Australia. Alternaria cone disorder is thought to be of minor importance in Pacific Northwest hop, occasionally reducing crop quality. However, cone browning incited by powdery 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. 2). 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. 3). 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.

Alternaria alternata can be found even on healthy cones and it is easy to confuse late-season damage from powdery mildew with Alternaria cone disorder. *Alternaria alternata* is one of the most common fungi found on decaying organic matter and in the air of hop yards. Recovery of the fungus from discolored cones does not prove that it was the primary cause of cone discoloration. Because the powdery mildew (and downy mildew) pathogens cannot be cultured on artificial media, methods used to recover *A. alternata* will not detect the powdery mildew fungus.

Figure 2. Reddish-brown discoloration of the tips of bracts and bracteoles of a cone affected by Alternaria cone disorder. (D.H. Gent)

Figure 3. Discoloration of cones affected by Alternaria cone disorder. (S.J. Pethybridge)

Disease Cycle

Alternaria alternata generally is a weak pathogen that invades wounds created by insect feeding, mechanical injury, or lesions created by other pathogens. Some strains of the fungus may survive as a decay organism on textiles, dead plants, leather, or other organic materials. On hop, Alternaria cone disorder is primarily a disease of cones damaged by mechanical injury. In the United Kingdom, the disease is reported to occur most commonly on late-maturing varieties exposed to wind injury, humid conditions, and extended periods of wetness on cones. The pathogen may survive between seasons on decaying plant material, organic matter, and/or as a weak pathogen on other plants.

The severity of powdery mildew has a direct association with the frequency of recovery of *A. alternata* from hop cones. Cones infected with the powdery mildew fungus during bloom and early stages of cone development are the most likely to have *Alternaria* species associated with them at harvest (Fig. 4). It is well known that powdery mildew can cause discoloration and damage to hop cones, but is unclear to what degree secondary infection by *A. alternata* increases this damage.

Management

Management of Alternaria cone disorder requires accurate diagnosis of the disease. Simply recovering the fungus from discolored cones does not necessarily indicate that it was the cause of the browning since the pathogen is found on healthy cones as well. Adequate control of powdery mildew will reduce cone discoloration that often is attributed to Alternaria cone disorder.

The disease can be minimized by reducing damage to burrs and cones caused by wind abrasion, by arthropod pests, and by other 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 such as trifloxystrobin (Flint) and boscalid plus pyraclostrobin (Pristine) applied for control of powdery and downy mildew likely provide some suppression of Alternaria cone disorder when applied later in the season.

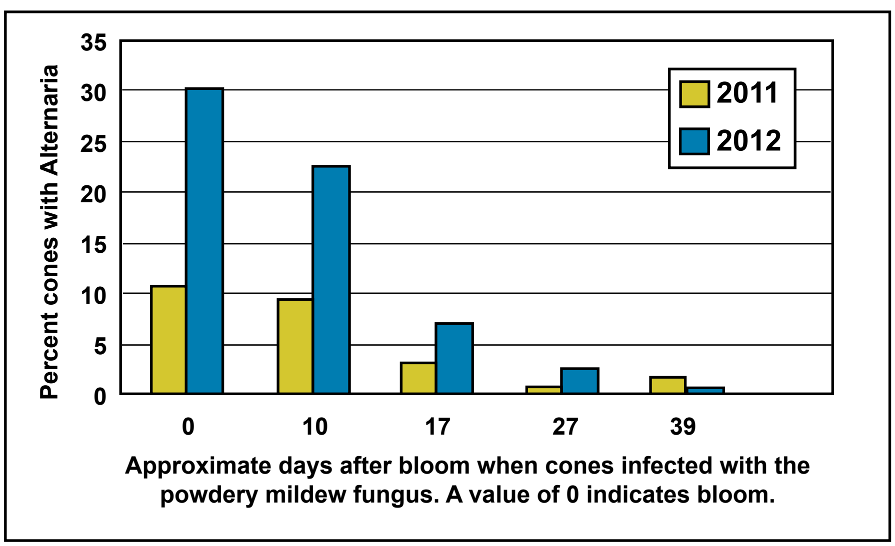


Figure 4. Association between stage when cones were infected with powdery mildew fungus and percent of cones with an *Alternaria* species at harvest in 2011 and 2012.

***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.

Black Root Rot

Frank S. 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. 5). 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 too 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 longer. 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

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 Brewer's Gold, Bullion, Cascade, Columbia, Comet, Eroica, Fuggle, Hallertau, 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 5. Extensive black discoloration caused by black root rot. Notice the distinct margin between healthy tissue and the black, diseased tissue. (R.A. Beatson)

Downy Mildew

David H. Gent, Dennis A. Johnson, Amanda J. Gevens, and Mary K. Hausbeck

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

Figure 6. Downy mildew "spikes" emerging in early spring. Note pale yellow color and down-curled leaves. (D.H. Gent)

Figure 7. Characteristic yellowing on young leaves of a shoot recently infected by the downy mildew pathogen. (D.H. Gent)

Symptoms

The disease first appears in spring on newly emerged, systemically infected shoots that are called "basal spikes" because of their resemblance to wheat spikes. Basal spikes are stunted and have brittle, downward-curled leaves (Fig. 6). A distinctive yellowing beginning at the center of affected leaves may be present on newly infected shoots (Fig. 7). A diagnostic characteristic of downy mildew is the presence of spores (sporangia) that appear purple to black in color and develop on the undersides of infected leaves (Fig. 8). After training, the main bines and lateral branches may also become infected, arresting the development of these shoots and leading to "aerial spikes" (Fig. 9). Typically, branches that become infected just as they begin to develop quickly desiccate and can be difficult to diagnose as downy mildew (Fig. 10). Infection of trained bines results in a cessation of growth, causing bines to fall from the string. These infected bines must be manually removed and healthy shoots retrained in their place. This often leads to yield loss because the optimal timing for training could have been missed and infected plant parts divert water and nutrients away from healthier, productive tissues.

Figure 8. Profuse sporulation on the underside of a hop leaf with downy mildew appears dark purple to black. (D.H. Gent)

Figure 9. Infection of shoots after training, a so-called "aerial spike." Notice the yellowing, stunting, and downward curling of leaves. (D.H. Gent)

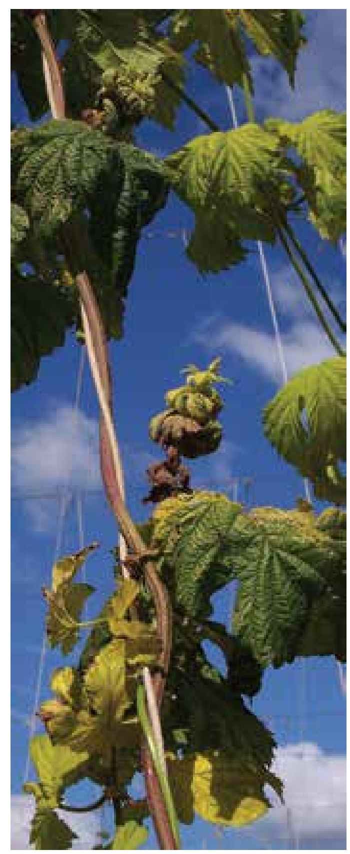


Figure 10. Emerging lateral branch with downy mildew. (D.H. Gent)

At a Glance: Downy Mildew

◆ Select the most resistant variety that is available for the intended market.

◆ Establish hop yards with disease-free planting materials.

◆ Thoroughly remove all foliage during spring pruning in regions where the growing season permits.

◆ Prune yards as late as possible without adversely affecting yield.

◆ Strip lower leaves from bines after training; remove basal foliage in mature yards.

◆ Manage the canopy to improve air flow and reduce humidity and wetness.

◆ Apply appropriate fungicides during the first year of production and when weather favors the disease.

◆ Rotate and tank-mix fungicide modes of action to delay development of resistance.

Downy Mildew Symptoms, cont.

Angular, vein-delimited lesions commonly occur on leaves next to spikes and are typically scattered on lower leaves (Fig. 11). Leaf lesions tend to be short-lived and desiccate in warm, dry weather, resulting in brown areas of dead tissue (Fig. 12).

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. 13). Infected cones may support sporulation on the underside of bracts and bracteoles, which is diagnostic for downy mildew when present, but is not always present on infected cones. The most severe yield damage results when infection occurs during bloom or the early stages of cone development.

Reddish-brown to black flecks and streaks are apparent in infected roots and crowns when roots are cut open (Fig. 14). The crown may be completely rotted in varieties susceptible to crown rot, such as Cluster varieties and Columbus.

Figure 11. Angular leaf lesions on hop leaves. The black discoloration is sporulation by the pathogen. (D.H. Gent)

Figure 12. Dry, angular leaf lesions caused by downy mildew. (D.M. Gadoury)

Figure 13. Dark brown discoloration of bracts and bracteoles on cones with severe downy mildew. (B. Engelhard)

Figure 14. Left, dark discoloration of rhizomes infected with *Pseudoperonospora humuli*. Right, healthy rhizome. (C.B. Skotland)

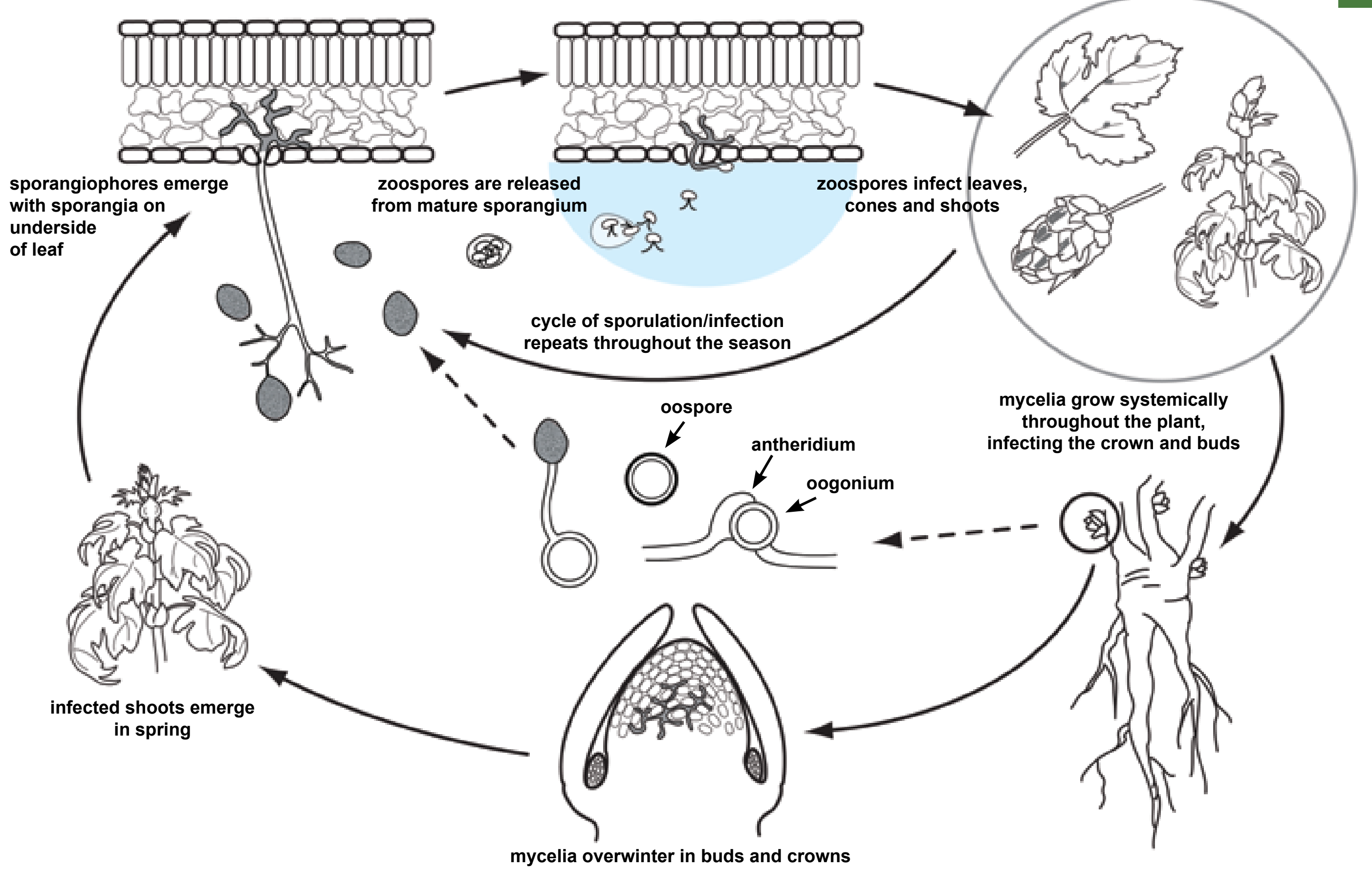


Figure 15. The life cycle of *Pseudoperonospora humuli* on hop. (Prepared by V. Brewster)

Disease Cycle

The downy mildew pathogen overwinters in infected dormant buds and crowns (Fig. 15). It spreads into developing buds during the winter and early spring, and some infected buds give rise to basal spikes when shoots emerge in the spring. The emergence of basal spikes is closely linked to plant growth and can be predicted using simple degree-day models. Sexual spores of the pathogen, termed oospores, are produced copiously in diseased tissue but their role in the disease cycle is unclear.

The pathogen sporulates profusely on infected tissues when nighttime temperatures are greater than approximately 43°F and relative humidity in a hop yard is greater than 90%. Sporangia are released daily in a cyclical pattern and are readily dispersed by air currents. Sporangia germinate indirectly to produce swimming zoospores when the temperature is favorable and free water is present. The most severe disease outbreaks often are linked to daytime rain because zoospores enter hop tissues through open stomata. 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 leaf wetness persists for 24 hours or longer. Shoot infection requires at least three hours of wetness.

Infection of shoots by the downy mildew pathogen can become systemic, producing spikes on previously healthy shoots and lateral branches. These infections produce 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. Crown infection also may occur via infection at the base of stems. Some varieties may support chronic infection. A severe downy mildew outbreak in one year tends to lead to earlier and more severe outbreaks in the following season because of systemic infection of rhizomes and crown tissues. Carbohydrate reserves are reduced in systemically infected plants, resulting in progressive weakening of the plant over time that reduces yield and may lead to plant death.

A study in Europe indicated the potential for the hop downy mildew pathogen to infect certain cucurbit crops and the cucurbit downy mildew pathogen to infect hop. However, studies with strains of the pathogens from the U.S. indicate this rarely occurs or is insignificant. Genetic evidence does not support cross-infection of hop and cucurbits in the field.

Table 3. Disease Susceptibility and Chemical Characteristics of the Primary Public Hop Varieties Grown in the U.S.

Variety	Usage	Disease Susceptibility*		
		Powdery Mildew	Downy Mildew	Verticillium Wilt
Brewer's Gold	Bittering	S	S	MR
Bullion	Bittering	S	S	R
Cascade	Aroma	R/MS	S	MR
Centennial	Bittering	MS	S	U
Chinook	Bittering	S	S	R
Columbia	Aroma	MS	MR	S
Comet	Bittering	R	S	R
Crystal	Aroma	R	S	R
East Kent Golding	Aroma	S	S	MR
Fuggle	Aroma	MR	MR	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	MS	S	U
Mt. Hood	Aroma	MS/R	S	S
Newport	Bittering	MR/R	R	U
Northern Brewer	Bittering	S	S	R
Nugget	Bittering	S/MS/R	S	S
Olympic	Bittering	S	MS	R
Perle	Aroma	S	R	MR
Saazer	Aroma	S	MS	S
Saazer 36	Aroma	S	MS	S
Spalter	Aroma	S	R	MR
Sterling	Aroma	S	MR	U
Teamaker	Aroma	MR	MR	S
Tolhurst	Aroma	S	S	U
TriplePearl	Aroma	S/R	S	U
U.S. Tettnanger	Aroma	S	MR	S
Vanguard	Aroma	S	S	U
Willamette	Aroma	S	MR	S

*Disease susceptibility ratings are based on greenhouse and field observations in experimental plots and commercial yards in the Pacific Northwest as of 2015. 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. For powdery mildew, some cultivars have multiple susceptibility ratings that reflect their potential reaction based on region and whether virulent strains of the powdery mildew fungus occur.

Management

No single management tactic provides satisfactory control of downy mildew. Strict attention to cultural practices, prudent irrigation management, and timely fungicide applications are needed to manage the disease successfully. Varieties vary widely in their susceptibility to downy mildew (Table 3), although no variety is completely immune. When possible, select the most resistant variety that is available for the intended market especially for use in areas with known downy mildew pressure (e.g., next to rivers or in low-lying areas with cool air pooling). The best resistance to downy mildew is found in European varieties such as Magnum, Perle, Orion, and Wye Challenger. Varieties derived from North American germplasms such as Cascade, Centennial, Chinook, Columbus, and Nugget, and many others that are popular with craft brewers, tend to be among the most susceptible to the disease.

Healthy rhizomes and softwood cuttings should be selected when establishing new hop yards since planting material may harbor the pathogen. In well-established yards, thorough removal of all foliage during spring pruning substantially reduces later disease development (Figs. 16 and 17). Pruning yards as late as possible and removing all green tissue generally reduces the severity of downy mildew (Fig. 18). Timing of pruning needs to be balanced with the optimal training timing for maximizing yield. In regions with short growing seasons, such as parts of the Upper Midwest, delayed pruning may not be possible without reducing yield.

Implementing tactics to reduce the relative humidity in a hop yard can decrease disease. Improving air flow, stripping leaves from bines after training, removing basal foliage, cultivating the soil, and minimizing weeds may reduce disease spread (Fig. 19). Stripping of leaves is not recommended in the planting year, and in areas where plant establishment is slow, basal foliage removal should be minimal even in the second year after planting. Decisions on stripping foliage and the extent of basal foliage removal also depend on the severity of downy mildew, presence of powdery mildew, and weeds. The presence of spider mites should also be considered since late-season basal foliage removal can stimulate mites to move up the

Figure 16. Examples of hop plants pruned thoroughly mechanically (A) or chemically by using a desiccant herbicide (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 (D) pruning can result in more severe outbreaks of both downy mildew and powdery mildew. (D.H. Gent)

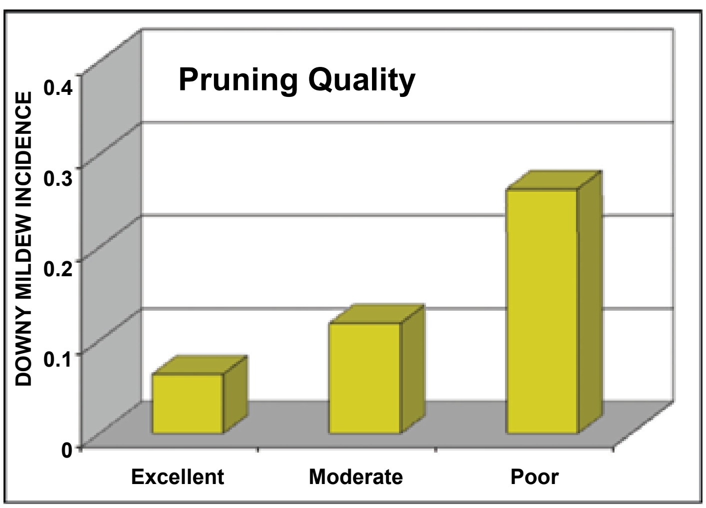


Figure 17. Association of spring pruning quality to the incidence of plants with downy mildew in 110 commercial hop yards in Oregon during 2005 to 2010. Excellent = No foliage or green stems remaining after pruning, Moderate = Foliage or green stems on some hills after pruning, and Poor = No pruning was conducted or foliage and green stems were present on all hills after pruning.

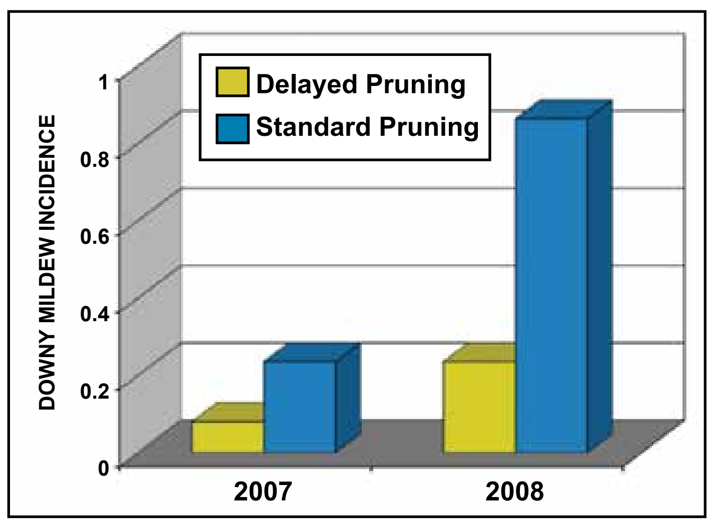


Figure 18. Association of spring pruning timing to the incidence of plants with downy mildew in 6 commercial yards of Willamette in Oregon. Hop yards that received the delayed pruning treatment were chemically pruned 10 to 14 days later than the growers' standard pruning timing.

Downy Mildew Considerations for Production Regions Outside of the Pacific Northwest

Environmental conditions differ significantly in hop production regions outside of the Pacific Northwest. For this reason, several components of the integrated disease management approach adopted by western states are in need of further validation in other regions. While pruning early hop growth to limit downy mildew provides a sound approach for limiting inoculum in the yard, the shorter production season in the Upper Midwest and other regions may be insufficient for adequate development of the crop if this technique is employed. Because many hop yards outside the Pacific Northwest are relatively new, downy mildew is not yet a major problem in every yard. Growers are encouraged to seek out planting material that has been tested for important pathogens. Preventive fungicides, including phosphonates, coppers, and downy mildew-specific active ingredients, are commonly used in Wisconsin and other areas in the Midwest and eastern U.S.

Figure 19. Example of stripping of lower leaves to aid in disease management (D.H. Gent)

plant. In wet environments, cover crops present during the growing season tend to create conditions which increase downy mildew, especially when not mowed or planted close to the hop row. Soil cultivation in general tends to reduce downy mildew.

In situations where downy mildew has developed late in the season, yards can be harvested early to minimize cone infection. However, yields can be reduced in both current and subsequent seasons when plants are harvested too early.

Timely fungicide applications are needed to manage downy mildew when weather is favorable to the pathogen. Fungicide applications made during the establishment year may be beneficial to help minimize crown infection and reduce disease levels in subsequent seasons. Under high disease pressure in western

Table 4. Approximate Period of Protection for Selected Downy Mildew Fungicides

Fungicide	Protection	Kickback	Notes
Aliette/ phosphonates	4-5 days	5-7 days	Heavily influenced by sensitivity of strains; kickback may only be suppression of sporulation.
Copper	5-7 days	None	Repeated application over many years may result in copper accumulation in soils. Some formulations may be allowable for use in organic systems.
Curzate	3 days	2 days	Active ingredient is unstable at high pH; avoid tank mixes with products that increase pH (e.g., bicarbonates).
Flint/Pristine	3-5 days	6 hours	Pristine also contains boscalid, a fungicide with good activity against powdery mildew. Pristine provides some suppression of hop looper when applied late in the season.
Forum/Revus	7 days	1-2 days	Post-infection activity for leaf infection is more pronounced than for shoot infection.
Tanos	5-7 days	2 days	Premix of two fungicides, including the active ingredient in Curzate.

Data are derived from greenhouse and field experiments in Oregon and literature for related diseases. Efficacy of any fungicide is heavily influenced by use history of a compound and sensitivity of the pathogen population. Data are approximate; actual performance is determined by weather, plant growth rate, disease pressure, and other factors. Avoid post-infection sprays whenever possible.

Oregon, a fungicide applied just after the first spike emerges and before spring pruning can provide substantial control of downy mildew later in the season. This can be timed using degree-days. Degree-day models are currently under evaluation for use in other production regions. Later fungicide applications should be timed to coincide with major infection events; several disease risk indexes are available as decision aids. Most fungicides have only limited activity after infection (Table 4) and should be applied preventively whenever possible; timing of fungicide applications is critical (Fig. 20).

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, more frequent applications, and tank-mixes with other fungicides are needed where this resistance is present. Phytotoxicity may occur on some varieties treated with high rates of phosphonate fungicides. 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. Note, however, that strobilurins have a high risk of inciting resistance in both the downy mildew and powdery mildew pathogens. Similarly, copper and folpet are primarily downy mildew fungicides but can provide some suppression of powdery mildew. Most products have increased efficacy when applied when disease is less severe, as illustrated for Aliette WDG and Flint in Figure 21.

See the
Pacific Northwest Plant Disease Management Handbook
at
http://pnwhandbooks.org/plantdisease/
for a current list of registered fungicides for Pacific Northwest states.

Always make sure that any fungicide is registered for use in your geographic area before applying it.

Figure 20. Left, a hop leaf treated with the fungicide Curzate 24 hours before inoculation. Right, treated with Curzate 72 hours after inoculation. (D.H. Gent)

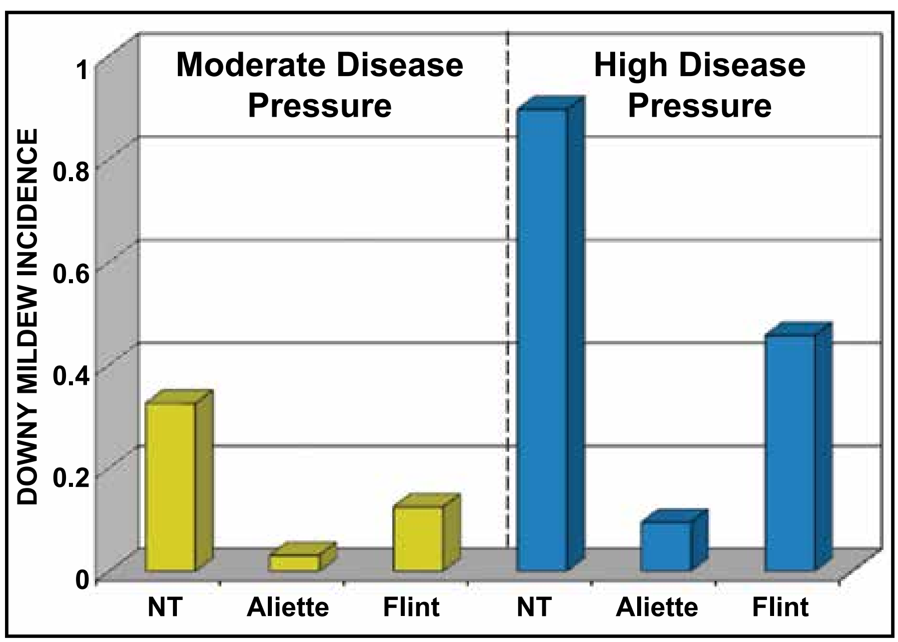


Figure 21. Efficacy of Aliette WDG and Flint under moderate and high disease pressure in Washington. NT = Non-treated.

At a Glance: Fusarium Canker

◆ Avoid propagation from cankered hills.

◆ Ensure plants are free of *Hop stunt viroid*.

◆ Avoid water-logging soils near the crown.

◆ Mound soil around the base of bines to promote growth of healthy, new roots and reduce wilting.

◆ Add lime around the crown to increase pH of acidic soils.

◆ Avoid use of ammonium nitrogen fertilizers.

◆ Minimize injury to plants during field operations, from wind, and from arthropod pests.

◆ Arching strings and maintaining tight trellis wires may help to reduce bine injury.

Fusarium Canker

Cynthia M. Ocamb and David H. Gent

Fusarium canker is caused by the fungus *Fusarium sambucinum*. Diseased plants are conspicuous and easily identified when affected bines wilt. Affected hills may not exhibit canker symptoms every year. Severe outbreaks can occur, however, especially following excessively wet conditions. Yield losses from Fusarium canker have not been quantified rigorously but are expected due to bine die-off or plant death. The disease is commonly present at a low incidence in hop yards, although in some circumstances (such as when plants are propagated from *Hop stunt viroid*-infected material) a high incidence may occur.

Symptoms

The base of an affected bine is swollen, tapering over a short distance (about 1/4 inch) near the point of attachment on the crown (Fig. 22). The decay progresses inward toward the center of the stem, weakening the point of crown attachment such that affected bines may break away from the crown before harvest with a tug or other pressure (e.g., wind or air-blast sprayer). Older leaves on the lower part of the bine may become yellow and then turn brown as they die. Leaves on wilted bines remain attached (Fig. 23). Disease symptoms often are not recognized until affected bines wilt suddenly, which is most common when water demand is greatest, such as at flowering or in response to high temperatures. Bine wilting is often evident after cultivation, pesticide applications with an air-blast sprayer, or high winds, since diseased bines may break off from crowns at these times. Severely affected plants, particularly young plants, may die out during winter or under periods of high soil moisture. Affected bines may be covered with whitish-pink to reddish-brown mold produced during growth and sporulation by the fungus on the outer portion of the lower stem (Fig. 24). Other pests such as Vertcillium wilt and California prionus beetle can cause wilting symptoms similar to Fusarium canker. The distinguishing characteristics for Fusarium canker are the swelling of the lower stem, constriction near the soil level, and lack of extensive vascular browning.

Figure 22. Swollen basal portions of bines affected with Fusarium canker. (D.H. Gent and N.R. Cerruti)

Disease Cycle

The disease cycle of Fusarium canker has not been investigated thoroughly. The fungus that causes the disease is widespread in soil and is considered a soil inhabitant after introduction to a site but can also be found in association with plant debris, diseased crowns, and apparently healthy planting materials. It is thought that the pathogen infects hop plants through natural openings or wounds created by mechanical or chemical damage (e.g., wind, cultivation, insect feeding, or herbicide injury) around the soil line. High humidity and persistent moisture near the crown favor the disease.

Figure 23. Wilted bine due to Fusarium canker. Notice that wilted leaves remain attached to the bine. (D.H. Gent)

Figure 24. Whitish-pink sporulation of the Fusarium canker fungus on an infected stem. (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, adventitious roots and can reduce incidence of bine wilting. Reducing free moisture near the crown due to irrigation can help, both in greenhouses and the field. Applying lime to increase pH to near neutral or slightly alkaline around the crown in acid soils and avoiding use of acidifying ammonium nitrogen fertilizers may help to reduce disease incidence. Minimizing injury to bines during field operations, reducing bine movement by tying bines and strings together, maintaining tight trellis wires to minimize bine sagging, and preventing damage to bines from arthropod pests help to reduce wounds that allow the fungus to gain entry into the plant. No fungicides are registered for control of Fusarium canker.

Fusarium Cone Tip Blight

David H. Gent and Cynthia M. Ocamb

Cone tip blight generally is a disease of minor importance, but in some instances 30% or more of cones can be affected. The disease can be incited by several *Fusarium* species, including *F. avenaceum*, *F. crookwellense*, and *F. sambucinum.*

Symptoms

Affected bracts and bracteoles at the tip of the cone turn medium to dark brown as the cone matures (Figs. 25 and 26). 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. It is characteristic of cone tip blight that all bracts and bracteoles of the symptomatic whorl(s) are affected. Browning and death of the strig (central axis that bears the nodes) along the region of affected whorls generally is apparent when the affected bracts and bracteoles are removed (Fig. 27).

Disease Cycle

Little is known about the disease cycle. The implicated *Fusarium* species can survive in soil, plant debris, other plant species, 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 stigmas. Observation suggests that the disease is favored by high humidity, dew events, or rainfall during bloom and cone development. A more closed-cone architecture at the tip, as found in Nugget and Sorachi Ace, may make certain varieties more susceptible than others.

Management

Control measures have not been developed for cone tip blight, as the disease occurs sporadically and control is not warranted in most hop yards. Little is known about differences in variety susceptibility, although field observations suggest some variation exists. Sorachi Ace and Centennial seem to be commonly affected by cone tip blight. Limited evaluations of fungicides indicate *Fusarium* spp. are recovered at a lower rate from burrs and cones treated with strobilurin fungicides (FRAC group 11). However, these treatments have not been successful for management of cone tip blight and strobilurin fungicides would be prone to developing fungicide resistance when used alone. Demethylation-inhibiting fungicides (FRAC group 3) that are registered for powdery mildew control may also suppress *Fusarium* species.

AT RIGHT: Figures 25 and 26. Top two images show medium brown discoloration of bracts and bracteoles due to cone tip blight. (D.H. Gent and S.J. Pethybridge)

Figure 27. Bottom image shows discoloration of strig, bracts, and bracteoles from cone tip blight. (D.H. Gent)

At a Glance:

Fusarium Cone Tip Blight

- ◆ Control seldom warranted.
- ◆ Time overhead irrigations to reduce humidity and periods of cone wetness, especially during bloom.
- ◆ Fungicide applications do not appear to be effective.

At a Glance
Gray Mold

- Minimal damage to hop.
- 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.

Gray Mold

David H. Gent

Gray mold generally is a disease of minor importance in hop. 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, blackberry, 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. 28 and 29). 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 in hop. Strobilurins (FRAC group 11) are particularly effective. However, in most years the disease causes minimal damage in regions with dry climates, and special control measures have not been necessary. Cultural practices such as increasing row and plant spacing and managing overhead irrigation to shorten the duration of wetness on cones may 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 28 and 29. Medium brown discoloration and fungal growth on the tip of a cone due to gray mold. (S. Radišek)

Powdery Mildew

David H. Gent, Mark E. Nelson, David M. Gadoury, Amanda J. Gevens, and Mary K. Hausbeck

Powdery mildew, caused by the fungus *Podosphaera macularis*, is one of the most important diseases of hop worldwide. The disease can cause severe crop damage, and in some cases crop failure is complete due to lost production and unacceptable cone quality.

Podosphaera macularis is prevalent throughout the Pacific Northwest, and powdery mildew is a major pest of hop in much of this region. The pathogen is also prevalent in the Upper Midwest and the eastern U.S., where it is relatively common on feral bines and on wild hop. At the time of this writing, powdery mildew has been confirmed from only a few commercial hop yards in Michigan, North Carolina, New York, and Quebec. The relatively few outbreaks of the disease outside of the western U.S. may be due in part to the relative newness and small acreage of the emergent hop industry in the Upper Midwest and eastern North America. It also may be due in part to the widespread planting of powdery-mildew resistant varieties in these regions. Historically, however, powdery mildew was a very important disease in New York in the early 1900s. This history, along with recently documented breakdown of resistance in some varieties, would indicate that powdery mildew could return rapidly to damaging levels as observed during 2015.

Symptoms

Disease signs appear as powdery white colonies on leaves, buds, stems, and cones (Fig. 30). 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 (Fig. 31).

Figure 30. Powdery white colonies on leaves, stems, and cones. (D.H. Gent)

Figure 31. Powdery mildew damage on very young (left) and more mature cones. (D.H. Gent)

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 if practical in your growing region.
- Apply appropriate fungicides as soon as possible to protect regrowth after pruning and throughout season.
- Eliminate mid-season basal growth in established yards.
- 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 Considerations for Production Regions Outside of the Pacific Northwest

In the Upper Midwest and northeastern U.S., powdery mildew has been observed in only a few instances and has not yet become established or common in most hop yards. Powdery mildew has been found on wild and feral hop plants in Maryland, Minnesota, and New York, and on cultivated plants in Michigan, New York, North Carolina, and Quebec, Canada. Scouting and accurate diagnosis is advised so as to limit early disease onset. Producers outside of the Pacific Northwest should also carefully consider the source of their planting materials, as strains of the pathogen exist in the western U.S. that can cause disease on varieties typically considered resistant such as Nugget, Cascade, Mt. Hood, Newport, and TriplePearl. Such strains were confirmed in Michigan, New York, and North Carolina in 2015 and may have been introduced into these states on diseased planting materials.

Powdery Mildew Symptoms, cont.

Affected cones may develop a characteristic white, powdery fungal growth, although in some cases fungal growth is visible only under bracts and bracteoles with magnification. Affected cones become reddish-brown as tissues are killed (Fig. 32) and may "bleach out," turning pale green or light brown after kiln drying (Fig. 33). The pathogen grows exclusively upon the surface of the plant, with the exception of microscopic absorptive structures (haustoria) that invade epidermal cells. Unlike downy mildew, which emerges and sporulates primarily through stomata on the lower surface of leaves, symptoms and signs of powdery mildew can occur on any surface of any green tissue of the hop plant.

Figure 32. Reddish-brown discoloration associated with powdery mildew.

Figure 33. Bleaching and loss of green cone color after kiln drying caused by powdery mildew. (Both photos D.H. Gent)

Disease Cycle

In all growing regions, the pathogen is thought to survive in a vegetative state as hyphae within dormant, infected buds on the crown. Crown buds infected in one season give rise to infected shoots the following year. These infected shoots are called "flag shoots" because of their resemblance to a white flag on the otherwise green foliage in spring (Fig. 34). Flag shoots occur on a small percentage of plants (typically less than 1%) and provide the initial spores to initiate outbreaks each year. Flag shoots emerge in sync with plant growth. A few can be found as soon as shoots begin to emerge in spring, and they continue to emerge until as late as May or even early June, provided that infected buds are not removed during spring pruning operations. The number of flag shoots produced in a given yard is related to prior occurrence of flag shoots in that yard, disease levels in the previous year, spring pruning practices, and winter temperature.

The disease initially centers on the flag shoots, then the pathogen moves via airborne spores (conidia) from infected crowns to young leaves as new growth emerges. This shifts the distribution of disease throughout a planting, into neighboring yards, and eventually throughout a growing region.

In the Pacific Northwest, the pathogen is known to overwinter only in association with crown buds, but east of the Rocky Mountains there are two distinct mating types of the pathogen, the presence of which can result in the development of a second form of overwintering. If disease builds to a level where the two mating types become paired on the same tissue, they can fuse to form durable resting structures called chasmothecia or cleistothecia (Fig. 35). This life stage of the pathogen may persist over winter on crop debris that was infected in the previous season. Chasmothecia mature gradually during winter and can release infectious spores during spring rains. The optimal conditions for infection by these spores, called "ascospores," are generally the same as those for the asexual spores (conidia). Infection by ascospores produces mildew colonies that are identical in appearance to those that result from conidia. Both versions of the life cycle of the pathogen are illustrated in Figure 36.

Figure 34. A young shoot in spring with severe powdery mildew ("flag shoot") resulting from bud infection the previous year. (D.H. Gent)

Figure 35. Small, yellow to black chasmothecia of the powdery mildew fungus on a leaf. (S.N. Wolfenbarger)

Powdery mildew development is favored by rapid plant growth, mild temperatures (50 to 82°F), high humidity (especially at night), and cloudy weather. Under ideal conditions of 65 to 70°F, the fungus can complete its life cycle in as few as five days on highly susceptible varieties.

Burrs and young cones are very susceptible to infection, which can lead to cone distortion, substantial yield reduction, diminished alpha-acids content, color defects, and premature ripening. Cones become somewhat less susceptible to powdery mildew with maturity, although they never become fully immune to the disease. Infection during the later stages of cone development can lead to cone browning and hastened maturity, with the degree of these effects directly linked to how much disease is present. Alpha-acids typically are not influenced greatly by late-season attack of powdery mildew, but yield can be reduced by 20% or more because of shattering of overly dry cones during harvest due to early maturity. Several weak pathogens and secondary organisms can be found on cones attacked by powdery mildew; control of powdery mildew reduces presence of these secondary organisms.

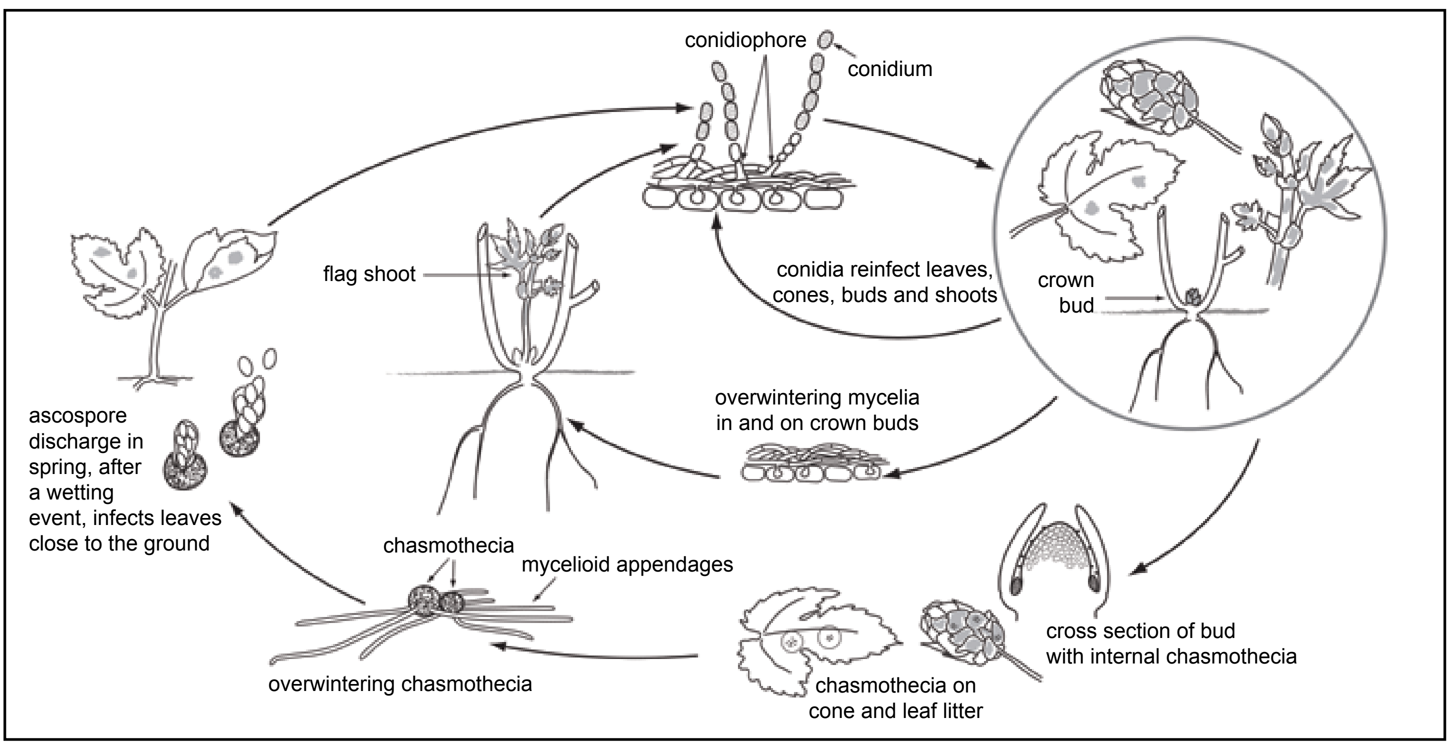


Figure 36. Life cycle of *Podosphaera macularis* on hop. The sexual stage of *P. macularis* (shown by arrows on the bottom and left side of the figure) is not known to occur in the Pacific Northwest. (Prepared by V. Brewster)

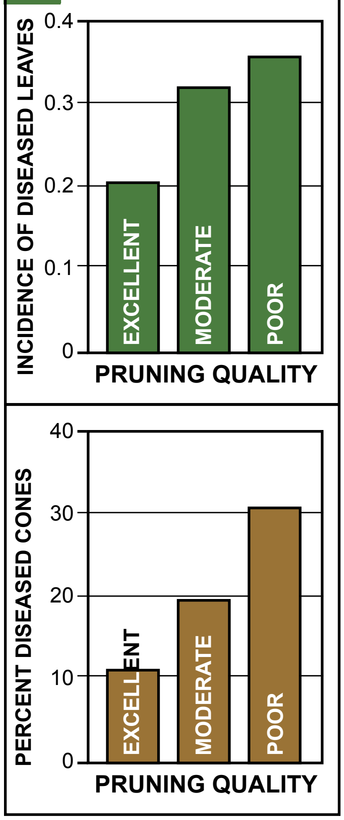


Figure 37. Association of thoroughness of spring pruning to the incidence of leaves (top) and cones (bottom) with powdery mildew in hop yards examined in Washington and Oregon in 2000 and annually from 2005 through 2010. Excellent = No foliage or green stems remaining after pruning. Moderate = Foliage or green stems on some hills after pruning. Poor = No pruning conducted or foliage and green stems present on all hills after pruning.

Management

Control of powdery mildew requires integration of varietal resistance, crop sanitation practices, adequate but not excessive fertilization and irrigation, and well-timed fungicide applications throughout the production season as well as during cone development. While growers may not be able to select resistant varieties because of market factors, some resistant varieties are available (Table 3, page 18).

The reaction of a hop variety to powdery mildew varies depending on where it is grown and which strains of the fungus are present. Mt. Hood, Newport, Nugget, TriplePearl, and several proprietary varieties possess a similar form of resistance that has historically rendered them immune to powdery mildew. However, strains of the pathogen capable of infecting these varieties are now widespread in the Pacific Northwest. Cascade has a different form of resistance to powdery mildew, but, similarly, strains of the fungus exist in the Pacific Northwest that can also overcome its resistance. Many varieties have useful levels of field resistance or tolerance, such as Comet. Selection of early-maturing varieties (e.g., Fuggle) can also help to escape late-season powdery mildew.

It is extremely important to obey the quarantines in place regarding interstate transport of hop planting material. This will delay the introduction of the second (mating) type into the Pacific Northwest and also the dissemination of virulent strains of the fungus into other production regions.

Successful management of powdery mildew begins in early spring. In the Pacific Northwest, thorough removal of all green tissue during pruning, including shoots on sides of hills and around poles or anchors, is an important component of powdery mildew management (Fig. 37). Mechanical pruning tends to be more effective than chemical pruning in eliminating flag shoots. In regions outside of the Pacific Northwest with short growing seasons, and where there is little to no powdery mildew pressure at this time, early-season pruning has not gained wide adoption, as it can result in poor productivity.

Where powdery mildew is problematic, regular fungicide applications are essential for economic production of most susceptible varieties. Appropriate timing of the first fungicide application after pruning is important to keep disease pressure at manageable levels. This application should be made as soon as possible after shoot regrowth in high-risk situations or when the disease is first detected in a region through scouting.

Many fungicide programs can give adequate disease control on leaves when applied preventatively. On cones, however, differences among fungicides are substantial. Mid-July through early August is an essential disease management period. The fungicide quinoxyfen (Quintec) is especially effective during this time. The powdery mildew pathogen has an extremely high risk of developing fungicide resistance, therefore careful attention to resistance management guidelines is critical.

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. Applying highly effective fungicides such as Quintec to young, developing cones can significantly reduce incidence of powdery mildew on cones at harvest.

The efficacy of any fungicide varies greatly depending upon disease severity (Fig. 38). The incidence of cones with powdery mildew is reduced when fungicide applications are made as late as possible during the growing season, as specified by the label. However, multiple years of trials in Washington have failed to demonstrate a consistent impact of these very late-season

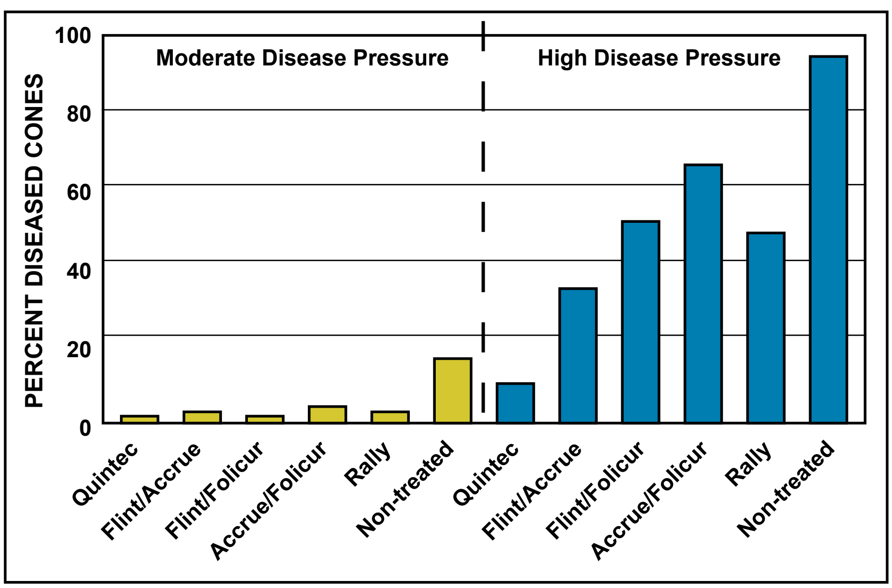


Figure 38. Efficacy of powdery mildew fungicides under moderate and high disease pressure in Washington. Notice that most fungicides provide acceptable control when disease pressure is moderate.

applications on yield, while their impact on cone color depends on disease pressure.

Fungicide applications alone are not sufficient to manage the disease. Under high disease pressure, mid-season removal of diseased basal foliage delays disease development on leaves and cones. Desiccant herbicides should not be applied until bines have grown far enough up the string so that the growing tip will not be damaged and bark has developed. In trials in Washington, removing basal foliage three times with a desiccant herbicide provided more control of powdery mildew than removing it once or twice, particularly on cones (Fig. 39). Established yards can tolerate some removal of basal foliage without reducing yield. This practice is not advisable in first-year plantings, and may need to be considered cautiously in the second year after planting in some situations.

Late-season powdery mildew can be easily confused with other diseases such as Alternaria cone disorder or gray mold, and even with spider mite damage. In the overwhelming majority of instances in the Pacific Northwest, however, the primary cause of late-season discoloration of cones is powdery mildew.

Crop damage can increase with later harvests. When powdery mildew is present, CTZ and Galena crops should be harvested by about 26% dry matter to maintain cone color and minimize losses due to shattering during picking.

The above recommendations apply to both hops produced for conventional commercial markets and those grown under guidelines for organic production. Under the additional constraints imposed by organic production guidelines, particular attention must be paid to selection of disease-resistant varieties. This is the foundation upon which organic production will succeed or fail with respect to the major fungal diseases. Available fungicide options for organic production are minimal and generally mediocre in efficacy under high disease pressure. Although frequently cited in popular literature, optimal fertilization, soil health, and water management alone are inadequate for disease control. Likewise, biorational compounds, biological controls, manure teas, and various botanicals and natural products have shown minimal to no efficacy against this pathogen under moderate to severe disease pressure.

Practice sound fungicide resistance management to prolong utility of key powdery mildew fungicides.

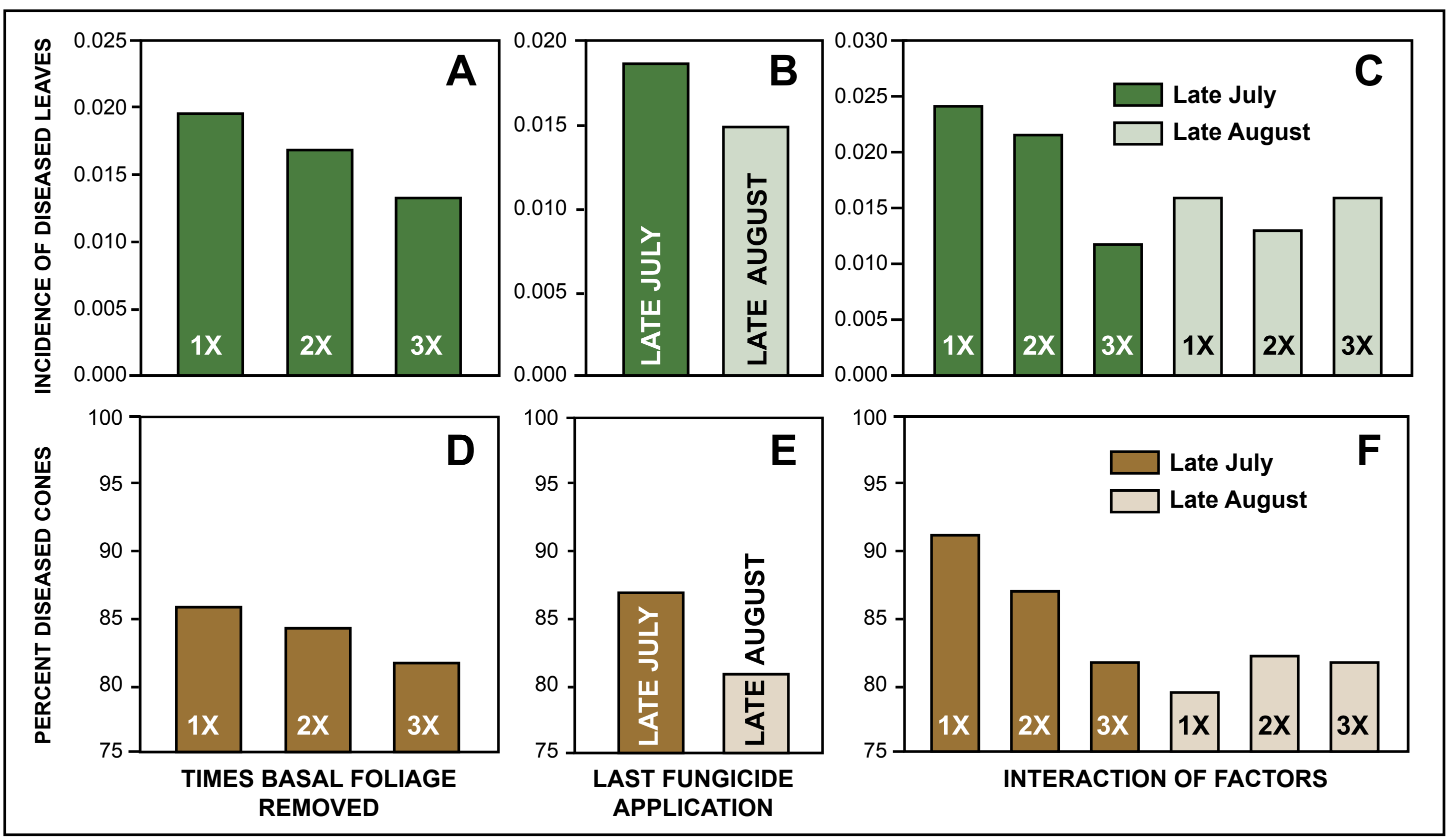


Figure 39. Incidence of leaves (A to C) and percent of cones (D to F) with powdery mildew depending on how many times basal foliage was removed (A and D), how late into the season fungicide were applied (B and E), and the interaction of these factors (C and F). Notice that intensity of basal foliage removal and date of the last fungicide application interact to influence disease levels on cones. Data from variety Zeus in Washington, 2012 to 2014.

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 seems unnecessary in most situations.

Red Crown Rot

David H. Gent

Red crown rot has been described on hop plants in Australia and Oregon. The disease is caused by the fungus *Phomopsis tuberivora*. The disease generally is of minor importance and seems to cause crop damage only when other factors weaken plants. Data from Australia indicate affected plants may suffer yield losses of up to 20%. In extreme cases in Oregon, plants have been killed by red crown rot and yield losses appear to be higher than 20% in these instances.

Symptoms

The pith tissue of affected roots and crowns is orange to red and develops into a progressive dry rot of the root (Fig. 40). There is a distinct boundary between diseased and healthy tissue (Fig. 41). Roots and crowns of apparently healthy plants typically have this appearance, but the severity of dry rot is more pronounced in diseased plants. Entire crowns may be destroyed in the advanced stages of the disease, leading to weak, uneven shoot growth, and yellowing of lower leaves (Fig. 42). 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 may be aggregated in roughly circular patches, although in some young plantings diseased plants may be more generally scattered across a yard.

Disease Cycle

Little is known about the disease cycle of red crown rot. In Victoria, Australia, the disease was thought to be associated with planting poor quality rootstock, injury to crowns during spring mowing of shoots, 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 includes alfalfa, beet, potato, and several trees and woody ornamentals. The fungus is a weak pathogen, and disease symptoms rarely develop on these hosts. In Oregon, damage from red crown rot has been observed only in a few instances, and in most cases plants were weakened by some other predisposing factor.

Figure 40. Reddish-brown decay and dry rot of a crown affected by red crown rot. (D.R. Smith)

Figure 41. Distinctive boundary between healthy and affected tissue in a root with red crown rot. (D.H. Gent)

Figure 42. Weak plant growth and yellowing of older leaves due to severe red crown rot. (D.H. Gent)

Management

Control measures for red crown rot have not been thoroughly investigated in the U.S. However, the disease currently appears to cause economic damage in relatively few yards, and specific management efforts generally do not appear necessary. 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 and carbohydrate reserves. 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 Australia, although conclusive evidence of a link between boron deficiency and the disease is lacking. In Australia, fumigation with dazomet provided an approximate 60% increase in yield in year one and 14% in year two. This practice has not been adopted in Australia due to the high cost of fumigation. In Oregon, fumigation has improved establishment in yards where red crown rot was present (Fig. 43). A study in Oregon found a link between high soil pH and red crown rot within a severely affected yard; it is unclear if pH is important for disease development in other situations.

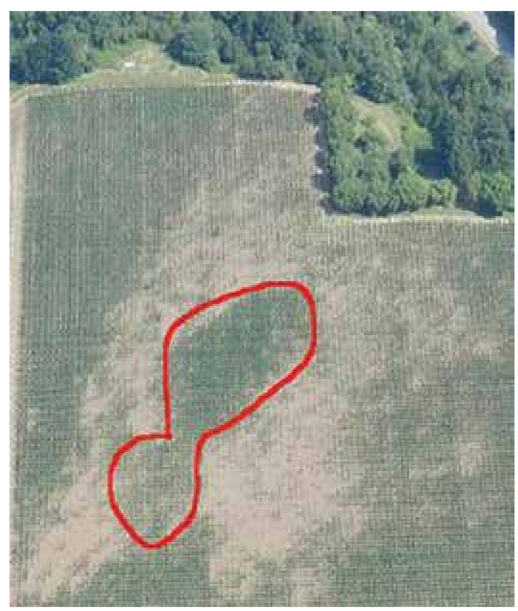


Figure 43. Weak and dead plants in a hop yard affected by severe red crown rot. The area indicated in red was fumigated before replanting. (D. Sbur)

At a Glance
Sclerotinia Wilt or White Mold

◆ Control measures usually are not needed in the Pacific Northwest.

◆ Limit excessive foliage and canopy wetness.

◆ Time irrigations to reduce wetness on plants and soil.

Sclerotinia Wilt (White Mold)

David H. Gent

Sclerotinia wilt, also referred to as white mold, affects nearly 400 weed and crop plant species, including green bean, pea, lima bean, canola, carrot, lettuce, potato, sunflower, and squash. The disease is caused by a fungus, *Sclerotinia sclerotiorum*, and is only an occasional problem on hop in wet, cool climates such as those found in the hop production regions in western Oregon and northern Idaho. 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. In some instances, the fungus can colonize stems higher on the plant. In one case in western Oregon, the fungus was found growing only high up on the stems near the string used to tie the bines for arching.

Figure 44. White, fluffy growth of the Sclerotinia wilt fungus on hop stems. The small black structures on the lesions are a diagnostic characteristic of the fungus. (M.L. Putnam)

Figure 45. Wilted bine in the variety Nugget caused by Sclerotinia wilt. (D.H. Gent)

During wet weather, fluffy white growth of the fungus may form on the infected tissue (Fig. 44). Small (about 1/16 to 1/8 inch), 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. Bines with smaller diameter seem more likely to fully wilt than larger diameter bines. Leaves generally remain green until the bine is girdled completely. Disease symptoms may appear similar to those caused by Fusarium canker or Verticillium wilt (Fig. 45). 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. In some crops, 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. 46). The soil surface must remain wet for several days or longer for apothecia to form, and with hop 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 several million airborne spores (ascospores). The airborne spores 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 shoots. 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 broadleaf weeds in and around hop yards.

Management

Control measures for Sclerotinia wilt of hop usually are not needed. In Oregon and northern Idaho, the disease tends to be most problematic during spring. Cultural practices that reduce the duration of wetness on plants and the soil surface can reduce disease incidence. These practices may include limiting nitrogen fertilization, removing excess basal shoots and leaves, stripping leaves from lower bines, delaying the first irrigation as long as possible, and timing irrigations to allow the top two inches of the soil to dry completely between irrigations. Avoid planting susceptible hosts such as canola in idle hop yards. A parasitic fungus, *Coniothyrium minitans* (marketed under the trade name Contans WG), is used in some crops as a soil treatment to reduce the number of sclerotia of the Sclerotinia wilt pathogen. The efficacy of this product for Sclerotinia wilt in hop has not been investigated.

Figure 46. A germinated sclerotium of *Sclerotinia sclerotiorum* with a mushroom-like structure (apothecium). (D.H. Gent)

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 on hop 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," comprising sugars, amino acids, and other substances. This solution provides a food source that supports the growth of dark-pigmented fungi that grow conspicuously on the surface of leaves and cones, reducing the quality of cones.

Symptoms

Once aphids colonize and begin feeding, plant tissues become covered with sticky honeydew and develop a shiny appearance. Signs of sooty mold soon develop on the honeydew as a flattened, black mass of fungal growth that resembles a fine layer of soot (Fig. 47). Burrs and developing cones later may become covered with honeydew when aphids are present later in the season, 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. 48).

Management

Sooty mold is managed by controlling hop aphids (Fig. 49) when populations exceed economic thresholds. Natural enemies of hop aphid can provide some level of control when not disrupted by insecticides, therefore broad-spectrum insecticides should be avoided when possible.

PHOTOS AT RIGHT, FROM TOP

Figure 47. Black sooty mold on hop leaves. (D.H. Gent)

Figure 48. Black sooty mold on a hop cone. Notice the white aphid castings present under the bracts and bracteoles. (D.H. Gent)

Figure 49: Hop aphid (winged form). For aphid photos and control information, see pp. 47-48. (L.C. Wright)

At a Glance
Sooty Mold

◆ Sooty mold is controlled by controlling hop aphid.

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

At a Glance
Verticillium Wilt

◆ Plant resistant varieties, especially in areas where lethal strains of the pathogen occur.

◆ Clean equipment between yards to minimize spreading the pathogen.

◆ Plant only disease-free rhizomes and plants.

◆ 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.

◆ Do not plant hop where heptachlor residues are present.

Verticillium Wilt

David H. Gent and Mark E. Nelson

Verticillium wilt is a potentially damaging disease of hop and numerous other hosts. On hop, Verticillium wilt has been reported from most production regions of the world. The disease may be caused by two related fungal species, *Verticillium nonalfalfae* (formerly V. *albo-atrum*) and *V. dahliae*. The host range and severity of disease caused by these pathogens varies; in general, *V. nonalfalfae* is of much more economic concern than *V. dahliae*.

Multiple strains of *V. nonalfalfae* have been described, which generally display a continuum of aggressiveness on hop. Some may cause relatively minor wilting symptoms (sometimes called non-lethal or fluctuating strains), while others can cause severe symptoms (lethal or progressive strains) that can rapidly kill susceptible varieties. Non-lethal strains of *V. nonalfalfae* have been reported on hop in Oregon. Lethal strains of the pathogen have not been reported from the U.S., but occur in England, Germany, and Slovenia. *Verticillium dahliae* causes a relatively minor wilt disease on hop. This pathogen has a broader host range than *V. nonalfalfae* and occurs commonly on hop in the U.S. and elsewhere.

Figure 50. Upward curling and wilting of leaves associated with Verticillium wilt caused by a non-lethal strain of *Verticillium nonalfalfae* (D.H. Gent)

Figure 51. Swollen bine with wilted leaves resulting from infection by a non-lethal strain of *Verticillium nonalfalfae,* one of the Verticillium wilt pathogens. (D.H. Gent)

Symptoms

Disease symptoms vary depending on the aggressiveness of the *Verticillium* pathogen that is attacking the plant. With non-lethal strains of *V. nonalfalfae*, disease symptoms often appear initially on lower leaves as yellowing and death of tissue between major veins and upward curling of leaves (Fig. 50). Affected bines become noticeably swollen (Fig. 51), and when these bines are cut open the vascular tissue exhibits a prominent medium to dark brown discoloration (Fig. 52). These symptoms generally develop near flowering or when plants become moisture stressed. Eventually, one or all of the affected bines on a plant completely wilt (Fig. 53). The severity of symptom development may vary from year to year depending on weather and other factors. Plants affected by non-lethal strains of the pathogen in one season may fully recover and appear healthy in the following year. All reports of Verticllium wilt caused by *V. nonalfalfae* in the U.S. to date have been associated with non-lethal strains of the pathogen.

In contrast, lethal strains of *V. nonalfalfae* cause rapid collapse of leaves and branches, killing plants of susceptible varieties. Bine swelling is less apparent with lethal strains of the pathogen, but the degree of vascular browning is more severe than that associated with non-lethal strains. With these more aggressive strains of the pathogen, disease symptoms become progressively more severe with time and are less affected by year-to-year variation in weather and grower management practices.

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 it does on plants in Oregon.

Disease Cycle

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 wilt symptoms. The fungus also spreads systemically in the plant and may invade leaves.

Verticillium nonalfalfae is known to infect potato, tomato, spinach, the ornamental plant tree-of-heaven *(Ailanthus altissima)*, and numerous broadleaf weeds that may occur in hop yards. *Verticillium dahliae* has a broader host range that includes more than 400 plants. Important hosts include cherry, maple, mint, potato, cantaloupe and other melons, as well as several herbaceous plants, woody ornamentals, and common weeds.

The Verticillium wilt pathogens are spread in hop yards during soil cultivation, in hop trash, in planting materials from infested yards, and in soil moved on equipment and workers. Weeds common to hop yards that can be infected by *Verticillium* spp. include common lambsquarters, pigweed, and shepherd's purse; 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. nonalfalfae* can survive three to four years in soil, and *V. dahliae* can survive for 15 years or longer.

Management

Planting resistant varieties and using strict sanitation procedures are essential where lethal strains of the pathogen exist to limit its spread. Most varieties produced in the U.S. are highly susceptible to lethal strains, with Fuggle being particularly 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. nonalfalfae* in soil. Cascade and Perle are reported to be less susceptible to non-lethal strains. 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. nonalfalfae* minimize damage from this pathogen as well. Residues of the insecticide heptachlor are reported to increase susceptibility of hop plants to Verticillium wilt caused by *V. dahliae.*

Figure 52. Diagnostic browning of vascular tissues caused by Verticillium wilt. A healthy bine is shown on the right. (D.H. Gent)

Figure 53. Wilting of bines affected by Verticillium wilt caused by a non-lethal strain of *Verticillium nonalfalfae*. (D.H. Gent)

Figure 54. Bines affected by the fungus *Diplodia seriata*. (D.H. Gent)

Figure 55. Reproductive structures (pycnidia) of the fungus *Diplodia seriata* formed externally (left) and internally (right) on affected hop stems. (D.H. Gent)

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. It is 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 in which the disease was present, all roots and stumps should be removed and destroyed.

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 unnecessary management actions.

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 and roots, resulting in weak bine growth, wilting of affected bines, and, in severe cases, plant death. Fuggle, Late Cluster, and Southern Brewer are known to be susceptible to the disease. Crown gall 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.

Diplodia seriata

A wilt disease caused by the fungus *Diplodia seriata* was reported from Upstate New York in 2012. Affected bines exhibit black discoloration and wilt late in the season; leaves remained attached to the wilted bines (Fig. 54). Reproductive structures of the fungus (pycnidia) form externally and internally on affected stems, most prominently in the cortex (Fig 55). These symptoms were reproduced on greenhouse-grown plants over a nine-month period. Little is known about the disease on hop. The low infectivity of the fungus and long incubation period required for symptom development may indicate that the organism is a weak pathogen and capable of causing plant damage only under certain conditions.

Drippy Stem Blight

A disorder of unknown cause has been observed from several hop yards in Washington and southern Idaho since 2012. In the reported instances, symptoms were first recognized during mid to late July. The main bines crack and become colonized with a sticky, putrid ooze that may drip onto leaves and the soil (Fig. 56). Flies and other insects are attracted to the exudate. Foam may be observed at the base of affected bines (Fig. 57). Affected bines may later wilt and desiccate. A yeast-like fungus, *Galactomyces geotrichum*, and several bacteria have been recovered from affected plants. To date, multiple attempts to reproduce symptoms with the yeast fungus under greenhouse conditions have failed. Inoculations with multiple bacteria are ongoing, although the cause of this problem remains unknown. The variety Cashmere appears especially susceptible, as occurrences of the problem have been reported to be widespread in multiple, first-year yards of Cashmere in both Idaho and Washington. Reports of drippy stem blight also have been made on Cluster and two proprietary varieties.

Rhizoctonia solani

Rhizoctonia solani has been reported in rare instances to cause lesions on young shoots of the variety Brewer's Gold in British Columbia and, more recently, in North Carolina. 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.

Figure 56. (FROM TOP) Sticky exudate on the main bine associated with drippy stem blight (D.H. Gent), stem cracking and decay on Cashmere (D.H. Gent), and slime dripping from the stem on Cluster (D. Whitener).

Figure 57. Foam produced at base of a Cashmere plant with drippy stem blight. (D.H. Gent)

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.

◆ The fungus *Diplodia seriata* has been confirmed in New York State, but appears to be of minor importance.

◆ Drippy stem blight, a disorder of unknown origin, is under investigation.

◆ 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.

◆ Carlaviruses are transmitted by aphids and through mechanical means.

◆ 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: *American hop latent virus, Hop latent virus,* and *Hop mosaic 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 damage. On sensitive varieties, chlorotic mosaic mottling can develop between major leaf veins (Fig. 58). 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 hop plants.

Figure 58. Yellow mosaic pattern on Chinook due to *Hop mosaic virus*. (K.C. Eastwell)

The three carlaviruses reduce growth, which is particularly detrimental when establishing new plantings and when attempting to achieve optimal yields early in the life span of a hop yard. Yield can be reduced by some 15%, but varieties sensitive to *Hop mosaic virus* can suffer losses up to 62%. Changes in brewing characteristics induced by these viruses are minor and appear to be analogous to over maturity of cones at harvest.

Disease Cycle

Carlaviruses are transmitted largely through mechanical means. Propagation and distribution of virus-infected plants is the primary mode through which they are spread long distances. Root grafting and mechanical transmission are thought to contribute to localized spread.

Carlaviruses are also transmitted in a non-persistent manner by aphids. This means that when an aphid feeds on an infected plant, it can acquire the virus and immediately transmit it to the next host plant on which it feeds. Transmission to subsequent plants is either very inefficient or does not occur at all. All three carlaviruses are transmitted by the hop aphid *(Phorodon humuli)*. *Hop mosaic virus* and *Hop latent virus* are also transmitted by the potato aphid *(Macrosiphum euphorbiae)* and green peach aphid *(Myzus persicae)*.

Carlaviruses typically have narrow host ranges, therefore the only hosts 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 if the viruses are present.

Management

Use of certified virus-free planting stock is the most practical method of limiting any virus disease. 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.* Infection by *Apple mosaic virus* reduces the ability to propagate hop plants from cuttings and reduces the success in establishing new hop yards.

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. 59-61). 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-acids 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 damage.

Figure 59. Necrotic ringspots and oak-leaf line pattern on Nugget due to *Apple mosaic virus*. (D.H. Gent)

Figure 60. Oak-leaf line pattern caused by *Apple mosaic virus*, without the development of ringspot symptoms. (D.H. Gent)

Figure 61. 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 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
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 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 hop plants was confirmed in 2004. The disease has been reported in hop-growing regions of Japan, Europe, and North America. *Hop stunt viroid* can reduce alpha-acids yield by as much as 60% to 80%.

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 planting material. Early-season growth of infected bines is delayed and foliage is generally pale relative to healthy bines (Fig. 62). During active growth, the length of the internodes of infected bines is reduced by as much as two-thirds compared to healthy bines. 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. 63). 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. 64). 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 arthropod vector. *Hop stunt viroid* has a greater tendency to move along rows

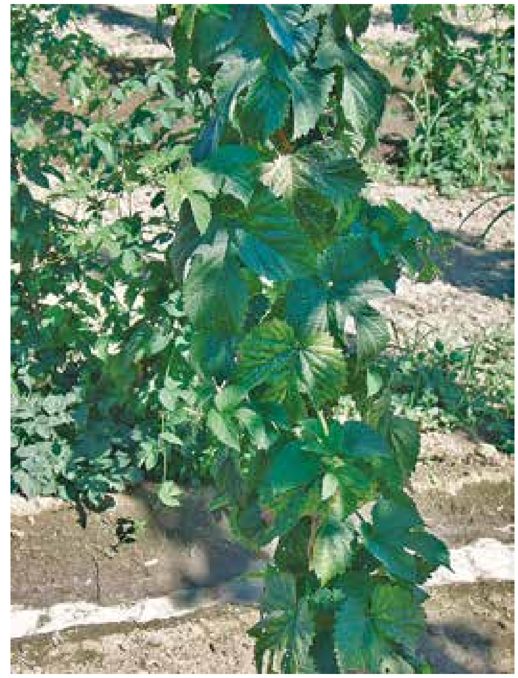


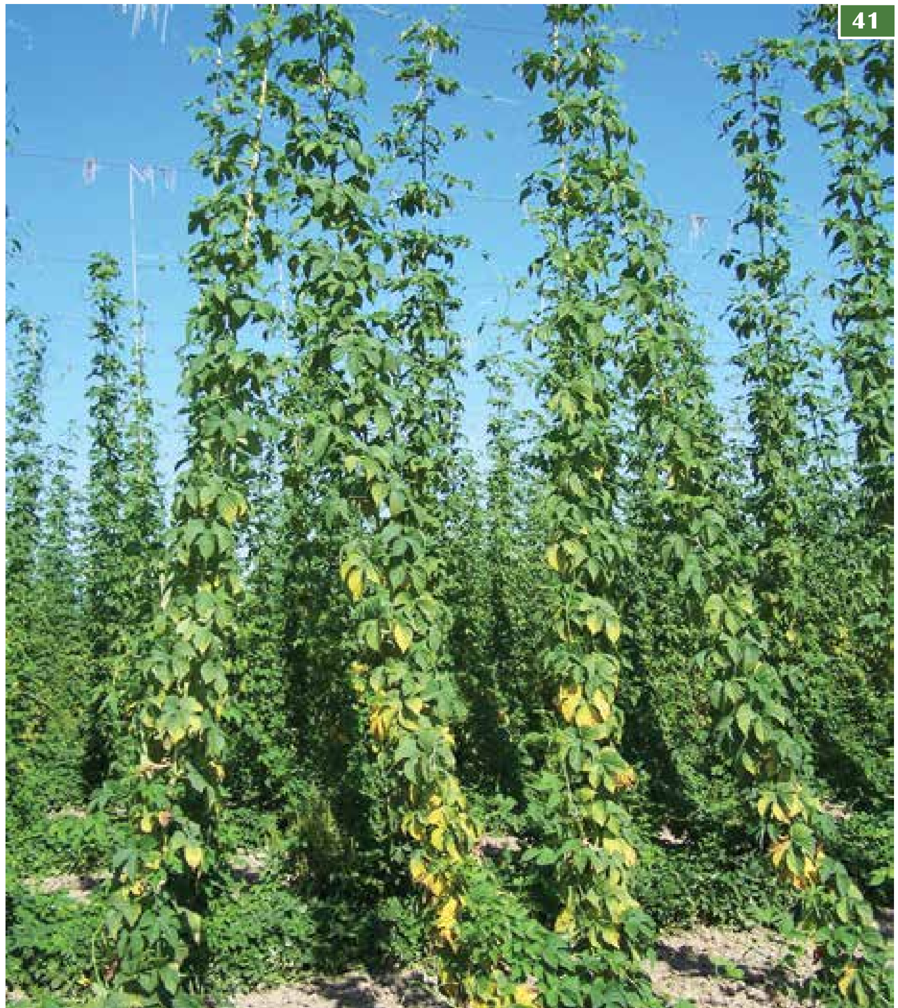
Figure 62. Pale green and yellow leaves on Willamette associated with *Hop stunt viroid*. (K.C. Eastwell)

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 in the spring, 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 substantially to transmission of the viroid.

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. If possible, 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 63. Reduced growth and sidearm development of Willamette due to *Hop stunt viroid*. (D.H. Gent)

AT RIGHT: Figure 64. Prominent yellow speckling along and between leaf veins associated with infection by *Hop stunt viroid*. (D.H. Gent)

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.

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

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

Other Viruses, Viroids, and Virus-like Agents

Kenneth C. Eastwell and Dez J. Barbara

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

Apple fruit crinkle viroid

Apple fruit crinkle viroid (AFCVd) is a sub-virus pathogen first reported to occur in hop 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 hop. 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).

Citrus bark cracking viroid

In 2007, *Citrus bark cracking viroid* was identified as the causal agent of a severe disease of hop in Slovenia. This viroid has been known as a minor pathogen of citrus in the United States since 1988, and has been identified in citrus in many countries. Currently, the outbreak in Slovenia is the only known occurrence in hop. The symptoms are described as being similar to those induced by *Hop stunt viroid* on the most sensitive cultivars. *Citrus bark cracking viroid* is easily transmitted through sap by physical contact with infected plants or contaminated equipment or workers. In Slovenia, the viroid spread very rapidly in hop. The precautions used for the management of *Hop stunt viroid* are applicable to *Citrus bark cracking viroid*.

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-acids production up to 20% in the limited number of symptomless varieties that have been studied. The variety Omega is sensitive to *Hop latent viroid* and infected plants of this variety express obvious symptoms including general chlorosis, poor growth, and retarded development of lateral branches (Fig. 65). Total alpha-acids 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 65. 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.J. Barbara)

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 hop plants 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.

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.

Other Viruses and 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.

Historical records suggest that the hop strain of *Arabis mosaic virus* occurred in North America. However, failure to detect the virus in recent widespread testing of hop plants in commercial production areas suggests that it may have been eradicated. The virus causes a range of symptoms including leaf mottling and deformation. In combination with a sub-viral satellite of *Arabis mosaic virus,* the disease known as "nettlehead" develops, which can be one of the most damaging virus diseases of hop. Some symptoms associated with *Arabis mosaic virus* are shown in Figures 66-68. *Arabis mosaic virus* is transmitted by propagation and also by the dagger nematode *Xiphinema diversicaudatum*, which is widely distributed in Europe but has an extremely limited presence in North America. A related virus, *Strawberry latent ringspot virus,* infects hop plants in eastern Europe and is also vectored by *X. diversicaudatum.* No clear symptoms have been described, and the impact on hop production is unknown.

In 2004, a phytoplasma was reported to naturally infect hop plants 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 have been reported on this continent.

Figure 66. Stunted shoots and leaf curling caused by *Arabis mosaic virus*. (A. Eppler, Justus-Liebig Universität, Bugwood.org)

Figure 67. Severe stunting of plants caused by *Arabis mosaic virus*. (A. Eppler, Justus-Liebig Universität, Bugwood.org)

Figure 68. "Nettlehead" disease caused by *Arabis mosaic virus* resulting in severe distortion. (A. Eppler, Justus-Liebig Universität, Bugwood.org)

Abiotic Diseases

Heptachlor Wilt

Mark E. Nelson and David H. Gent

At a Glance
Heptachlor Wilt

◆ Do not plant hop yards where heptachlor was previously applied.

◆ Avoid planting sensitive varieties in fields that may contain heptachlor residues.

◆ Heptachlor residues may increase hop susceptibility to Verticillium wilt.

◆ A negative soil test may not be a reliable indicator of the risk of heptachlor wilt.

Heptachlor is an insecticide that was used in the Pacific Northwest and likely other areas of the United States on several crops, 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.

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; stems may also exhibit a characteristic brown spotting that develops into a rot (Fig. 69). The bases of bines may swell and become brittle, causing them to break off from the crown. Leaves become yellow and die, followed by cone desiccation and wilting of entire bines (Fig. 70). 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 69. Stem of a plant with heptachlor wilt shows rough, corky bark as well as brown spots that can develop into a rot. (D.H. Gent)

Figure 70. Yellowing of leaves (left) and desiccation of cones (right) due to heptachlor wilt. Symptoms often are more pronounced at the top of the plant. (D.H. Gent)

Management

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

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.

Nematodes

Fred W. Warner, George W. Bird, Frank S. Hay, J Robert Sirrine, and David H. Gent

Pest Description and Crop Damage

Nematodes are non-segmented roundworms found in soil, water, and tissues of living organisms. Several species of nematodes are known to feed on hop roots. The most common species associated with hop is the hop cyst nematode, *Heterodera humuli*.

Plant-parasitic nematodes, such as those that feed on hop, are microscopic. They can impact hop directly through feeding or indirectly by creating infection sites for other pathogens or by vectoring viruses. The perennial nature of hop, the size of its root system, and its rapid growth rate during the spring suggest that hop plants may have a great capacity to tolerate nematode feeding. Nematode injury appears most likely to impact growth of young plants. Other stress factors, such as drought or heat, can exacerbate symptoms of nematode feeding.

Symptoms of nematode feeding injury on hop are likely to include general yellowing of leaves and poor growth in patches of yards that may expand over time. Plants in infested yards may be stunted, debilitated, and have reduced bine lengths. Accumulation of manganese (and, to a lesser extent, other nutrients) is reported to be impaired in young Cascade plants injured by hop cyst nematode. When symptoms occur in yards that cannot be attributed to other causes, nematodes should be considered as a possible cause.

Nematodes of Note

HOP CYST NEMATODE

The hop cyst nematode occurs in most hop production areas and is regarded as the most important plant-parasitic nematode on hop. Hop cyst nematodes generally undergo one to two generations per year. Eggs, contained within cysts, hatch into worm-like juveniles as hop plants break dormancy in the spring. The juveniles penetrate the hop roots and initiate feeding sites. Females are cream-colored, lemon-shaped, and approximately 1/20-inch long. Females can produce over 250 eggs, which are laid internally. After producing eggs, the females darken, harden, and die, forming protective cysts around their eggs.

Cyst nematodes in general are very destructive pathogens of their hosts. In addition, they are very persistent, as they can lay dormant in the soil for a decade or more in the absence of hosts.

In a study in Australia, a 38% reduction in dry weight of hops per string was observed between plants in a yard with the highest population density of *H. humuli* and those with the lowest. Losses have not been documented or quantified in U.S. hop yards, but one study indicated that high population densities are required for extensive damage.

Importantly, hop cyst nematodes may interact with *Verticillium* spp. to reduce hop growth and increase the severity of wilt symptoms.

DAGGER NEMATODES

Dagger nematodes *(Xiphinema* spp.) are a concern in perennial cropping systems where viruses are major limiting factors. Dagger nematodes are vectors of nepoviruses, the most common on fruit in North America being *Tomato ringspot virus*. The most important nepovirus in hop production is *Arabis mosaic virus* (ArMV-H), which occurs in many countries, including Canada. However, ArMV-H and its primary vector, *X. diversicaudatum,* have not been detected recently in hop grown in the U.S. The most common species of dagger nematode found in Michigan and many fruit growing regions of the U.S. is the American dagger nematode, *X. americanum*. At this point, there are no reports of *X. americanum* serving as a vector for ArMV-H. *Strawberry latent ringspot virus* is another nepovirus found in hop, but it has only been reported in Europe.

LESION NEMATODES

The lesion nematode *(Pratylenchus penetrans)* is a species of plant-parasitic nematode commonly found in temperate regions. This nematode has an extremely wide host range, causing lesions on the roots of many agricultural crops. These wounds can facilitate the introduction of soil-borne fungi, including *Verticillium* spp. It is not known whether lesion nematodes predispose hop to infection by *Verticillium dahliae* or *V. nonalfalfae* (formerly known as *V. albo-atrum*), which cause wilt in hop. See Verticillium Wilt under Diseases.

At a Glance
Nematodes

- Hop cyst nematode is the species most closely associated with hop.
- In most cases, the effect of nematodes is not sufficient to warrant control measures.
- Soil samples can reveal nematode infestation.
- Avoid planting into sites known to be infested with nematodes.
- Nematodes' role as a potential pest of hop is not well understood.

Figure 71. Sampling soil for plant-parasitic nematodes in a research hop yard. (G.W. Bird)

OTHER NEMATODES

Other nematodes known to be associated with hop include the potato rot nematode and needle nematodes. The most common needle nematode found in Michigan, *Longidorus elongatus*, has been found in hop yards in Germany but no hop yards in Michigan to date. In Michigan, it is confined to very sandy soils (>70% sand content). *L. elongatus* tends to be a very destructive nematode and it can also vector nepoviruses.

Root-knot nematodes (*Meloidogyne* spp.) cause the greatest amount of economic losses across the spectrum of agricultural crops worldwide. The northern root-knot nematode, *M. hapla*, is the most frequently encountered root-knot nematode species in temperate regions of the U.S. but has not been reported in association with hop.

Monitoring and Thresholds

As a rule of thumb, the site should be sampled for plant-parasitic nematodes before the establishment of any perennial crop to avoid future problems. While specific thresholds do not exist, infested sites remain infested and planting into them should be avoided. Hop cyst nematode females can be seen with the naked eye after they develop into egg-filled cysts and rupture through the epidermis of hop roots.

Management

Control of plant-parasitic nematodes in other perennial crops during the establishment phase has been shown to increase yields, but this has not been quantified in hop.

Avoidance is the key management strategy for nematode infestation in hop. Besides refraining from planting into heavily infested soil, planting stock should be certified as free of hop cyst nematodes. Hop cyst nematodes may be disseminated within and among hop yards in infested rhizomes and in irrigation water and floodwater. Sanitation of machinery, tools, and equipment moving within and between yards is also a key tactic in preventing the spread of nematodes.

Hop cultivars differ in their susceptibilities to hop cyst nematodes. In Oregon, cysts have been recovered from Backa, Brewer's Gold, Bullion, Fuggle, and Kent varieties, while in Idaho, Cascade was reported to be more heavily infested than other varieties.

Mocap EC (ethoprop) is labeled for use on hop in most states as a pre-plant and post-plant insecticide/nematicide. However, cyst nematodes can be difficult to control chemically and no information is available to suggest that Mocap use results in population reductions of hop cyst nematodes.

In most cases, hop seems to tolerate nematode feeding fairly well. Due to the rapid multiplication rates of most nematode species and the possible difficulties inherent in applying effective doses of nematicides, the use of these compounds is unlikely to be economical or effective once a yard has been established.

APHIDS

Hop Aphid

Amy J. Dreves and Douglas B. Walsh

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. 72). Winged forms are darker green to brown with black markings on the head and abdomen (Fig. 73). Both forms have long, slender antennae 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* that can reduce yield. *Hop mosaic virus* is discussed under Virus and Viroid Diseases.

Figure 72. Wingless hop aphid nymphs (pale white) and adults (yellowish-green) on the underside of an infested leaf. (D.G. James)

Figure 73. Winged form of the hop aphid. Notice the dark green to brown color and black markings on the head and abdomen. (L.C. Wright)

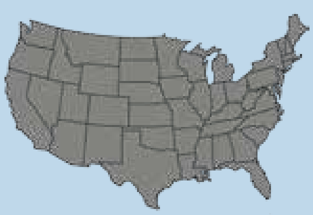
Biology and Life History

Hop aphids overwinter as eggs on ornamental and agricultural species of the genus *Prunus*, including plum, cherry plum, sloe, and damson (Fig. 74). 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,

Figure 74. Wingless hop aphids on an overwintering *Prunus* sp. (L.C. Wright)

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 is widepread in North America (Source: BugGuide.net) and should therefore be considered a potential pest throughout the U.S.

Maps are provided in this section to give a general indication of regions in which a particular pest has been found. Local conditions may vary. Even though the map may indicate the pest is not present in your area, it is best to contact your local cooperative extension office for the most up-to-date pest occurrence information.

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. 75 and 76) 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. In cooler hop-growing summer climates such as western Oregon, hop aphids can persist in substantial abundance throughout summer and may require treatment through August. In warmer summer conditions that persist in hop-growing regions such as the Yakima Valley of Washington State, aphid populations can reach densities exceeding 30 aphids per leaf in June, but crash to below detectable levels without treatment in the hot and dry conditions of July and August. In these warmer, drier climates, research has demonstrated that aphid infestation of hop yards in June does not result in a reduction in the yield and quality of hops at harvest in late August or early September if hop aphid populations never recover in August.

Figure 75. Yellow pan trap for hop aphid. (J.D. Barbour)

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.

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. In areas where multiple applications are necessary for control, it is recommended that aphicide classes be rotated to avoid resistance. Several systemic and contact activity insecticides are registered that can selectively control aphid populations while causing little harm to natural enemies of aphids and other hop pests, including some that can be applied by chemigation via the hop yard's drip irrigation system.

Figure 76. Suction trap for hop aphid. (T.M. Mowry)

BEETLES

California Prionus Beetle

James D. Barbour

Pest Description and Crop Damage

Adult California prionus *(Prionus californicus)* are large, brown to black beetles 1 to 2 inches in length with long antennae characteristic of the longhorned beetle family, to which this insect belongs (Fig. 77).

California prionus larvae are cream colored, 1/8 to 3 inches long (Fig. 78), and have strong, dark mandibles that are used to chew plant roots. Legs, though present, are small and inconspicuous. 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.

Adult California prionus beetles do not feed, but larvae feed on plant roots, resulting in decreased nutrient uptake, water stress, and reduced plant growth. Severe infestations can completely destroy crowns and kill plants. Less severe infestations cause wilting, yellowing, and death of one or more bines (Fig. 79). Feeding damage is likely to be associated with the occurrence of secondary crown rot pathogens.

Biology and Life History

Mature larvae pupate in the soil during early spring in cells constructed from soil and lined with root material. Pupae are 1 to 2 inches long, cream colored, and look like pale, mummified versions of the adult.

Adult California prionus beetles in the Pacific Northwest emerge from pupation sites 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.

Figure 77. Adult California prionus beetles (left, male; right, female). Adult beetles are 1 to 2 inches long with prominent antennae. (J.D. Barbour)

Figure 78. California prionus larva feeding in a hop crown. Larvae are cream colored, legless, and range in size from 1/8 to 3 inches long. 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 79. Wilting, yellowing, and death of bines caused by California prionus feeding damage. (J.D. Barbour)

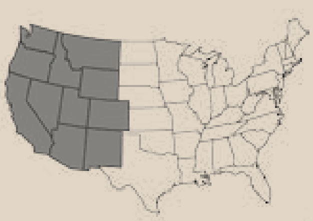
At a Glance
California Prionus Beetle

◆ Monitor for beetle presence using pheromone traps.

◆ 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' range is western North America. (Source: BugGuide.net)

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. Males can also be captured at traps baited with a synthetic version of the mating pheromone released by females. Economic thresholds and economic injury levels based on capture of males at light or pheromone traps have not been established.

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 in a mating disruption program is currently being investigated. Research indicates that male beetles have difficulty locating females in areas where dispensers emitting pheromone are deployed: when dispensers containing 50 mg of synthetic pheromone are deployed at the rate of 100 per acre, capture of males at traps containing low-dose lures (mimicking calling female rate) is reduced by more than 90% compared to capture at similar traps in areas where pheromone dispensers are not deployed (Fig. 80). The pheromone also can be used to monitor for the presence of beetles in hop yards.

Ethoprop (Mocap EC) is labeled for control of California prionus in hop. The long preharvest 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.

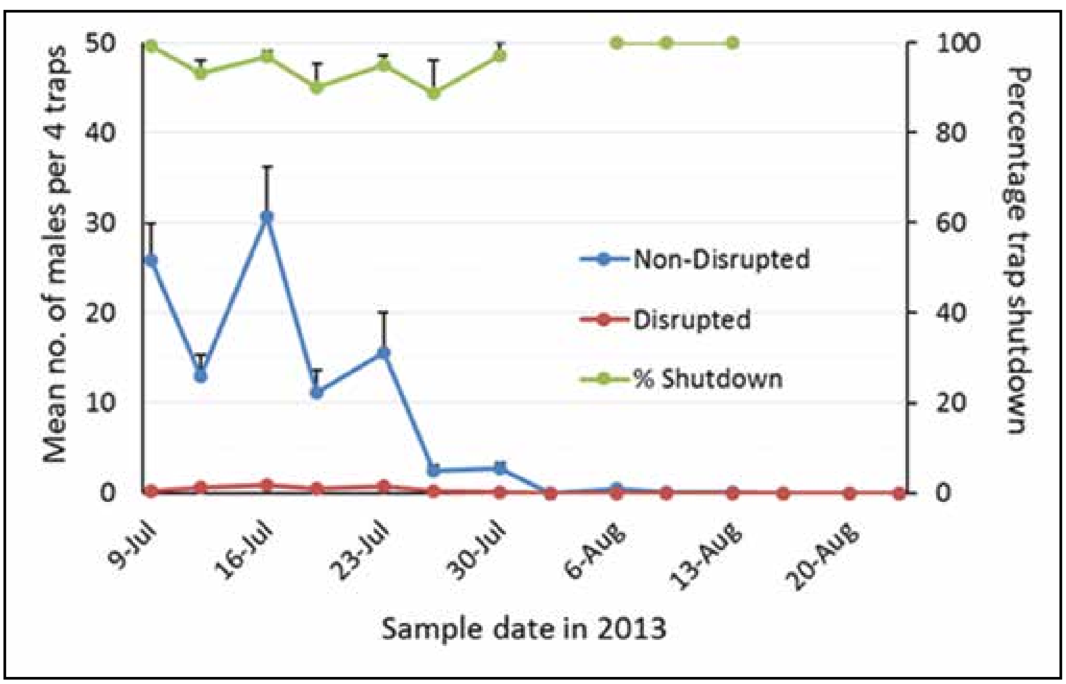


Figure 80. Mean number of males captured per four traps in mating-disrupted plots and non-disrupted plots and percentage trap shutdown in mating-disrupted plots in commercial Idaho hop yards in 2013. Disrupted plots contained 100 dispensers per acre, each containing 50 mg of synthetic *P. californicus* mating pheromone. Non-disrupted plots contained no pheromone dispensers. Both mating-disrupted and non-disrupted plots were at least 2 acres in size and each contained four traps baited with low-dose pheromone lures that mimicked a calling female.

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. 81) 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. 82). 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 and may occur in hop growing regions east of the Rocky Mountains.

Figure 81. 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 and other protected areas such as under bark and within cracks in poles. 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 to leaves and roots. Larger plants can withstand more feeding injury than smaller plants; baby hops may be susceptible.

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.

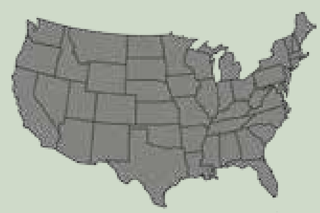
Figure 82. Severe feeding damage caused by hop flea beetle resulting in a "shothole" appearance. (F. Weihrauch)

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 such as mustards are nearby.

◆ Need for treatment is unlikely, especially in mature hops.

◆ Certain insecticides applied for aphid control usually control flea beetles.



While the exact range of hop flea beetle is not known, *Psylliodes* spp. are cosmopolitan (Source: BugGuide.net) and should therefore be considered a potential pest throughout the U.S.

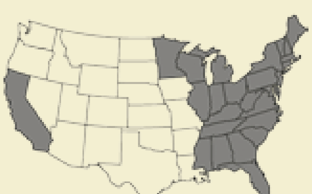
At a Glance
Japanese Beetle

◆ Adults feed on surface of leaves and may feed on flowers, burrs, and cones.

◆ Their tendency to aggregate makes them easy to spot in the hop yard.

◆ New, small, or stressed plants may sustain more damage.

◆ Consider spot treatments when infestation levels warrant chemical intervention.



Japanese beetle has been reported in all states east of the Mississippi River and in California.

Japanese Beetle

Erin Lizotte

Pest Description and Crop Damage

Japanese beetles *(Popillia japonica)* are native to Japan and were first documented on the East Coast of the U.S. in the early 1900s. Populations have slowly spread west and are now present in much of eastern Canada and every state east of the Mississippi River. The beetle was also reported in California in 2005. Adults are 3/8 to 1/2 inch long with a metallic green thorax and copper-colored wing covers. Adults have 12 distinct tufts of white hairs on the abdomen; the legs and head are black (Fig. 83). Japanese beetle larvae are white, C-shaped grubs that live in the soil. The larvae vary in size from 1/8 inch when newly hatched to about 1 inch when fully grown.

Adult Japanese beetles aggregate, feed, and mate in large groups after emergence, often causing severe and localized damage (Fig. 84). They feed on the top surface of leaves, skeletonizing the tissue between the primary leaf veins (Fig. 85). If populations are high, they can remove all of the green leaf material from entire plants. Japanese beetles may feed on other plant parts, including developing burrs and cones.

Biology and Life History

Japanese beetles overwinter as larvae in the soil, feed on grass roots in the spring, and pupate into adults in early summer. Adult emergence varies depending upon latitude, temperature, and day length. Adults lay eggs in soil and on turf from summer to early fall. Larvae hatch from the eggs about 10 days later and feed on grass roots. If adequate moisture is available from rain or irrigation, the grubs will molt to second and then third instars by fall. As temperatures drop in the fall, larvae migrate deeper into the soil to avoid the frost, moving back up to feed on grass roots in the spring.

Figure 83. Adult Japanese beetle on hop plant. Note the diagnostic 12 white tufts of hair along the abdomen and the metallic green thorax. (E. Lizotte)

Monitoring and Thresholds

Visually inspecting the hop yard for Japanese beetles should be standard scouting protocol for growers east of the Mississippi River. Due to their aggregating behavior and substantial size, Japanese beetles are typically easy to detect but may be highly localized in the hop yard, requiring a thorough site inspection. Feeding damage can be missed when it initiates in the upper parts of hop plants; scouts should inspect the entire plant for damage. Baited pheromone and floral traps are commercially available and may be useful for detecting emergence and severity. However, traps often attract adult Japanese beetles, which can contribute to damage, therefore traps are not considered a commercially viable control option.

At this time there is no established treatment threshold for Japanese beetles in hop. Established, unstressed, and robust plants can likely tolerate a substantial amount of leaf feeding before any negative effects occur. If burrs or cones are being damaged, however, a more active management approach may be warranted. Those managing hop yards with small, newly established, or stressed plants should take a more aggressive approach toward Japanese beetle management, as plants with limited leaf area and those already under stress will be more susceptible to damage.

Management

Adult Japanese beetles feed on hundreds of different plant species, adapting easily to a variety of landscape types. This, coupled with the pests' aggregating behavior, makes reinfestation a constant and frustrating management challenge for growers. Some studies have shown differences among hop varieties in the effect of Japanese beetles, with Chinook and Cascade having lower levels of damage, and Hallertau and Northern Brewer having the greatest.

A number of registered pesticides are available in the eastern U.S., where Japanese beetles are prevalent. Japanese beetles are difficult to control and are most effectively knocked back with broad-spectrum insecticides, including organophosphates and pyrethroids. Unfortunately, due to their toxicity to beneficial mite predators, use of these broad-spectrum insecticides, particularly in mid to late summer, can induce twospotted spider mite outbreaks. Research in fruit crops has shown that pyrethroid insecticides that are registered on hop, including bifenthrin and beta-cyfluthrin, have good contact activity against adult beetles and can provide seven to 10 days of residual control. Malathion is an effective broad-spectrum organophosphate that is also registered for use on hop. Based on research in fruit crops, it can take up to three days for malathion to take effect; it provides 10 to 14 days of residual control.

Growers may also apply a registered neonicotinoid insecticide such as imidacloprid or thiamethoxam. Neonicitinoids are easier on beneficial predatory mites, but have been shown to contribute to increased pest mite populations by increasing female mite longevity and fecundity when they are exposed to sublethal doses. Neonicitonoids should provide contact toxicity for two to five days as well as residual antifeedant activity against Japanese beetle adults based on efficacy trials in fruit crops.

Pesticides approved for use in organic production include neem-based products like azadirachtin, which should provide one to two days of residual activity and good contact toxicity. Surround, a kaolin clay based particle film, has shown good efficacy against Japanese beetles in blueberry and grape plantings. Surround leaves a white, dusty film on the plant that acts as a physical barrier and irritant; therefore it requires excellent coverage to be effective.

Figure 84. Adult Japanese beetles mating and feeding on hop. (E. Lizotte)

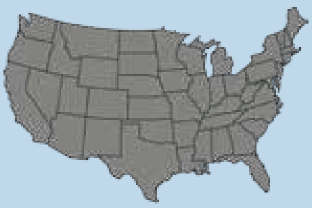
To help mitigate the negative effects of insecticide applications on mite populations, growers should consider spot treatments to heavily infested areas. Refer to pesticide recommendations appropriate to your region, and always read and follow the pesticide label.

Application of parasitic nematodes to soil to control Japanese beetle larvae is generally not an effective means of reducing damage by adults in the hop yard. While nematodes may reduce grubs in the soil, hop foliage will still be damaged by adults flying in from other, untreated areas.

Figure 85. Skeletonized hop leaf damaged by Japanese beetle feeding. (E. Lizotte)

At a Glance
Root Weevils

◆ While both adults and larvae feed on hop, root damage by larvae is the most problematic.



Root weevils are widely distributed in the U.S.

Figure 86. Adult black vine weevil with characteristic bowed antennae and mouthparts at the end of a long snout. (D.G. James)

Figure 87. Root weevil larva. (P. Greb)

Root Weevils

James D. Barbour

Pest Description and Crop Damage

Root weevils are beetles with elbowed antennae and long snouts (Fig. 86). Several species, including strawberry root weevil *(Otiorhynchus ovatus)*, rough strawberry root weevil *(O. rugosotriatus)*, and black vine weevil *(O. sulcatus)* attack hop. The black vine weevil is the largest and most common of these in hop, however, the life cycle, appearance, and damage caused by these species are similar. Most adults are oblong, gray to black beetles ~½ inch long; the strawberry root weevil is ~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 heads (Fig. 87).

Economic losses can result from larvae feeding on the roots of hop plants (Fig. 88). 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 feeding damage caused by black vine weevil larvae. Heavy infestations may require that individual plants or, rarely, even whole hop yards be removed from production.

Adult weevils feed on leaf edges, creating rough notches, and sometimes (when populations are high) on leaf interiors, but this feeding is not known to cause economic loss (Fig. 89). Weevil feeding often can be distinguished from caterpillar feeding by the more ragged feeding notches and lack of frass and because weevils feed during the evenings and are not present during the day like caterpillars. In addition, caterpillar feeding generally moves up the plant while weevil feeding remains near the hop yard floor.

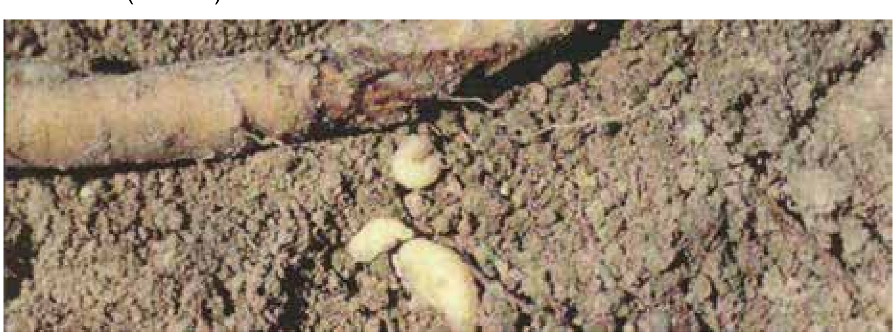


Figure 88. Root weevil larvae and associated feeding injury on a root. (C. Baird)

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. 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

Adult weevils can be monitored (typically beginning in April) with the use of grooved boards and pitfall traps. 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. Application should be timed to coincide with presence of late-instar larvae, soil temperatures above 50°F, and adequate soil moisture. Scientific evidence for application timing is lacking, but growers who manage weevils with nematodes tend to apply them in late summer or fall, intending to reduce abundance of large larvae feeding on roots in the spring. Similarly, growers tend to apply foliar insecticides approximately three weeks after adult emergence but before egg laying begins. Applications may be more effective at night when adult weevils are most active.

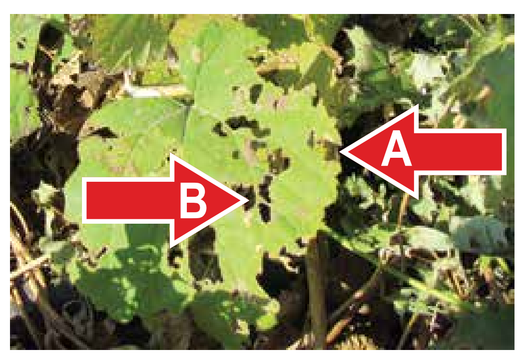


Figure 89. Adult black vine weevil feeding typically notches leaf edges (A) and less typically is seen on leaf interiors (B). (T. Brooks)

Rose Chafer

Melanie Filotas

Pest Description and Crop Damage

The rose chafer *(Macrodactylus subspinosus)* is a native beetle related to June and Japanese beetles. It is found predominantly in northeastern North America, but has been detected as far west as Colorado. Adults are elongate, tan-colored beetles approximately ½ to 5/6 inch in length, with long, spiny, reddish-brown to orange legs and wings that do not completely cover the abdomen (Fig. 90). Newly emerged adults are covered in yellow hairs that wear off the head and thorax over time, revealing a black color. The larvae are white, C-shaped grubs with a dark head capsule and three pairs of legs, approximately 0.6 to 0.75 inches long at maturity. Larvae are often difficult to find.

Rose chafer adults tend to aggregate in large numbers on the buds, blossoms, fruit, and foliage of a wide variety of plants, including grape, rose, and a number of other landscape and fruit species. On hop, rose chafers feed on leaf tissue between veins, skeletonizing them (Fig. 91). They will occasionally feed on developing flowers, burrs, and cones. While they can cause considerable localized defoliation, they typically are patchy in distribution and rarely infest entire hop yards. Rose chafer tends to be a more sporadic pest of hop than Japanese beetle.

Biology and Life History

The rose chafer life cycle is similar to that of Japanese beetle, overwintering as older larvae in the soil and moving up in the spring to feed on the roots of grasses until they pupate. Rose chafer adults emerge earlier than Japanese beetles, typically in late May or early June. Adults often appear suddenly and in large numbers. The adults feed and mate for three to four weeks, laying eggs in groups in sandy soil. The eggs hatch about one to three weeks later, and the young larvae feed on plant roots until the soil temperature drops in the fall, when they move below the frost line to overwinter.

Rose chafers contain a toxin that can kill birds and small animals if ingested.

Monitoring and Thresholds

Rose chafers are best monitored by visual inspection of plants from top to bottom during routine scouting of hop yards in May and June. Due to their size, adults are easy to detect. Due to their patchy distribution, however, they can be very localized both within a single hop yard and between yards, with some yards never experiencing a problem. Rose chafers often appear in the same spot over multiple years, so locations with a problem one year should be checked in subsequent years.

There is no established threshold for rose chafer on hop. Established hop yards and healthy plants can likely tolerate substantial defoliation without significant negative effects. Small, newly established, or stressed plants will be more susceptible to feeding damage and may require more aggressive management. Similarly, substantial damage to marketable tissue, such as burrs and cones, may also warrant more aggressive management.

Management

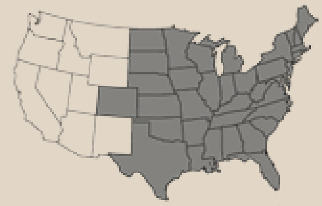
Where only a few beetles or a very localized infestation is present on small plants, it may be possible to physically remove and destroy these beetles, but they are often distributed too high in the hop canopy for this to be practical.

Pheromone traps are available for rose chafer, and intensive, mass trapping of adults over several years has been known to help reduce populations in other crops. However, as with Japanese beetle, use of traps can attract large numbers of adults from other areas, so use of traps as a control method is generally not recommended in hop. Rose chafer adults are attracted to sandy, grassy areas to lay eggs, so use of non-grass cover crops on sandy areas in and around hop yards may cause some beetles to seek new egg-laying sites.

While few insecticides are registered for rose chafer on hop, many Japanese beetle products may have incidental efficacy against rose chafer. As with any arthropod management, broad-spectrum insecticides will also negatively affect the beneficial insect complex and may lead to secondary outbreaks of twospotted spider mite.

At a Glance Rose Chafer

◆ Similar in some respects to Japanese beetle, rose chafer is a more sporadic pest of hop.



Predominantly found in NE North America, rose chafer has been detected as far west as Colorado.

Figure 90. Adult rose chafer on hop plant. Note the spiny, reddish-brown legs and yellow hairs covering the body, which wear away with age, revealing darker areas underneath.*

Figure 91. Adult rose chafer feeding on hop. Note the skeletonized damage.*

*(M. Filotas, © Queen's Printer for Ontario, 2015. Reprinted with permission.)

Western Spotted Cucumber Beetle

James D. Barbour

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.

While other spotted cucumber beetles are widely distributed, this species is found only in Arizona, California, Colorado, and Oregon. (Source: BugGuide.net)

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. 92). 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 1,200 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.

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 cucumber beetles.

Figure 92. Adult western spotted cucumber beetle. (J.N. Dell, Bugwood.org)

Garden Symphylan

Amy J. Dreves and Douglas B. Walsh

Pest Description and Crop Damage

Garden symphylans *(Scutigerella immaculata)* are small (1/8 to ¼ inch long), white, centipede-like animals with long, beaded antennae (Fig. 93). Newly hatched nymphs resemble adults but have six pairs of legs. As they grow, they add a new pair at each of six subsequent molts; adults have 12 pairs of legs. The eggs are pearly white, spherical with ridges, and are laid in clusters in the soil.

Symphylan species are ubiquitous in the environment. *Scutigerella immaculata* feeds below ground on fine roots and above ground on growing plant parts in contact with soil. In hop, this pest typically is not damaging to established plants, but can be problematic in new plantings (Fig. 94).

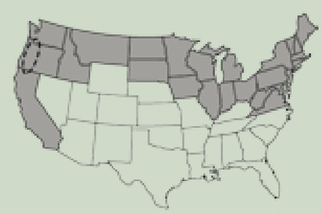
Conditions that favor symphylan activity include areas with high moisture and heavy soils with a high organic matter content. Under dryer, more mild

Figure 93. The centipede-like garden symphylan. Adults are 1/8 to 1/4 inch long. (Ken Gray Image Collection, Oregon State University)

Figure 94. 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)

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.



While present in the western, north central, and northeastern U.S., garden symphylans are primarily known to be a pest of hop in the cool, moist growing region of western Oregon.

conditions and in hop yards with relatively loose soils, the vigor of hop plants enables them to outgrow deleterious impacts of the garden symphylan. When conditions favor garden symphylan, their feeding can reduce vigor (Fig. 95), resulting in stunted plants, poor plant establishment in newly planted yards, and, in relatively rare instances, early decline of established plantings. Root damage from garden symphylan feeding also may increase plant susceptibility to soil-borne pathogens.

Biology and Life History

The garden symphylan spends its entire life in the soil or in plant material and debris that contact 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.

Figure 95. Stunting, weak growth, and yellowing of leaves caused by garden symphylan feeding injury. (W.F. Mahaffee)

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, then search the soil surface and plant parts in contact with the soil for garden symphylans. Another method to assess garden symphylan presence is to bait for symphylans in early spring (prior to planting in new fields) 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. A final method is to take soil samples at a depth of 6 to 12 inches during fall or early spring, break the soil samples up on a piece of dark plastic or cloth, and look for symphylans. No threshold has been established for garden symphylan in hop.

Management

Established plantings can tolerate moderate symphylan damage, however, management can be important 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 can kill symphylans directly or can result in mortality indirectly by exposing them to desiccation and predators. Care must be taken to avoid cultivating too close to 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 hop varieties are considered resistant.

Several insecticides are available for symphylan management. When needed, they 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.

LEAFHOPPERS

Potato Leafhopper

Lilian B. Calderwood and Heather M. Darby

Pest Description and Crop Damage

Potato leafhopper *(Empoasca fabae)* is a light green, wedge-shaped insect that can be found scuttling on the underside of leaves of hop and other plants. Adults are about 1/8 inch long; first-instar nymphs are about half that size (Figure 96). Potato leafhoppers feed with piercing-sucking mouthparts on host plant vascular tissue. This restricts phloem and, eventually, xylem flow to the rest of the leaf, resulting in leaf edge yellowing and curling in addition to stunted internode growth. Visual damage caused by potato leafhopper ("hopperburn") can be seen five to seven days after feeding has occurred (Figure 97).

Potato leafhopper feeds on more than 200 broadleaf plants. It was first documented as a pest of hop in New York during the 1940s and has once again been reported to cause damage to hop plants. In some cases this injury has been observed to kill first-year hop plants.

Biology and Life History

Potato leafhopper does not normally survive the winter at northern latitudes. Rather, adult females overwinter on southern pine and migrate north on spring trade winds. Typically, adult females arrive in the Midwest about 30 days before arriving in the northeastern U.S. Upon arrival, they feed and lay eggs in hop leaf and stem tissue. Nymphs hatch three to 10 days after oviposition. The wingless nymphs go through five instars over the course of 10 to 14 days before molting into winged adults. In another seven to 10 days, females begin oviposition. On average it takes three weeks for an egg to develop into an adult. Eggs and nymphs can develop at temperatures between 50 and 75°F.

The number of generations of potato leafhopper depends on temperature and their arrival date in spring—three generations per season have been observed in northern Vermont with four generations likely in warmer climates.

Monitoring and Thresholds

Economic thresholds have yet to be developed for potato leafhopper in hop. Pest management specialists recommend scouting the underside of three leaves per hop plant per cultivar weekly in regions where this pest is considered problematic.

Management

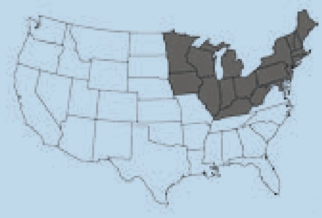
Data are limited regarding management of potato leafhopper in hop. They may prefer certain cultivars. Scouting data in Vermont has consistently, albeit anecdotally and on small plots, shown that potato leafhoppers are more prevalent on Liberty, Fuggle, Mt. Hood, Tettnanger, Santium, and Newport. Variety selection, therefore, may help reduce leafhopper damage in hop.

Some growers with small hop yards plant a trap crop (vegetation intentionally planted to draw an insect pest away) with the intent of reducing potato leafhopper damage to hop. In a 2014 Vermont study, unmowed red clover planted in the drive row served as a trap crop for potato leafhopper. Significantly more leafhoppers were collected from hop plants where the drive row was mowed grass than from hop plants with established, unmowed red clover in the drive row.

Natural enemies of potato leafhopper present in eastern U.S. hop yards include minute pirate, big-eyed, and damsel bugs; green and brown lacewings; ladybird beetles; parasitoid wasps; and spiders. At this time, application of insecticides to control potato leafhopper is recommended only if high numbers are present on first- or second-year hop plants. Eastern organic growers have found that products containing azadirachtin or pyrethrins can be effective against potato leafhopper. Products with active ingredients beta-cyfluthrin or imidacloprid are used for potato leafhopper control in other crops under conventional management. Use of broad-spectrum insecticides to control potato leafhopper may lead to secondary outbreaks of other pests such as twospotted spider mite.

At a Glance
Leafhoppers

- Feeding by potato leafhopper can restrict flow within hop vascular tissues.



While widespread in North America, potato leafhopper is considered a pest of hop primarily in the Midwest and northeastern U.S.

Figure 96. First, second, and third instar potato leafhopper nymphs.*

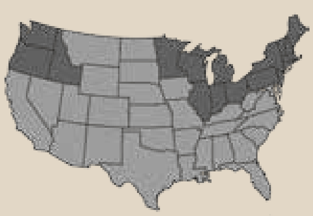
Figure 97. Hopperburn: Visual V-shaped chlorosis injury caused by potato leafhopper.*
*(UVM Extension Northwest Crops and Soils Team)

At a Glance
Lepidopteran Larvae

◆ In the Pacific Northwest, only the hop looper, bertha armyworm, and common gray moth caterpillar typically reach damaging population levels.

◆ Not all moth and butterfly species are present in all hop growing regions.

◆ Caterpillars (larvae) can defoliate hop plants when present in large numbers.



Hop looper is known in Pacific Northwest and northeastern U.S. hop-growing states and should be considered a potential pest of hop throughout the U.S.

LEPIDOPTERAN LARVAE

James D. Barbour, Charlie L. Rohwer, Christopher R. Philips, and Chelsea A. Gordon

Pest Description and Crop Damage

The larvae (caterpillars) of numerous moths and butterflies are known to attack hop. These include hop looper *(Hypena humuli)*, bertha armyworm *(Mamestra configurata)*, common gray moth *(Anavitrinella pampinaria)*, red admiral *(Vanessa atalanta)*, eastern comma *(Polygonia comma)*, question mark *(Polygonia interrogationis)*, redbacked cutworm *(Euxoa ochragaster)*, spotted cutworm *(Amathes c-nigrum)*, European corn borer *(Ostrinia nubilalis)*, omnivorous leaftier *(Cnephasia longana)*, obliquebanded leafroller *(Choristoneura rosaceana)*, hop vine borer *(Hydraecia immanis)*, rustic rosy moth *(Hydraecia micacea)*, and fall webworm *(Hyphantria cunea)*. Lepidopteran larvae can defoliate hop plants when present in large numbers. Levels of damage depend upon region and infestation level.

In the major hop growing states of the Pacific Northwest, only the hop looper, bertha armyworm, and common gray moth typically reach damaging populations. The adults of each of these 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, which is present but less distinct in males (Fig. 98). Both sexes have an elongate "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. 99).

Hop looper larvae are pale green with two narrow, white lines on each side of the back and one on each side (Fig. 100). 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. They reach a length of approximately 1 inch at maturity. When disturbed, small larvae drop to the ground on a silken thread, while

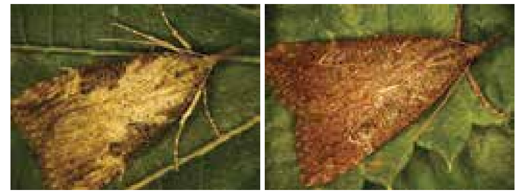


Figure 98. Left, female hop looper. Right, male hop looper. Notice the distinct W-shaped dark patch along the front edge of each forewing of the female. (D.G. James)

Figure 99. 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)

Figure 100. Hop looper larva is pale green with narrow white lines. (D.G. James)

Figure 101. Hop looper feeding results in a characteristic lacey appearance. (D.G. James)

Figure 102. Bertha armyworm larva has a dark back and yellow to orange stripe. (D.G. James)

larger larvae may thrash violently from side to side. When present in large numbers, hop looper larvae can defoliate hop plants, giving them a characteristic lacey appearance (Fig. 101). 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 crop damage.

Bertha armyworms are dark-backed caterpillars with a yellow to orange stripe on each side and a tan to light brown head (Fig. 102) 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 heads, 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. As with hop loopers, bertha armyworm larvae defoliate hop plants, but decreases in hop yield are caused when armyworm feeding severs stems, causing cones to fall to the ground.

Common gray moth larvae are light brown, resembling twigs (Fig. 103). They have a flat “face” and are mottled with tan, white, black, and occasionally pink. Two raised, dark dots appear on the back.

Red admiral butterflies are black or dark brown with a prominent red band on both the forewing and the hind wing. Its wingspan approaches 2 inches. Larvae of the red admiral butterfly have been found on young hops during May in Oregon, sometimes in numbers sufficient to alarm growers and trigger the use of insecticides. However, these attacks are transient, with summer generations of the butterfly feeding on stinging nettles and unlikely to be damaging to hops.

The eastern comma and the question mark range throughout much of the eastern U.S. and southern Canada, south to northern Florida and the northern Gulf Coast states and west to Arizona, eastern Wyoming, and Colorado. When viewed from the top, the adult butterflies of both species are orange with dark markings (Fig. 104). The undersides of their wings are mottled brown resembling leaf litter or bark (Fig. 105). Their size varies from 2.5 to 3 inches. The eastern comma has a spot that resembles a comma, while the question mark has a set of small spots that resembles a question mark. The larvae of both species vary in color and are

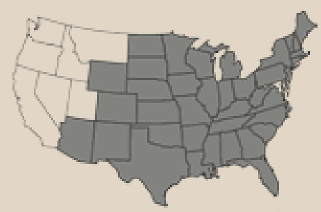
Figure 103. Common gray moth larvae are light brown and resemble twigs. Ubiquitous in most U.S. hop-growing states, they are one of the more damaging caterpillars in the Pacific Northwest. (T. Murray)

Figure 104. The question mark butterfly has a pattern of dots on the top surface of its wings said to resemble a question mark. (C.A. Gordon)

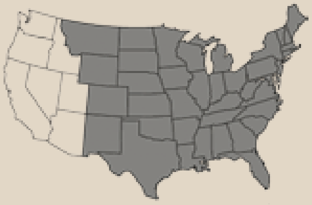
Figure 105. The underside of a question mark butterfly’s wings. (C.A. Gordon)

Bertha armyworm’s range includes the western U.S. as far east as Texas. (SOURCE: BugGuide.net)

Lepidopteran pests considered present or potentially present throughout the continental U.S. include common gray moth, red admiral butterfly, and a number of Noctuid moths (the larvae of which are called cutworms).

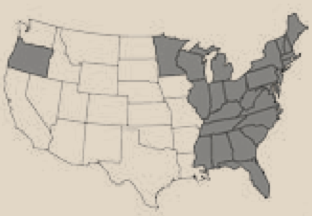


Eastern comma and question mark butterflies are known throughout the eastern U.S. and ranging west as far as Arizona and eastern Wyoming.



European corn borer is an eastern U.S. pest ranging west to the Rocky Mountains.

Omnivorous leaftier is known in Washington and California (SOURCE: BugGuide.net) as well as Oregon, where it is considered a nut tree pest (SOURCE: insect.pnwhandbooks.org)



Obliquebanded leafroller is common throughout eastern North America and also present in Oregon hop yards. (SOURCES: BugGuide.net, D.H. Gent)

covered in spines. Eastern comma larvae can vary from white to greenish-brown to black, with spines varying from black to white with black tips. Question mark larvae are black with white or yellow lines and spots. On some specimens, the white or yellow lines and spots are so predominant that the larvae appear yellow in color. Their spines can be yellow-orange or black. Either species can feed voraciously on hop leaves, defoliating hop plants when present in large numbers (Fig 106). The eastern comma is also known as the "hop merchant" because growers in the early 1900s would base their projections for the year's prices on the luster of its chrysalis.

Cutworms are the larval (caterpillar) stage of Noctuid moths and dwell in the soil (Fig. 107). Their color varies, but cutworms are mostly dark with distinct dorsal markings (e.g., spots or stripes). The skin is usually smooth and glassy.

European corn borer adults are small, tan night fliers about ½ inch long. At rest, they hold their wings over the body, making a triangle. Eggs are oval, flattened, and creamy, darkening to a beige or tan, and are deposited on the underside of leaves in an overlapping pattern. Larvae are light brown or pinkish gray with a brown to black head and a yellowish-brown thoracic plate with round, dark spots on each body segment. Pupae are yellowish-brown, ½

Figure 106. Bine defoliated by question mark feeding. (C.A. Gordon)

Figure 107. Cutworms are Noctuid moth caterpillars. (D.G. James)

Figure 108. Bine exhibiting tunneling by and frass from European corn borer. (J.L. Obermeyer)

Figure 109. This bine was killed by tunneling activity of the European corn borer. (J.L. Obermeyer)

Figure 110. Obliquebanded leafroller adult (moth) on hop leaf. (J.L. Obermeyer)

Figure 111. Leafroller larva. Note yellow-green color and dark head. (J.L. Obermeyer)

Figure 112. Fall webworm webbing can encase bines and be a nuisance for harvest workers. (J.L. Obermeyer)

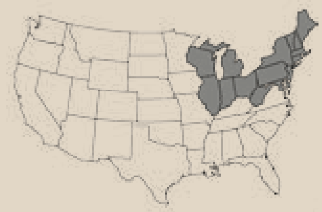
to 2/3 inch long and about 1/8 inch wide. This pest damages hop when its boring disrupts vascular tissues (Fig. 108), which can weaken or kill the bine above the feeding site (Fig. 109) and also can create potential opportunities for infection by pathogens.

Omnivorous leaftier adults are tan moths with an approximate wingspan of ½ inch. Larvae are off-white to orange with a tan head and are a bit longer than ½ inch. They have been known to feed on hop in early spring.

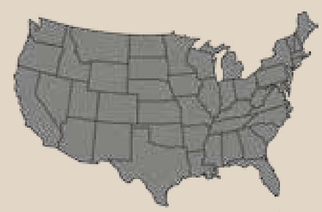
Obliquebanded leafroller adults are 1/3 to ½ inch long with wingspans of ¾ to 1 inch. Their forewings are reddish-brown and crossed by three oblique, chocolate brown bands (Fig. 110). Eggs appear as greenish-yellow masses, laid on the upper surface of leaves. The larvae, which are approximately 3/4 inch long, are yellowish-green with a black or brown head (Fig. 111), and pupae are dark brown, about ½ inch long, and usually found in rolled leaves. Foliar feeding by obliquebanded leafroller is not a major concern on hop, but larvae are reported to feed on cones in some regions. Some Oregon growers use insecticides to control this pest.

Both the hop vine borer and the rosy rustic moth are pinkish-brown adults with 1-1/4- to 1-1/2-inch wingspans. Eggs are brown and oval, often laid in parallel rows hidden under dried grass leaves and sheaths. Hop vine borer larvae have a brownish-red head with square purple or brown spots running along the back and similarly colored lines along the sides. Rosy rustic moth larvae have a similar head and pink-hued bands of color. Pupation takes place in the soil; pupae are dark brown and approximately ½ to 1 inch long. Immature larvae of the hop vine borer have historically been known to bore into the hop plant stem or growing point, killing the shoot and feeding internally or externally on belowground tissue, severely weakening plants. Very little damage has been reported recently, but historic losses from 10 to 50% were reported in New York in the late nineteenth century, when hop vine borer was one of the leading pests of hop.

Fall webworm, in addition to feeding on hop plants in the manner of the other Lepidopteran larvae, create webs that are a nuisance for workers at harvest (Fig. 112). Introduced in the 1940s from Yugoslavia, it is present throughout the U.S.



Hop vine borer is known in the northeastern U.S. (Massachusetts) and west to Wisconsin, spreading southward and westward. (SOURCE: BugGuide.net) Range of the rosy rustic moth is likely similar.



Fall webworm is present throughout the U.S. (SOURCE: BugGuide.net)

At a Glance
Lepidopteran Larvae

◆ 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.

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. 113), 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. 114). 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. 115) 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.

Common gray moth is present throughout the continental U.S. The larvae feed on apple, ash, clover, elm, pear, poplar, and willow trees as well as hop. In Washington State, the common gray moth can outbreak and be one of the predominant caterpillar pests of hop.

Eastern commas and question marks have not been considered economically important pests in hop for many years, due to the vast majority of U.S. hops being grown in the Pacific Northwest, where they are not known to occur. With production increasing in the Great Lakes states and eastern North America, however, these caterpillars are potential pests to watch. Both have been known, historically and in other parts of the world, to feed on hop plants. When present, these caterpillars tend to feed at night. During the day, they can be found on the underside of hop leaves. Eastern comma larvae may roll leaves around themselves during the daytime. In addition to hop, the larvae feed on American elm, nettles, false nettles, and hackberry. Typically both species have two generations per year. They overwinter as adults in cracks and crevices of rocks and trees. Overwintered adults fly into hop yards in the spring to lay eggs singly or in stacks on the underside of leaves or on stems. The summer brood emerges as larvae to feed on hop leaves until they pupate. The pupae vary in color from tan to dark brown with two rows of gold or silvery-white spots (Fig. 116). Pupae can be found attached to the underside of hop leaves by silk. The adults that emerge from these pupae are present throughout the summer, laying eggs that

Figure 113. A slightly flattened, circular egg of the hop looper. Eggs are laid singly. (D.G. James)

Figure 114. Pupating hop looper. (D.G. James)

Figure 115. Egg mass of the bertha armyworm. Eggs are laid in groups of 50 to 100 or more. (D.G. James)

will develop into the winter brood. Adults feed on rotting fruit and tree sap. Question mark adults have also been observed feeding on dung and carrion.

Cutworms are nocturnal, emerging from the soil at night to feed on foliage and buds. They are pests on early-season growth. Heavy infestations can defoliate newly trained bines and destroy the growing tip of new shoots.

European corn borer is polyphagous, feeding on over 200 different host plants throughout the U.S. east of the Rocky Mountains. Its eggs hatch four to nine days after oviposition. Its number of generations varies from one to four, depending upon region and weather conditions. In northern New England and Minnesota, one generation is typical, while three to four generations occur from Virginia south. In areas with one to two generations annually, the first adult moths usually occur during June to July and August to September.

Obliquebanded leafroller is common throughout eastern North America. Eggs hatch 10 to 12 days after oviposition. Its larvae are pests of fruit trees (apple, cherry, peach, pear), holly plants, oak trees, pine trees, rose bushes, and other woody plants. Two generations per year are typical over the majority of its range, with one generation in northern areas and at higher elevations. Adults are present in late June to July and again in late August to September.

Hop vine borer is a native pest, while the closely related rosy rustic moth is an introduced pest. Both feed on numerous crops and are considered pests of corn, which is a concern to hop growers in areas where vast acreage of corn is grown. Both species overwinter and hatch on grasses as new shoots emerge. Controlling weeds near hop yards, especially quackgrass, is the best management tactic.

Fall webworm feeds primarily on the leaves of hardwood trees. They overwinter as pupae in silken cocoons, typically under bark flaps, emerging in spring as adult moths. Females lay up to 1,500 eggs in a mass, and larvae molt up to 11 times, feeding on leaves of host plants and spinning silken webbing (Fig. 117). Fall webworm completes only one generation in the north, but up to four in the south.

Monitoring and Thresholds

No economic threshold has been established for lepidopteran pests in hop. 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 3-foot section of hop row, grasping a bine at or just above head-height, and shaking vigorously for 10 to 15 seconds. This dislodges large caterpillars to the tarp, where they can be observed and counted. European corn borers are monitored in other crops by correlating blacklight trap catches (both sexes) with pheromone trap catches (males only).

Management

Hop looper parasitism rates can reach 70%, therefore treatment can be critical in regions where they are present. Cutworm treatment is warranted in newly established fields when scouting reveals that they are active. In more mature fields, treatment for cutworms typically takes place if the pest is found after pruning in early spring.

Several pesticides are labeled for control of hop looper, bertha armyworm, obliquebanded leafroller, and other lepidopteran pests. In most cases, these readily control even the larger instars. *Bacillus thuringiensis* subsp. *aizawai* is effective and highly specific to caterpillars. Use of selective insecticides helps to maintain populations of predators and parasitic wasps and flies that attack lepidopteran pests and aid in their control. The fungicide pyraclostrobin (Pristine) also provides about 50% suppression of hop looper when applied later in the season for powdery mildew.

Picking caterpillars from plants by hand can provide basic control in small yards.

ABOVE: Figure 116. Pupa of a question mark butterfly. (C.A. Gordon)

BELOW: Figure 117. It is easy to see how the silken webbing spun by the fall webworm could pose a nuisance to workers at harvest. (J.L. Obermeyer)

At a Glance
Twospotted Spider Mite

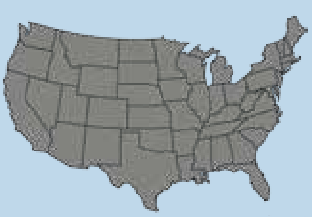
◆ Monitor "problem" hop yards with the disposable cup method in late winter or early spring to determine extant overwintering mite populations.

◆ Monitor hop plants weekly beginning in mid- to late May.

◆ Monitoring is particularly important in August, when populations can build rapidly.

◆ Provide plants with adequate but not excessive nitrogen fertility and water.

◆ Reduce dust, especially in hot dry weather.



Twospotted spider mites are present throughout the U.S.

MITES

Twospotted Spider Mite

Douglas B. Walsh and James D. Barbour

Pest Description and Crop Damage

Twospotted spider mites *(Tetranychus urticae,* Figs. 118 and 119) are closely related to spiders and ticks. They, along with other members of the Tetranychidae family, spin webs and are collectively called spider mites. In hop, the twospotted spider mite is the predominant mite among a small group of closely related spider mite species including McDaniel spider mite *(T. mcdanieli)* and Willamette spider mite *(Eotetranychus willamettei,* Fig. 120).

Adult female twospotted spider mites are small, oval, yellow to yellow-green arthropods, approximately 1/50 inch long, with a large black feeding spot on each side of the abdomen. Newly hatched spider mites (larvae) have three pairs of legs, whereas all other life stages (protonymphs, deutonymphs, and adults) have four. Spider mites at all life stages produce webs from silk glands located near their mouthparts (Fig. 121). Webbing may protect the mite from wind, rain, natural enemies, and exposure to chemicals (e.g., spray droplets may become trapped in a barrier of webbing and fail to contact the mite). The silky webbing is also useful for a variety of different functions including dispersal, colony establishment, pheromone communication, and adhesion to leaf substrate during quiescence; it may also play a role in mating.

Spider mites damage their host plants while feeding, using specialized piercing-sucking, stylet-like mouthparts to penetrate through the outer epidermal cells and into parenchyma cells, and thus removing chlorophyll and other cell contents. The loss of chlorophyll results in a visibly patchy discoloration of leaf tissue (Fig. 122), as well as a reduced photosynthetic rate and production of nutrients. Economic injury occurs as populations build up and feeding increases on leaves, leading to damage accumulated over a period of days. Extreme levels of damage within the canopy can eventually cause complete defoliation and webbing over of the hop bine.

Figure 118. Adult female spider mite has prominent black spots on each side and is approximately 1/50 inch long. (D.G. James)

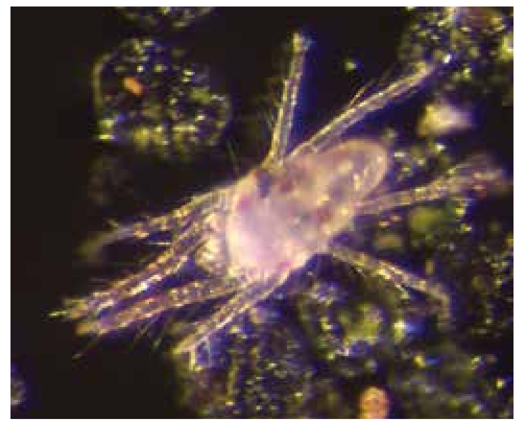


Figure 119. Adult male spider mite. Males are approximately 3/4 the size of females and have a more pointed abdomen. (D.H. Gent)

Figure 120. Male Willamette mite. (T.G. Piraneo)

Most economic damage, however, is caused by spider mites feeding on cones, which results in dry, brittle, discolored (red) cones that tend to shatter, reducing both quality and quantity of yield (Figs. 123 and 124). Late-season mite feeding on both leaves and cones has been documented to reduce the alpha-acids content in hop cones at harvest. 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.

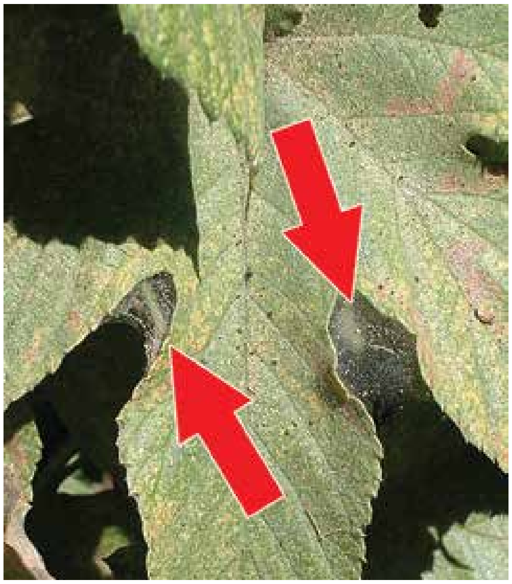


Figure 121. Spider mites spin webbing, the presence of which is associated with severe infestations. (D.G. James)

Figure 122. This patchy discoloration is the result of loss of chlorophyll from spider mite feeding. (D.G. James)

ABOVE: Figure 123. Hop yard exhibits dry, brittle, discolored cones resulting from spider mite feeding. Defoliation can also occur. (D.R. Smith)

AT RIGHT: Figure 124. Close-up of dry, brittle, and discolored (reddish) cones resulting from spider mite feeding. (D.H. Gent)

At a Glance Twospotted Spider Mite

◆ Treat to prevent cone infestations using foliar-applied miticides.

◆ 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.

◆ 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.

ABOVE: Figure 125. Spider mite adult, nymphs, and eggs. Eggs are clear to pearly-white spheres approximately 1/200 inch in diameter. (S. Broughton, Department of Agriculture & Food Western Australia, Bugwood.org)

BELOW: Figure 126. Winter sampling array of beverage cups on sticky cards. This type of monitoring is useful for hop yards with a history of severe mite infestations. (T. Brooks)

Biology and Life History

The life cycle of *T. urticae* progresses through four stages (egg, larva, protonymph, deutonymph) before molting into its fifth and final stage as an adult male or female (Fig. 125). Males are smaller, with a tapered posterior end to their body, while females are larger and more round in shape. Eggs appear as translucent pearl-like spheres, 0.005 inch in diameter, and are deposited singly. The development period of the eggs varies from three days at 75°F to 21 days at 34°F. Eggs become opaque as they mature, until hatching into a larva. The larvae, along with the next two nymphal stages (protonymph and deutonymph), are all active immature stages that feed on the host plant. Each molt includes a period of quiescence during which the mite is inactive and attaches itself to the leaf substrate. The amount of time spent developing in each stage depends on temperature and humidity. At optimal temperatures of 86 to 90°F, twospotted spider mites can develop from egg to adult in as few as seven or eight days. Outbreaks of mites in hop usually occur during the hottest summer months of July and August when their populations can increase rapidly. There are numerous overlapping generations per year. Males reach maturity first, then search and wait beside a female deutonymph in the resting state. Copulation occurs almost immediately after an adult female emerges.

A fertilized female will produce offspring of both sexes, favoring females at a ratio of 3:1. If eggs are not fertilized, arrhenotokous parthenogenesis occurs, resulting in the production of haploid males. The haplodiploidy genetic system enables a single female to initiate a new colony and cause a potential outbreak. Oviposition begins with an average of five or six eggs laid per day, with total egg production up to 100 to 150 in a lifetime. Females lay their eggs within or under webbing.

In temperate regions that experience hard winter frosts and extended freezes, twospotted mites overwinter exclusively as mated adult females in a state of reproductive diapause. Diapause is cued by a decreased photoperiod, lower temperatures, and decline in the quality of the host plant. Once spider mites enter a diapause state in hop yards, they move into the soil and organic plant residue near the soil surface at depths of ½ inch within the ground cover. As winter approaches in temperate climates, mated adult females replace most of the water in their bodies with hydroxyketo-carotenoids, causing their bodies to turn orange-red. These metabolic changes slow respiration and inhibit freezing. Research has demonstrated that female twospotted spider mites in full diapause can survive supercooling to temperatures as low as -39°F. Diapausing twospotted spider mite females also terminate feeding and are negatively photokinetic. With the onset of improved environmental conditions and increasing temperatures in spring, spider mites break diapause and emerge from their overwintering site seeking host plants for sustenance and oviposition. Spider mites emerging from diapause are often observed on young shoots emerging in early spring. As females begin feeding in the spring, they revert back to their warm-season greenish coloration and regain their feeding spots. Egg laying will commence, with the first several eggs laid resulting in male offspring while the majority of eggs laid afterwards being biased toward female.

Monitoring and Thresholds

Winter Samples: Spider mite (and predatory mite) abundance can be monitored during the dormant season using a simple but effective method involving a 1-gallon plastic bag, a garden hand trowel, yellow sticky cards, and plastic beverage cups (Fig 126). In the hop yard, collect a small trowel of soil litter from the top inch around at least 25 dormant or semi-dormant hop crowns (Fig. 127) and place these samples all together, mixing them lightly, in the gallon bag. Indoors, fill 25 five-oz disposable cups approximately halfway with material. Place each cup upright on a 3- by 5-inch yellow insect sampling sticky card on a table or countertop at heated room temperatures

of roughly 70°F for a week. At the end of this week, remove the cups and use a hand lens to count the pest and beneficial mites present on the sticky cards (Fig. 128). Be aware that the adult female spider mites will be in their winter orange/red-colored morph and should not be confused with several species of predatory mites (Fig. 129). While there is no specific threshold, this method gives a general idea of the mite populations present. Specifically, this sampling technique is recommended in hop yards that had severe infestation the prior growing season as a method to determine that in-season sampling should be initiated early in these yards the subsequent growing season.

In-Season Foliar Samples: 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 3- to 6-foot level early in the season; however, after approximately mid-June, as the vines approach the trellis, samples should be taken from leaves higher in the canopy. 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.

Preliminary research has demonstrated that mite feeding before mid-July is minimally damaging to yields and alpha- and beta-acids content in hops at harvest. However, mite feeding in August, even at relatively low populations of mites (>15 mites per leaf), can reduce yield and alpha-acids content in the hops. 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. As harvest approaches, cones should be collected and evaluated for the presence of spider mites. Economic loss to mite feeding injury is often reduced 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, such as *Stethorus* spp. and predatory mites (see Beneficial Arthropods section). Unfortunately, spider mite populations can build rapidly—especially in hot, dry conditions—therefore monitoring is important, particularly in August.

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 natural enemies of spider mite. Overtillage of soil can also increase hop yard dust and exacerbate spider mite infestations.

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, biologically disruptive 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.

A number of foliar-applied miticides are available for control of twospotted spider mites in hop. Consult your region's current list of registered acaricides and information regarding their application. Several of these are reported to be relatively safe to predatory insects and mites (see Table 1, page 7). 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., after early June) tend to exacerbate mite outbreaks most severely.

Resistance to several miticides has been documented within specific populations of twospotted spider mites in Washington State. Care should be taken to use active ingredients related in their mode of action judiciously to hinder the further development of miticide resistance.

Figure 127. Collecting soil around hop crowns for winter sampling method. (T. Brooks)

Figure 128. Beneficial whirligig mite (top) and spider mites collected from sticky cards during winter sampling. (T. Brooks)

Figure 129. Overwintering female twospotted spider mite (shown with egg nearby) takes on an orange to red coloration during diapause. (T. Brooks)

At a Glance
Slugs & Snails

◆ Monitor for presence on hills in early spring.

◆ Cultivation between rows can kill mollusk pests or expose them to death by weather and predators.

◆ Damage can be mistaken for that of flea beetles or cucumber beetles.

◆ Slime trails indicate the presence of slugs and snails.

◆ Iron phosphate bait is available in some areas.

◆ Bait at planting time in yards with a history of slug infestation, if the label permits.

Figure 130. Gray field slug. Slugs range in size from ¼ to 2 inches in length. (J. Berger, Bugwood.org)

Slugs and Snails

Amy J. Dreves and Sally D. O'Neal

Pest Description and Crop Damage

Slugs can be a problem in some hop yards, most notably those with wide row orientation in western Oregon. Several species can be found in hop yards, but the most common are the gray field slug *(Deroceras reticulatum,* Fig. 130) and the brown-banded slug *(Arion circumscriptus)*. These soft-bodied mollusks range in length from ¼ inch to 2 inches. The gray field slug (also known as gray garden slug) ranges from light gray to dark brown to almost black, 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. The brown-banded slug is tan with brown stripes on its sides. All slugs have a respiratory pore behind the mid-point and on the right side of the mantle. The body of the gray field slug has a boat-like shape behind the keel (i.e., the foot) 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, hot, or windy 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 shoots.

Snails are closely related to slugs but have an external shell. Snails are recognized as a problem in the Great Lakes and eastern U.S. hop-growing regions.

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, with 200 to 400 eggs laid during the lifetime of an individual slug. 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 observing hop shoots during the pest's critical stage of emergence in the early spring. Open bait traps or slug blankets/boards can be placed on the ground near hop hills to monitor for slugs. After several nights, the traps should be examined for the presence of slugs. Treatment should be considered if the field has a history of slug or snail damage or if excessive damage to foliage or growing tips is observed and slugs or snails are determined to be present.

Management

The most effective control of slugs and snails can be achieved in early spring when temperatures begin to warm and hop plants start to grow. Hop is at its greatest risk of damage by these mollusks 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 spring conditions favor slugs in hop yards. Soil cultivation between hop plants in early spring can kill slugs and also expose them to predators and desiccation. Birds, frogs, snakes, Sciomyzid flies, harvestmen (daddy longleg 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.

Iron phosphate (Sluggo), and iron chelate/sodium ferric EDTA (Ferroxx, Iron Fist) are effective in controlling slugs. 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 work at most temperatures, and slugs will not recover after ingesting the bait.

Beneficial Arthropods and Pathogens

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 hop, beneficial arthropods can often provide partial and, in rare instances, 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 7);
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) arthropod groups is illustrated in Figure 131, below.

At a Glance Beneficial Arthropods

- Learn to ID beneficial arthropods in the hop yard.
- Preserve them through use of selective pesticides.
- Conserve when possible.

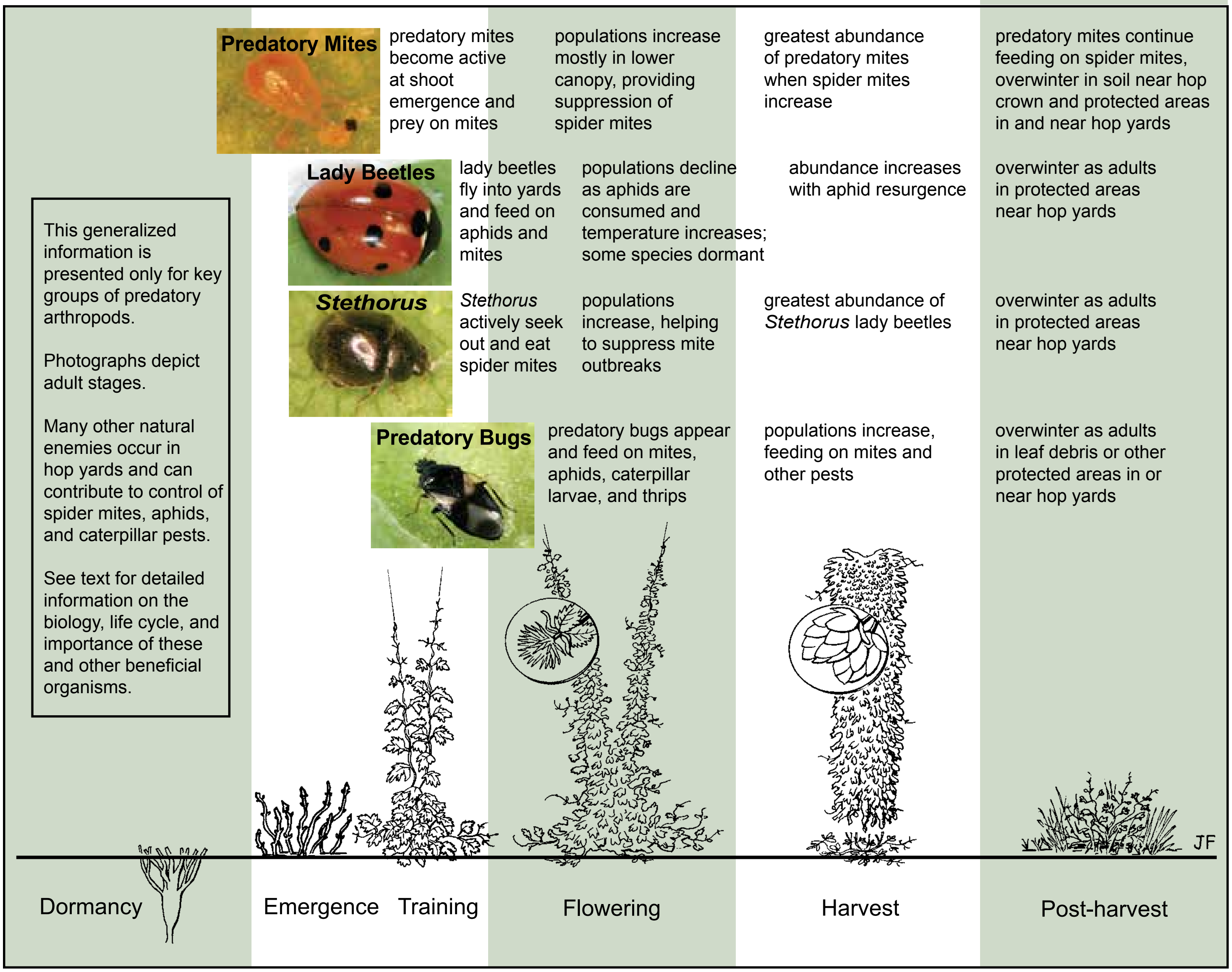


Figure 131. Seasonal development and activity of four key groups of predatory arthropods that occur on hop: predatory mites, aphid-eating lady beetles, mite-eating *(Stethorus)* lady beetles, and predatory bugs. Information is generalized; multiple factors influence the presence and abundance of beneficial arthropods in hop yards. Detailed sections for each of these predator groups and for other beneficial arthropods appear on the following pages. (Illustrations by Joel Floyd)

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.

Predatory Mites

A number of predatory mites occur on hop. In the Pacific Northwest, these include the phytoseiids *Galendromus occidentalis* (western predatory mite), *Amblyseius fallacis*, 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. *Galendromus occidentalis* and *N. fallacis* are generally pale tan-colored, pear-shaped, shiny, and more active than spider mites (Figs. 132-135). *A. fallacis* adults, also pear-shaped, start out white and turn brownish-red after feeding. *A. fallacis* tend to die out after abamectin is sprayed in the hop yard.

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 (Figs. 132 and 135). 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. 136).

Figure 132. Adult predatory mite, *Galendromus occidentalis*, lower right, with its opaque, oblong egg. Above left is a twospotted spider mite adult. Most predatory mites range in size from 1/50 to 1/25 inch in length. (D.G. James)

Figure 133. Adult predatory mite, *Neoseiulus fallacis*. Notice shiny appearance and distinctive pear shape. (D.G. James)

Figure 134. *Neoseiulus fallacis* are shinier and faster than *G. occidentalis* and are able to feed on pollen as well as on spider mites. They flourish under cool, moist conditions such as those found in western Oregon. (D.G. James)

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 one to five 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.

Most hop yards in Washington State 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 on 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.

Less is known about the biology of *Anystis* mites, which are becoming more frequent in hop yards as pesticide inputs lessen. They are active predators of hop aphid and, to a lesser extent, mites 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 continues to decrease.

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. It is common to find predatory mites actively feeding on spider mites in hop yards after shoot emergence in early spring. Later in spring, however, populations of predatory mites in hop yards generally 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 (one to five 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 *Galendromus occidentalis* and *Neoseiulus 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 and sulfur fungicides. 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.

Figure 135. *Galendromus occidentalis* immature and two (oval) eggs. The round eggs at the top and left are pest mite eggs. (T. Brooks)

Figure 136. An anystid mite, *Anystis* spp. These are larger than other beneficial mites. (A.J. Dreves)

Predatory Lady Beetles

Hop yards are readily colonized by several species of lady beetles (Coccinellidae), which play a major role in suppressing aphid and, to a lesser extent, spider mite 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.

At a Glance
Aphid-Feeding Lady Beetles

- ◆ Lady beetle adults and larvae help control aphids, spider mites, 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. 137). 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 U.S. 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 137. 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 than round (Fig. 138). 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, elongate, 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. 139). 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. 140). 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. 141). 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. 142). 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. 143). 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 (Fig. 144). 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 1,200 aphids may be consumed during larval development.

Figure 141. Adult *H. axyridis* vary in color. (D.G. James)

Figure 142. Fourth-instar *H. axyridis* larva. (D.G. James)

Figure 143. Overwintering *H. axyridis.* (D.G. James)

Figure 144. This lady beetle pupa is likely that of *H. axyridis.* (E. Lizotte)

Figure 138. Convergent lady beetle adult. (R. Ottens, Bugwood.org)

Figure 139. Alligator-shaped convergent lady beetle larva has orange spots. (D.G. James)

Figure 140. Convergent lady beetle adults congregating during aestivation. (D.G. James)

A generalized summary of the seasonal development and activity of key predatory arthropods including lady beetles is illustrated in Figure 131, page 71.

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. 145). 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. 146), and grow to the same length as adults before they pupate (Fig 147).

AT RIGHT: Figure 145. Adult seven-spot lady beetle. (D.G. James)

AT RIGHT, TOP: Figure 146. Alligator-like larva is dark gray with orange spots. (R. Otten, Bugwood.org)

AT RIGHT, BOTTOM: Figure 147. Pupal stage lasts 3 to 12 days. (D.G. James)

Biology and Life History

This exotic species is a relative 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 or more 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.

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

Aphid-eating lady beetles can be important to natural suppression of hop aphids in areas where high temperatures do not keep aphid populations below damaging levels. 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 disperse from hop yards after release. Despite feeding primarily on aphids, these lady beetles also can feed on spider mites, thrips, and other small insects, and thus contribute at some level to overall 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. 148). 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. 149). 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. 150). The larvae grow from 1/25 to 1/16 inch long, becoming reddish as they mature, at first on the edges of the body. The entire larva turns reddish just prior to pupation. The pupae are black, flattened, and somewhat pointed on the posterior end, with the entire body covered with yellow hairs (Fig. 150).

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 148. Adult mite-eating lady beetles are 1/25 to 1/16 inch long.
MIDDLE: Figure 149. White, oval eggs are less than 1/50 inch long.
BOTTOM: Figure 150. Newly hatched *S. picipes* larva. (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 151. Pupa of the mite-eating lady beetle *S. picipes* has 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 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

Adult minute pirate bugs are 1/12 to 1/5 inch long, oval, and black or purplish with white markings on the forewings (Fig. 152). 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. 153). Newly hatched nymphs are transparent with a slight yellow tinge, turning yellow-orange to brown with maturity (Fig. 154). They are fast moving, wingless, and teardrop-shaped.

Figure 152. Adult minute pirate bug. (D.G. James)

Figure 153. First-instar nymph and egg of the minute pirate bug. 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 may contribute to control of late-season pests, particularly spider mites and hop loopers.

Figure 154. Minute pirate bug nymphs are wingless and teardrop-shaped. Older ones are yellow-orange to brown in color. (D.G. James)

Big-Eyed Bug
Geocoris pallens

Description

Big-eyed bugs play a beneficial role in Pacific Northwest hop yards. They are widely distributed across the western U.S. and range eastward to the Midwest. 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. 155). 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 155. Adult big-eyed bug has 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 1,600 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.

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. 156). Eggs are elongate, approximately 1/25 inch long, and inserted into plant tissue, often at the midrib of a leaf, with only the "lid" and a respiratory horn visible (Fig. 157). Nymphs are mottled pale gray with long gray hairs on the thorax and abdomen (Fig. 158). 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.

Figure 156. Oval, shiny black adult predatory mirids. (D.G. James)

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.

Figure 157. Elongate predatory mirid eggs are inserted into plant tissue. (D.G. James)

AT LEFT: Figure 158. Predatory mirid nymphs are mottled pale gray with long gray hairs on the thorax and abdomen. (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. In regions with warmer summers, predatory bugs are most important when aphid populations are present in late spring and early summer. In cool summer locations, predatory bugs are important for aphid control in late summer.

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. They have round, beady eyes and an extended, three-segmented, needle-like beak (Figs. 159 and 160). They are larger than other predatory bugs, ranging from 2/5 to 4/5 inch in length. Assassin bug 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. 161). Nymphs are small versions of adults, although early instars are often ant-like.

Biology and Life History

Assasin 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.

Damsel Bugs
Nabis spp.

Description

Damsel bugs are mostly yellowish, gray, or dull brown, slender insects up to ½ inch long with an elongate head and long antennae (Figs. 162 and 163). 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.

Figures 159 and 160. Adult assassin bug feeding on a beetle larva. (D.G. James)

Figure 161. Raft of eggs laid by an assassin bug. (D.G. James)

Figures 162 and 163. Adult damsel bug. (D.G. James)

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. Families are distinguished primarily by differences in wing venation. Adults are usually small, ranging from less than 1/12 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, Figs. 164-166); others smaller (<1/3 inch) with fewer veins on wings (Braconidae and Trichogrammidae); and some 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. Yellow jackets, hornets, paper wasps, and sand wasps will also attack and consume larger prey such as caterpillars.

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 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.

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.

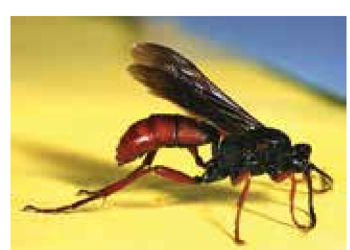
At least nine species of parasitoids are associated with the various life stages of the hop looper. Looper pupae are attacked by two ichneumonid wasps in Washington, *Pimpla sanguinipes* and *Vulgichneumon brevicinctor*. These species can be very abundant in hop yards after harvest and can help reduce 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.

At a Glance
Parasitic Wasps

- Wasps are important parasitoids of eggs, larvae, or pupae of hop loopers and other caterpillar pests.
- Encourage flowering ground covers that provide nectar for wasps.
- Use insecticides and miticides safe to wasps.





Figures 164, 165, and 166.
Various ichneumonid wasps. Adults are up to 1 inch in length. (D.G. James)

At a Glance
Parasitic & Predatory 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.

Parasitic and Predatory Flies

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

Dance Flies

Adult dance flies (Fig. 167) are small- to medium-sized (< ¼ inch) and dark in color. They have a humpbacked thorax, a long, tapering abdomen, and slender legs. Dance flies are predators as adults and larvae, consuming smaller insects like aphids. Adults 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.

Figure 167. Adult dance fly. (D.G. James)

Figure 168. Adult hover fly. (D.G. James)

Figure 169. Hover fly larva attacking a hop aphid. (D.G. James)

Hover Flies

The yellow-and-black-banded adult hover fly resembles a stinging bee or wasp, but only has one pair of wings (Fig. 168). 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. 169). The pupae are pear-shaped and greenish to dark brown (Fig. 170). 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 seven 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 170. Hover fly pupa. (D.G. James)

Long-legged Flies

These small- to medium-sized (¼ to 3/8 inch), slender flies can be metallic-green, blue, or bronze in color; they have long legs, and large, prominent eyes (Fig. 171). The wings are clear with some darker markings, depending on species. The larva is maggot-like. 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 suppression of aphids and spider mites to some degree.

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. 172) 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. 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.

Tachinid Flies

These parasitic flies are gray-black, robust, and have stout bristles on their body similar to house flies (Fig. 173). Tachinids parasitize the caterpillars of moth pests of hop, including armyworms, cutworms, leafrollers, and hop loopers (Fig. 174). 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, where research has shown they have an impact on hop looper populations. 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 can be monitored using yellow sticky traps. They are susceptible to pesticides, therefore they should become more frequent in hop yards as broad-spectrum chemical inputs decrease.

Figure 171. Long-legged fly.

Figure 172. Predatory midge larvae are <1/8 inch long.

Figure 173. Tachnid fly.

Figure 174. Hop looper larva killed by a tachinid fly larva, which has now pupated (top). Tachinid fly larva exiting a hop looper larva (bottom). (4 photos D.G. James)

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. 175). They emit a foul odor and basically become liquefied, releasing endospores of *B. 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.

AT LEFT: Fig. 175. Hop looper larva infected with a bacterium. (D.G. James)

At a Glance Predatory Thrips

◆ Recognize and identify predatory thrips.

◆ Adults become active among the bines in early spring.

◆ Predatory thrips can help regulate populations of spider mites, aphids, and moth eggs during mid summer summer.

◆ Use insecticides and miticides safe to predatory thrips.

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 are found in hop yards: sixspotted 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. 176); and the black hunter thrips is brown-black with opaque, narrow wings (Fig. 177). Larvae are almost colorless to yellow but become darker as they mature. The pupal stage is dark-colored with yellowish-white appendages.

Figures 176 and 177. Banded thrips and black hunter thrips adults. (W. Cranshaw, Colorado State University, Bugwood.org, and D.G. James)

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, a non-feeding prepupa, and a pupa stage. Females lay eggs on the underside of leaves, usually near the mid-vein. Prepupae 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 regulate spider mite populations during spring and summer.

Predatory Thrips Monitoring, Importance in IPM, and Compatibility with Pesticides

Predatory thrips can be counted with sticky traps or a hand lens and beating tray. Populations can build rapidly in early to mid-summer. Predatory thrips are generally sensitive to broad-spectrum pesticides.

Snakeflies and Lacewings

Description

Snakeflies and lacewings are closely related. Snakeflies' common name derives from the superficially snake-like appearance that is suggested by the unusually long "neck" (frontal thorax) and long, tapering head (Figs. 178 and 179). Snakeflies are voracious feeders of a wide variety of small insects. Adult snakeflies are weak flyers with long, transparent wings.

Lacewings are common predators in hop yards, primarily feeding on mites and aphids. They include *Chrysopa, Chrysoperla,* and *Hemerobius* spp. Adults are soft-bodied, approximately 3/5 to 9/10 inch long, and green or light brown in color). They have long, hair-like antennae and two pairs of transparent, lacy wings netted with fine veins (Fig. 180). 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. 181). They are laid singly or

Snakeflies and Lacewings Monitoring, Importance in IPM, and Compatibility with Pesticides

Snakeflies and lacewings can be monitored by shaking bines over a tray or by using sticky traps. Along with key predators, their importance in biocontrol is considerable, contributing to suppression of aphids, mites, and loopers. Broad-spectrum pesticides are harmful to lacewings and snakeflies; some newer selective materials appear safer.

Figures 178 and 179. Two views of an adult snakefly. Notice the unusually long "neck" that is a characteristic of these insects. (D.G. James)

in groups. The larvae resemble small caterpillars or lady beetle larvae (Fig. 182). 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 prepupae, 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.

Biology and Life History

The snakefly life cycle has four stages: 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.

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 180. Adult green lacewing. (D.G. James)

Figure 181. Lacewing egg laid singly on a stalk. (E. Lizotte)

Figure 182. Larva of the green lacewing. Notice the prominent jaws that project forward. (D.G. James)

At a Glance
Snakeflies and Lacewings

◆ 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 a hop yard is a clear sign of low pesticide input.

◆ Use insecticides and miticides safe to lacewings and snakeflies.

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. 184 and 184), crab spiders (Fig. 185), 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 hop. 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 wind and debris. The abundance and diversity of spiders in hop yards is linked to the large-scale landscape complexity (i.e., hop yard margins, overwintering habitat, weediness) and local management practices (e.g., pesticide use, tillage practices).

Figure 183. A jumping spider (*Phidippia* sp.) feeding on a beetle larva. (D.G. James)

At a Glance Spiders

- Spider presence in a hop yard 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.

Figure 184. A jumping spider. (D.G. James)

Figure 185. A crab spider on a hop plant. (E. Lizotte)

Weed Management

Rick A. Boydston, Bernard H. Zandstra, and Robert Parker

Weeds in hop yards can interfere with production by impacting the growth and yield of hops (direct interference) or by interfering with field operations (indirect interference). Weeds compete with hop plants for nutrients, water, and—to a lesser extent—light. (Hop by nature grows tall and is trained to grow on an upright trellis system, therefore competition for light is not the problem it can be with other crops.) Some weeds also provide a favorable environment for certain pathogens or insects, including promoting the survival of detrimental pests during the period when hop plants are not actively growing. A heavy density of weeds in the hop yard can interfere with spraying, training, and harvesting, reducing both the efficacy and efficiency of various practices. Therefore, weed management must be considered in an integrated hop pest management program.

Weeds can present problems throughout the year in hop yards. Summer annual weeds are those germinating in the spring or summer, producing seed in late summer, and then dying. These weeds can interfere with spraying operations, distort sprinkler patterns, and interfere with harvest. Winter annual weeds typically germinate in the late summer or fall, overwinter, flower and produce seed in the spring, and die in early summer. These weeds typically have little direct impact on hop growth but can deplete stored soil moisture, interfere with hop yard maintenance, slow spring field operations, and host insect pests and pathogens. Perennial weeds live more than two years and often reproduce and spread from vegetative stolons or rhizomes. These weeds can create problems similar to those posed by annual weeds and are often much more difficult to control with herbicides and cultivation. Perennial weeds can be spread with tillage operations.

A few representative annual and perennial weeds are pictured in Figures 186 to 192. The pages that follow contain basic information on planning and executing an integrated weed management program in hop, as well as photos of many of the weeds that can be problematic in hop yards.

Representative Annual Weeds

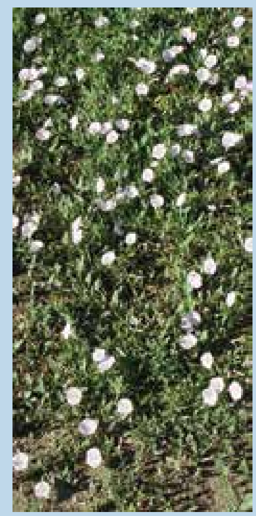
Figure 186. Prickly lettuce. (R. Parker)

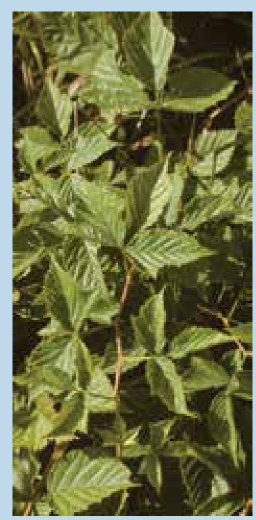
Figure 187. Lambsquarters. (R. Parker)

Figure 188. Kochia. (R. Parker)

Figure 189. Pigweed. (R.A. Boydston)

Representative Perennial Weeds





FROM TOP:
Figure 190. Canada thistle.
Figure 191. Field bindweed.
Figure 192. Blackberry.
(R. Parker)

Figure 193. Canada thistle seedling. (R.A. Boydston)

Figure 194. Common groundsel seedlings. (R. Parker)

Figure 195. Russian thistle seedlings. (R.A. Boydston)

Figure 196. Green foxtail seedling. (R.A. Boydston)

Figure 197. Kochia seedlings. (R.A. Boydston)

Figure 198. Shepherd's purse seedling. (R.A. Boydston)

Figure 199. Common lambsquarters seedling. (R.A. Boydston)

Figure 200. Puncturevine seedlings. (R. Parker)

Planning a Weed Management Program

Several factors should be considered when planning a weed management program in a hop yard. Weed species, tillage, row spacing, irrigation, cover crops, duration of crop (rotation), and herbicides all need to be integrated to develop an effective weed management strategy. A brief overview of some of these factors is presented in this section.

The first step in managing weeds in a cropping system is to identify the weed species present (See Weed Seedling Identification sidebar, opposite). The photos presented in this section are intended to aid in the identification of weeds at various growth 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.

Weed seed, stolons, and rhizomes can be brought in on soil and plant material when planting new hop yards. Cleaning equipment before moving it from one field to another, planting hop free of weed seed and vegetative propagules, screening irrigation water, and controlling weeds around field borders will help mitigate 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 eliminate 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 lambsquarters seed will germinate each year. With certain summer annual weeds, secondary dormancy will occur and seed germination stops when the temperature reaches a critical point. Winter annual weeds generally will not germinate until soil temperatures and/or day length begin to decrease. Perennial herbaceous weeds (e.g., Canada thistle, field bindweed, quackgrass) 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 201. Horseweed seedling.
(R.A. Boydston)

Figure 202. Pigweed seedling.
(R.A. Boydston)

Figure 203. Barnyardgrass seedlings.
(R.A. Boydston)

Figure 204. Curly dock seedling.
(M.A. Goll)

Figure 205. Flixweed seedling.
(R.A. Boydston)

Figure 206. Prickly lettuce seedling.
(R.A. Boydston)

Weed Seedling Identification

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

◆ Many weeds (e.g., hairy nightshade, common lambsquarters, 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 193 to 206.

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

Cultural (Non-chemical) Tactics

Tillage has a major impact on weed spectrum and population. Weed seed response to burial and exposure to light varies by species. Disking in the spring stimulates certain seeds to break dormancy and germinate. Tillage or cultivation practiced for annual weed control should be done as shallow as possible to avoid bringing new weed seed to the soil surface. Most annual weeds germinate from the upper 2 inches of the soil profile and can be controlled with shallow tillage without bringing deeper weed seed to the upper soil profile where it can readily germinate. Repeated tillage can weaken perennial weeds and exhaust reserves stored in rhizomes and stolons. However, tillage can spread small pieces of rhizomes and stolons to new areas not previously infested and create new or larger patches of perennial weeds.

The use of a fall-planted cover crop can reduce winter annual weed emergence and 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. This has the effect of reducing the soil seed bank. 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 (Roundup) before hop shoots emerge.

Tillage can be used to incorporate certain soil-active herbicides, such as trifluralin (Treflan). Again, shallow incorporation in the upper 2 to 3 inches of the soil profile will place the herbicide in the zone of annual weed seed germination where is it the most effective. Poorly timed tillage and traffic in the hop yard can also disturb preemergence herbicide barriers and expose untreated soil, allowing weeds to germinate and establish.

Organic mulches have been utilized in some organic hop yards to suppress weeds. Growing a cover crop and then mowing it and blowing the residues onto the hop crowns can suppress annual weeds. However, use of organic mulches can also have impacts—both positive and negative—on insect pests, voles, or plant pathogens. Synthetic mulches may also be useful in certain situations to suppress weeds, but are not widely used in conventionally grown hop yards.

Figure 207. Redroot pigweed. (R. Parker)

Figure 208. Aptly named red-root pigweed root. (R. Parker)

Figure 209. Powell amaranth is a pigweed species distinguished by its longer, slimmer inflorescence. (R. Parker)

Figure 210. Prickly lettuce leaves. (R. Parker)

Figure 211. Mature prickly lettuce plant. See also Figures 185 and 206. (R. Parker)

Figure 212. Puncturevine fruit. (R. Parker)

Figure 213. Puncturevine plant. (R. Parker)

New Hop Yards

Managing weeds during planting of a new hop yard is critical for the successful establishment of the newly planted hops. Planting schemes that allow for repeated and close cultivation to the hop plants reduce expensive hand weeding costs. Shallow, rather than deep, cultivation should be practiced to reduce the amount of new weed seed brought into the germination zone (upper 2 inches of soil).

Glyphosate (Roundup) can be used prior to hop emergence, but should be avoided once hop plants have emerged. Norflurazon (Solicam) is labeled for use as a preemergence herbicide in new plantings and can reduce the number of cultivations or hand weeding required. Pendimethalin (Prowl H_2O) is not restricted to established plantings, so this control can also be applied to new plantings. Clethodim (Select Max) can be applied to control emerged grass weeds that have escaped cultivation or pre-emergence herbicide treatments.

Once new hop plants have been strung and are approximately 6 feet tall, weeds can be suppressed with contact herbicides such as paraquat (Gramoxone) or carfentrazone (Aim).

Figure 214. Henbit plant. (R.A. Boydston)

Figure 215. Small kochia plant. See also mature plant, Figure 188. (R. Parker)

Figure 216. Common groundsel. (R. Parker)

Figure 217. Green foxtail stem with leaf. (R.A. Boydston)

Figure 218. Green foxtail inflorescence. (R.A. Boydston)

Figure 219. Henbit flower. (R.A. Boydston)

Figure 220. Field bindweed flowers. See also plant, Figure 191. (R. Parker)

Figure 221. Horseweed plant. (R. Parker)

Figure 222. Mature horseweed plants. (R. Parker)

Figure 223. Horseweed inflorescence. (R. Parker)

Figure 224. Horseweed buds. (R. Parker)

Figure 225. Curly dock inflorescence. It is a perennial broadleaf weed. (M.A. Goll)

Figure 226. Barnyardgrass is an annual grass weed. (R.A. Boydston)

Figure 227. Bermudagrass is a perennial grass weed. (R.A. Boydston)

Herbicides

Herbicides are becoming more widely used for controlling weeds in hop, but the number of herbicides available in hop production is limited. 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), quackgrass, 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 incorporation (via rainfall, irrigation, or mechanical means) after application. Tools such as disking and postemergence herbicide application can help control weed escapes. Disadvantages of disking are that soil disturbance can stimulate weed seed germination and 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 postemergence herbicide that matches the weed spectrum.

Several herbicides are registered for use in hop production: pendimethalin (Prowl H_2O), trifluralin (Treflan and several other trade names), norflurazon (Solicam), clopyralid (Stinger), 2,4-D amine (various trade names), glyphosate (Roundup), clethodim (Select), carfentrazone (Aim), flumioxazin (Chateau), paraquat (Gramoxone), and pelargonic acid (Scythe).

Pendimethalin, trifluralin, and norflurazon are primarily soil-applied and are applied prior to annual weed emergence. Trifluralin must be mechanically incorporated into the soil, whereas pendimethalin and norflurazon may be mechanically incorporated or incorporated into the soil by sufficient overhead moisture. Norflurazon can persist in the soil and injure rotation crops or cover crops, so proper planning is needed to avoid potential problems with this herbicide. Clopyralid, glyphosate, and 2,4-D are postemergence herbicides applied to actively growing weeds. Clopyralid is selective on some broadleaf weeds, particularly those in the sunflower, nightshade, pea, and smartweed families, and is particularly useful for control of perennial weeds in those plant families. 2,4-D controls a wider 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, but also will kill or seriously injure hop plants if allowed to contact hop foliage. Clethodim is selective in controlling most annual and perennial grass weeds found in hop yards and is applied after emergence of these weeds. Pelargonic acid, while registered, is not widely used.

Paraquat effectively controls emerged weeds and is sometimes tank-mixed with norflurazon. Carfentrazone and paraquat are used as desiccants 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 as well as burning back field bindweed. It should be used with care, exactly as directed; damage has been reported in young hop yards when contact occurs on stems with underdeveloped bark. 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.

Table 5 presents a summary of the effectiveness of herbicides and cultural control practices for several common weeds in hop yards.

Specific herbicide use guidelines for Washington, Oregon, and Idaho can be found in the annually updated *Pacific Northwest Weed Management Handbook,* available from the Washington State University, Oregon State University, and University of Idaho extension services and online at http://pnwhandbooks.org/weed/

Table 5. Efficacy Ratings for Weed Management Tools in Hop

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 preemerged weeds, Post = Foliar-active against emerged weeds. Note that weed size or stage of growth is an important consideration with most postemergence herbicides.

		ANNUAL BROADLEAVES							PERENNIAL BROADLEAVES						
MANAGEMENT TOOLS	**Type**	**Kochia**	**Lambsquarters**	**Prickly Lettuce**	**Mallow**	**Mustards**	**Pigweed**	**Puncturevine**	**Bindweed**	**Blackberry**	**Curly Dock**	**Canada Thistle**	**Perennial Grasses**	**Annual Grasses**	**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 must be good. Perennial weeds will regrow. Follow label directions carefully to avoid hop damage, especially early in the season and in young yards.
clethodim (Select Max)	Post	-	-	-	-	-	-	-	-	-	-	-	G	G-E	Repeat applications may be needed for perennial grasses.
clopyralid (Stinger)	Post	P	P	E	P	P	P	P	P	P	G	G-E	- -	- -	
flumioxazin (Chateau)	Pre	E	E	E	F	G	G	G	P	P	P	P	P	F-G	If small weeds are emerged, use in combination with a postemergence herbicide.
glyphosate (Roundup & others)	Post	E	E	E	P	E	E	E	F	E	?	E	F-E	E	Rating based on weeds not being dusty. Correct timing important on perennials. Repeat applications may be needed for Canada thistle and perennial grasses; timing and rates are critical for these weeds.
norflurazon (Solicam)	Pre	G	P-F	E	F	G	G	E	P	P	P	P	F	G	
paraquat (Gramoxone & others)	Post	E	E	E	F	E	E	E	P	P	P	P	P	F-G	Rating based on weeds being small and not dusty.
pendimethalin (Prowl H_2O)	Pre	G	E	F	P-F	F	E	G	G	P	P	P	P-F	E	
trifluralin (Treflan & others)	Pre	G	E	F	P	F	E	G	F	P	P	P	P	G	Requires mechanical incorporation for best results.
CULTURAL (NON-CHEMICAL)															
Cover crop between rows		U	U	U	U	U	U	U	F	F	F	F	P	U	Efficacy depends on cover type and stand quality.
Crowning (mechanical)		F	F	F	F	F	F	F	P	P	P	P	P	?	
Cultivation between rows		E	E	E	E	E	E	E	see comments				P-E	E	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	G-E	Can be good to excellent if very persistent in efforts.

weed photographs continue next page...


Figure 228. Common mallow. (R.A. Boydston)


Figure 229. Common purslane plants. (R. Parker)


Figure 230. Common purslane flowers. (R. Parker)


Figure 231. Individual purslane plant.
(S. Dewey, Utah State University, Bugwood.org)


Figure 232. Blue mustard plant. (R.A. Boydston)


Figure 233. Blue mustard seed pods. (R. Parker)


Figure 234. Severe blue mustard infestation. (R. Parker)


Figure 235. Curly dock. See also mature plant's inflorescence, Fig. 225. (M.A. Goll)

Calculating Treated Acres versus Sprayed Acres

Herbicide rates 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. If hop plants were in rows spaced 14 feet apart and the herbicide label indicates the herbicide is to be applied at 2 pints per acre, then 2 pints of herbicide is enough to treat 3.5 field acres of hop plants. Since 2 pints equal 32 fluid ounces, each planted acre of hop will receive only 9.14 fluid ounces of herbicide.

Figure 236. Flixweed inflorescence. (R. Parker)

Figure 237. Flixweed plant in flower. (R. Parker)

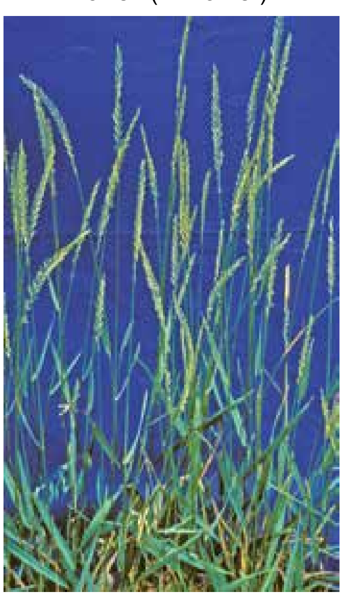


Figure 238. Quackgrass. (S. Dewey, Utah State University, Bugwood.org)

Figure 239. Mature inflorescence of Canada thistle. See also Figure 190. (R. Parker)

Figure 240. Quackgrass rhizomes. (R.A. Boydston)

Figure 241. Quackgrass plant and rhizome. (S. Dewey, Bugwood.org)

Figure 242. Bermudagrass plants. See also Figure 227. (R. Parker)

Figure 243. Bermudagrass inflorescence. (R. Parker)

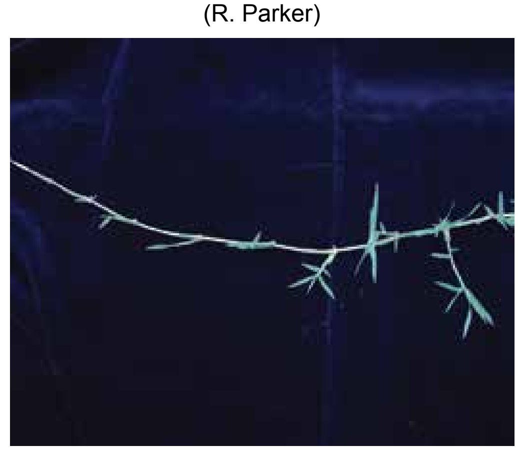


Figure 244. Bermudagrass stolon. (R. Parker)

Table 6. 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 6 presents herbicide injury symptoms commonly observed on hop. Figures 245 through 256 display typical symptoms associated with herbicides commonly used in hop yards.

Herbicide	Symptoms
2,4-D (Weedar, others)	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 (Fig. 245).
carfentrazone (Aim)	Sprayed foliage will exhibit chlorotic (yellow, Fig. 246) and necrotic (brown) stem tissue, with stem cracking reported on some hop varieties (Fig. 247). Sprayed growing points are killed. Chlorotic and/or necrotic spotting will be observed on leaves (Fig. 248) and stems (Fig. 249) if the herbicide drifts. Stem cracking, yellowing of lower leaves, and wilting in late season has been reported in younger hop yards.
clethodim (Select Max)	No symptoms have been observed on hop 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 (Stinger)	Upward leaf cupping and some stem twisting sometimes will be exhibited, particularly on sprayed foliage (Figs. 250 and 251). Leaf cupping is seldom observed above the zone of spray contact.
glyphosate (Roundup)	Leaves may be chlorotic, necrotic, and malformed (Figs. 252 and 253). Leaf veins will often remain green while the areas between the leaf veins are yellow to white. Developing stems have shortened stem internodes. Cones may be malformed. Plants are often severely injured or killed. Symptoms may persist into the next growing season.
norflurazon (Solicam)	Leaf veins may be chlorotic to completely white (Fig. 254). The symptoms are usually temporary.
paraquat (Gramoxone, others)	Sprayed foliage will exhibit chlorotic and necrotic leaf tissue (Fig. 255). 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. 256).
pendimethalin (Prowl), trifluralin (Treflan)	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 245. 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 246. Chlorotic (yellow) leaf tissue due to carfentrazone. (D.H. Gent)

Figure 247. Stem cracking due to carfentrazone. (D.H. Gent)

Figure 248. Chlorotic spotting of leaves caused by carfentrazone drift. (D.H. Gent)

Figure 249. Necrotic spotting on stems due to carfentrazone. (D.H. Gent)

Figure 250. Severe cupping of leaves due to high rate of clopyralid applied to control Canada thistle. (D.H. Gent)

Figure 252. Yellowing and stunting of leaves and shoots caused by a fall application of glyphosate. (M.E. Nelson)

Figure 251. Slight cupping of leaves exposed to clopyralid. Leaf cupping is seldom observed above the zone of spray contact. (D.H. Gent)

Figure 253. Severe chlorosis of leaves impacted by glyphosate, in which the areas between the leaf veins are bleached to almost white. (D.H. Gent)

Figure 254. Leaf veins bleach yellow to white when injured by norflurazon, but plants generally recover. (D.H. Gent)

Figure 255. Yellowing and death of leaves caused by paraquat applied for spring pruning during cold weather. (D.H. Gent)

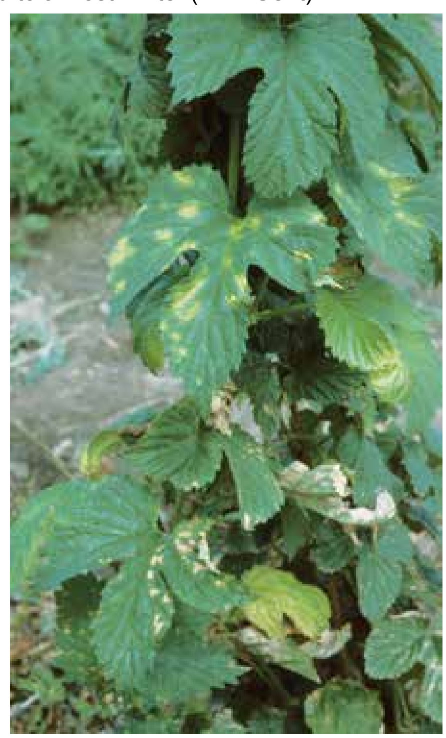


Figure 256. Yellow spots on leaves caused by paraquat drift. (R. Parker)

Nutrient Management and Imbalances

David H. Gent, J Robert Sirrine, and Heather M. Darby

Hop plants produce abundant biomass in the form of bines, leaves, and cones. High-yielding plants such as hop require adequate nutrition. Many of the various nutrients required by hop may be deficient or in excess of the crop's needs. It can be difficult to pinpoint the cause of abnormal plant symptoms, especially if multiple production factors lead to the same symptom. General symptoms associated with nutrient imbalances are described in this section, as well as known nutrient interactions with diseases and arthropod pests.

Fertilization recommendations are beyond the scope of this pest management guide and are not provided. Recommendations vary widely in published literature, differing among production regions, varieties, irrigation methods, soil types, and production goals. Readers should seek input from local experts for guidance appropriate to their region and situation.

Figure 257. Stunting, distortion, and crinkling of young leaves associated with boron deficiency. (J. Portner)

Figure 258. Misshapen shoot tip from boron deficiency. (J. Portner)

Figure 259: Misshapen, "fluffy-tipped" leaf due to boron deficiency. (T. McGee)

Boron

Boron deficiency can result in delayed emergence of shoots; stunting, distortion, and crinkling of young leaves (Fig. 257); and yellowing and death of shoot tips (Fig. 258). Leaves of affected plants may be small and brittle, and may develop a fluffy-tipped appearance due to impaired development of lobes (Fig. 259). Deficiencies are most common in acid and/or sandy textured soils. Boron deficiency has been suggested as a contributing factor in red crown rot.

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 (Fig. 260, right-hand image, and Fig. 261). Iron deficiency is most common in alkaline soils, although it can be induced in highly acidic soils (approximately pH 5.7 or less) because of enhanced solubility and uptake of manganese.

Iron chlorosis (yellowing) is common when hop plants are forced to grow through the winter in a greenhouse. In these conditions, high nitrogen fertilization and rapid plant growth rates appear to exacerbate iron chlorosis.

Chlorosis of newly formed leaves from temporary iron and zinc deficiency is sometimes observed in spring—when soils are cold and wet— just after plants are fertilized with nitrogen and phosphorous (Fig. 260). This effect is more pronounced in young plantings than mature yards.

Figure 260. Second-year Cascade plants grown side-by-side in a hop yard in Oregon and photographed in mid-May. The plant at right was fertilized in early May with an ammonium nitrate solution and shows typical yellowing between veins associated with iron deficiency, whereas the asymptomatic plant at left was not fertilized. (D.H. Gent)

Magnesium

Symptoms appear first on older leaves as yellowing between leaf veins, and in severe cases can be followed by death of these areas and defoliation (Fig. 262). 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 soil pH below 5.7, which interferes with iron uptake and can induce an iron deficiency.

Root feeding by hop cyst nematode is reported to reduce manganese uptake, as well as uptake of other nutrients.

Molybdenum

Molybdenum deficiencies appear first in older leaves as yellowing and white speckling. Deficiencies have been reported on hop 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. 263). 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 aphids. Efforts should be taken to balance crop demands with nitrogen inputs and to avoid over-application of nitrogen, particularly at times in the season when a pest of concern is present. For instance, large doses of nitrogen applied later in the season (e.g., late June to early July) may induce spider mite outbreaks. Conversely, some evidence suggests that unduly low rates of nitrogen fertilization also may increase spider mites.

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

Solutions of ammonium nitrate are used occasionally to defoliate basal leaves on hop. Some small annual weeds also are sensitive to ammonium nitrate sprays.

Figure 261. Yellowing of the youngest leaves resulting from iron deficiency. Notice that symptoms are less pronounced on older leaves. (J. Portner)

Figure 262. Yellowing and death of tissue between leaf veins caused by magnesium deficiency. (C.B. Skotland)

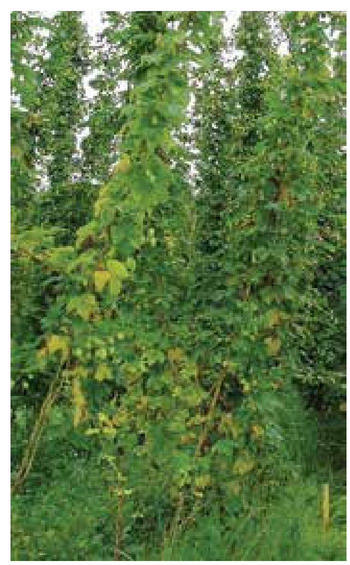


Figure 263. Weak growth and yellowing of lower leaves associated with nitrogen deficiency. (J. Portner)

Soil and Tissue Testing

Growers are encouraged to monitor soil and plant nutrients through soil and petiole/leaf testing to ensure sufficient, yet not excessive, nutrient uptake.

Annual soil testing can provide a snapshot of current soil conditions and guide fertilizer needs to optimize yield and potentially reduce incidence of arthropod pests and disease. At a minimum, testing should include pH (see sidebar on p. 100) and macronutrients such as potassium, phosphorous, calcium, and magnesium. Sulfur can also be assayed, although predicting plants’ needs from soil tests is difficult. Determining levels of the micronutrients boron, iron, manganese, molybdenum, and zinc is also recommended, as deficiencies have been noted in other crops. Soil pH may have to be adjusted over time to ensure proper uptake of these nutrients.

Petiole and tissue testing are also encouraged and can provide an indication of nutrient uptake. Growers should work with local laboratories to determine appropriate protocol for taking and submitting petiole samples. Results should be collected annually and compared with plant growth and yield to best inform management decisions.

pH

Soil pH influences several biological and chemical processes. Excessively low or high pH may induce nutrient deficiencies and/or toxicities, and may interact with disease development.

Surface soil pH acceptable for hop production is reported to **range from 5.7 to 7.5**, although the influence of surface pH on yield is less clear.

Acid soil pH tends to favor Fusarium pathogens, but may suppress Verticillium wilt.

Alkaline soil pH tends to suppress Fusarium diseases (due in part to immobilization of zinc), whereas it favors Verticillium wilt.

The **form of nitrogen applied** can influence pH and, ultimately, susceptibility to certain diseases. Ammonium (NH_4) sources of nitrogen tend to be acidifying, whereas some nitrate (NO_3) fertilizers increase soil pH, therefore selection of a particular form of nitrogen may moderate disease levels in some instances.

Figure 264. Weak growth and reduced side arm development associated with zinc deficiency. (C.B. Skotland)

Phosphorus

Symptoms of deficiency first appear on lower leaves as downcurved, 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 substantially when hop plants are deficient in phosphorous.

In addition to having deleterious effects on water quality, excessive phosphorous fertilization may induce zinc deficiencies, particularly in alkaline soils or soils otherwise marginally deficient in zinc. Phosphorous acid (phosphite) compounds often are applied as part of foliar fertilizers and can suppress downy mildew, black root rot, and, to a limited extent, powdery mildew. However, phosphorous acid itself has no plant nutritive value.

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, and potassium deficiencies may reduce nitrogen use efficiency.

Sulfur

Deficient plants have stunted growth, spindly stems, and yellowing of younger leaves. In general, soils with high leaching potential may be deficient in sulfur. Sulfur is commonly deficient in the acidic, coarse-textured soils of western Oregon.

Zinc

Hop plants are very sensitive to zinc deficiency. Plants deficient in zinc have weak growth, short lateral branches, and poor cone production (Fig. 264). Leaves are small, misshapen, yellow, curl upward, and can become brittle (Fig. 265). 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 can cause remission of symptoms associated with *Apple mosaic virus.*

Figure 265. Cupped, brittle leaves caused by zinc deficiency. (J. Portner)

Resources

For Further Reading

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Iowa State University
Department of Entomology.
http://bugguide.net

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Compendium of Hop Diseases and Pests.
American Phytopathological Society Press,
St. Paul, MN.

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Hops.
Chapman and Hall, London.

Rybáček, V. 1991.
Hop Production.
Developments in
Crop Science Series.
Elsevier.

Pesticide Registration Information

The following resources contain information on current pesticide registrations. Your state's agriculture department is the ultimate authority for up-to-date information on pesticide registration in your hop yard.
See "State Departments of Agriculture," below.

Kelly Solutions, **http://kellysolutions.com**

Pacific Northwest Insect Management Handbook,
http://insect.pnwhandbooks.org

Pacific Northwest Plant Disease Management Handbook,
http://pnwhandbooks.org/plantdisease/

Pacific Northwest Weed Management Handbook,
http://pnwhandbooks.org/weed/

Pesticide Information Center Online (PICOL),
http://cru66.cahe.wsu.edu/LabelTolerance.html
at Washington State Pest Management Resource Service (for Washington and Oregon),
http://extension.wsu.edu/wsprs

State Departments of Agriculture

The U.S. Department of Agriculture Risk Management Agency posts links to each state's department of agriculture on its website at
http://www.rma.usda.gov/other/stateag.html

Future Directions

The 2015 *Pest Management Strategic Plan for U.S. Hops,* funded in part by the USDA National Institute of Food and Agriculture through the Western Integrated Pest Management Center, is available online at
http://www.ipmcenters.org/pmsp/pdf/US-hops-PMSP2015.pdf

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NOTE: When an item is mentioned in multiple places within the guide, the primary citation, if applicable, is given in **bold type**.

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