New England Greenhouse Conference

Powdery mildew on sage.

Greenhouse whiteflies on sage.

PEST MANAGEMENT *for* HERB BEDDING PLANTS GROWN *in the* GREENHOUSE

Leanne Pundt, Extension Educator
Cooperative Extension System
University of Connecticut

Tina Smith, Extension Educator – Floriculture Program
Department of Plant, Soil and Insect Sciences
University of Massachusetts

Salvia officinalis (sage).
(L. Stack, Univ. of ME)

C: Foliar nematodes on sage. Note the affected leaves may turn yellow and brown. Symptoms are easily confused with those caused by fungal or bacterial leaf spots, so samples need to be submitted to a diagnostic lab.

University of Connecticut
COOPERATIVE EXTENSION SYSTEM
College of Agriculture and Natural Resources

UMASS EXTENSION

Adult two-spotted mites have two dark spots on either side of their body. Oval eggs and whitish, empty egg shells can also be (not been) seen. (D. Gilrein, Cornell Univ.)

Fine stippling (flecking) on mint caused by feeding of the two-spotted spider mite.

Catmint with thrips feeding injury. Note white scarring on expanded leaves.

Adult thrips on cards. Note small size when compared to fungus gnat. (J. Sanderson, Cornell Univ.)

Thrips larvae. (J. Sanderson)

Four-lined plant bug on mint. Note brown, dead spots on leaves.

Dark, sooty mold fungus grows on honeydew secreted by soft scales, as well as aphids, white-flies and mealybugs.

Spotted garden slug with eggs. (D. Gilrein, Cornell Univ.)

Brown, soft scale on bay.

Asiatic garden beetle. (D. Gilrein, Cornell Univ.)

(Roger Adams, UConn)

Japanese beetle may feed on basil and other herbs grown outdoors.

Cabbage looper. (T. J. Boucher, UConn)

Adult four-lined plant bug.

PEST MANAGEMENT FOR HERB BEDDING PLANTS GROWN IN THE GREENHOUSE

Leanne Pundt, Extension Educator
Cooperative Extension System
University of Connecticut
http://www.hort.uconn.edu/ipm/ipmghse.htm
http://www.negreenhouseupdate.info

Tina Smith, Extension Educator, Floriculture Program
Department of Plant, Soil and Insect Sciences
University of Massachusetts
http://www.umass.edu/umext/floriculture
http://www.negreenhouseupdate.info

INTRODUCTION

Commercial herb bedding plant production is increasing and with it, a recognition that disease and insect pests can adversely affect their market quality. Herbs can be marketed for their culinary, fragrance, medicinal and ornamental uses. However, they are considered to be a minor or specialty food crop and there are few pesticides registered for use on them. The laws controlling the use of pesticides are more strict for food crops than for ornamentals. A review of pesticide labels indicates only a limited number of insecticides and fungicides are labeled specifically for herbs grown in greenhouses. In addition, no growth regulators are labeled for use on herbs. The maximum safe amount of residues, known as tolerances, must be set for every food use before a pesticide is registered. If the "days to harvest" (the minimum number of days between the last pesticide application and harvest) are followed, the residue on the crop should be below the tolerance level. Most herbs are considered to be "herbs and spices" but a few, such as parsley, may be considered "leafy vegetables" (see tables 3 and 4).

Integrated Pest Management (IPM) offers a practical way to effectively manage pests on herbs. High quality herbs can be grown by using regular monitoring, accurate problem identification, sound cultural practices, and timely implementation and evaluation of appropriate management strategies. IPM brings together all available management options including cultural, physical, mechanical, biological and chemical tactics. Regular monitoring can alert growers to developing pest and cultural problems while they are still minor and can be more easily managed.

To begin, obtain up-to-date cultural information and schedules for producing herbs as bedding plants. Many herbs are native to regions with soils that are neutral to slightly alkaline. They grow best in a very well drained growing media with a pH range of 6.0 to 7.0, but tolerate pH outside of this range.

Herbs generally prefer a drier growing media and lower fertility levels than do bedding plants. Drier growing conditions help prevent diseases such as root rots and *Botrytis*. Some herbs, however, such as basil, parsley and a few mints, prefer moist conditions. Proper scheduling, spacing and sufficient light levels are needed to avoid leggy, overgrown herbs. If started to early, fast growing herbs can easily become overgrown. Most herbs can be grown at the same temperatures as bedding plants: 70 to 75°F day temperatures and 60°F night temperatures.

DISEASE MANAGEMENT

Accurate identification of diseases is essential for effective management. Some diseases of herbs include Botrytis blight, damping off, crown and root rots, web blight, powdery mildew, rusts, fungal leaf spots, vascular wilts, bacterial diseases, viruses and nematodes. Non-infectious diseases or disorders caused by environmental concerns, nutritional imbalances, high soluble salts, improper planting depth (i.e. planting too deeply) or spray injury can mimic infectious diseases or predispose plants to infection. Infectious diseases usually begin on only a few plants, whereas disorders often affect a large number. Sanitation, the use of resistant cultivars, reduction of humidity levels and the appropriate use of fungicides or biofungicides are all part of the integrated approach to disease management that is needed to produce high quality herbs.

Sanitation and the Use of Resistant Cultivars

Start with a clean greenhouse and train employees in proper sanitation procedures. Discard old stock plants and unsold or "pet" plants that may harbor unwanted pests. Eliminate weeds both inside and outside the green-

Dirty hoses left on the greenhouse floor can lead to re-infestation of potting media with pathogens. Use hooks to keep hose nozzles off the floor. (Photo by Tina Smith, University of Massachusetts)

house. Sanitize the benches, walls and floors to eliminate algae and pathogens. Algae provides a breeding ground for shore flies and fungus gnats. After the greenhouse has been sanitized, care must be taken to avoid recontamination with pests and pathogens. Dirty hose nozzles and tools and unsanitary growing conditions can result in reinfestion of potting media. Use hooks to keep hose nozzles off the floor.

Purchase seed and plant material from reliable sources. Use resistant varieties where feasible. Seed catalogues feature a limited number of disease resistant and tolerant varieties of herbs. For example, the basil varieties 'Aroma 2', 'Green Gate' and 'Nufar' have resistance to Fusarium wilt. Produce stock plants from cuttings taken from vigorous, healthy plants that are free of insects and diseases and are true to type. Promptly remove any stock plants that are diseased or low in vigor. To avoid carrying insects and diseases into propagation areas, scout propagation houses before production areas.

Use separate greenhouses for herb production to help protect herbs from any insect or diseases that may be present on ornamentals and to make the treatment of herbs easier if pesticides are needed. Keep stock plants separate from propagation and production areas to help maintain clean stock plants.

Techniques to Reduce Humidity

High relative humidity encourages the development of many foliar diseases including Botrytis blight, powdery mildew and Rhizoctonia web blight. Reduce condensation by using horizontal airflow (HAF). HAF fans help to keep air moving in the greenhouse. Air that is moving is continually mixed. The use of HAF helps to minimize temperature differentials in the greenhouse and prevent cold spots where condensation occurs. The mixed air along the surface does not cool below the dew point, so condensation does not form on plant surfaces. The use of computer control systems for environmental modification allows reduction of humidity levels to less than 85%.

Condensation can also be reduced by heating and venting the warm moist greenhouse air. Heat and vent 2 to 3 times per hour in the evening after the sun sets and early in the morning at sunrise. Many herb growers also use oversized vent fans and louvers to increase airflow in their greenhouses. Always water early in the day so the plant foliage can dry before nightfall to help prevent foliar diseases. Space plants so sufficient air circulation exists between them.

Biofungicides

Biofungicides are fungicides that contain living organisms such as fungi and bacteria. They must be used preventatively as they will not cure diseased plants. Biofungicides may suppress plant diseases by competition, attacking or feeding on the pathogen, or by producing secondary toxins that can inhibit the growth of pathogens.

Many different types of biofungicides are being used with variable results by growers. These variable results may be due to differences in the particular crop or plant, the soil mix used, the soil pH, the fertilizer program and the level of disease pressure. Herbs highly susceptible to crown and root rots may not respond to biofungicides as well as herbs that are less susceptible to root diseases. Soil pH may also influence the activity of these products. If susceptible herbs are overfertilized or overwatered, Pythium root rot can cause significant damage whether or not a biofungicide had been applied.

Growers can conduct their own trials by leaving a small portion of plants untreated to act as a control. This way the effect of the biofungicide on crop growth and root health can be evaluated. Regular root inspections are needed to determine if roots are healthy and free from disease. Several products are labeled specifically for herbs (see table 4).

Specific Diseases

Botrytis Blight

Botrytis cineraria may cause leaf blights, stem cankers, damping off and, occasionally, root rot. Plants may be attacked at any stage, but tender new growth and freshly injured and dying tissues are the most susceptible.

Symptoms: *Botrytis* produces gray, fuzzy-appearing spores on the surface of infected tissues under humid conditions. Almost all herbs are susceptible but **basil, lemon balm, parsley** and **thyme** may be especially vulnerable. Air currents and splashing water can easily disseminate the spores. Favorable environmental conditions include a film of moisture for 8 to 12 hours, relative humidity of 93% or greater, and temperatures between 55° and 65°F. After infection, colonization of plant tissues can occur at temperatures up to 70°F.

Management: Management of environmental conditions such as temperature, humidity and duration of leaf wetness, sound cultural practices and fungicides help prevent disease development.

1. Control weeds and remove plant debris between crop cycles and during production. Dispose of diseased plants and debris in a plastic trash bag. To avoid spreading spores to uninfected plants, keep the bag closed while moving it through the greenhouse.
2. Provide good air circulation and reduce humidity within the canopy. Proper planting dates, fertility, watering and height management prevent overgrown plants, thereby reducing humidity within the canopy.
3. Water in the morning, never late in the day. Rising daytime temperatures causes water to evaporate from the foliage and dry the leaf surface.

Damping off, Crown and Root Rot

Damping-off is a common disease of germinating seeds

and young seedlings. Several fungi such as *Pythium*, *Rhizoctonia*, *Alternaria*, *Sclerotinia* and *Phytophthora* cause damping-off. These fungi are easily transported from contaminated soil to pathogen-free soil by infected tools, hose ends, water splash and hands. Young seedlings are most susceptible to damping-off. However, later in the crop cycle, the same pathogens may cause root and stem rots.

Symptoms: Infected seeds fail to germinate. Seedlings may also collapse with a dark, necrotic stem canker at the soil line. Seeds that germinate slowly, such as parsley, are especially susceptible.

When mature plants are infected with crown and root rot, leaves turn yellow and wilt and plants are stunted. Roots are often discolored and turn black or dark brown. When infected with root rots, the outer cortex of the root sloughs off leaving a central core. High moisture levels and high soluble salts favor the development of *Pythium*.

Drier soil, however, favors *Rhizoctonia*, an organism that is more active in the upper portion of the media. *Rhizoctonia* can also grow up from the soil causing web blight. Stems and leaves collapse rapidly and turn mushy with fine, web-like fungal mycelium present. Dense, lush plant canopies, and humid conditions favor the development of web blight. Proper plant spacing is needed to insure adequate airflow around plants. **Rosemary, basil, mints, parsley, rue, thyme** and many other herbs are susceptible to web blight.

Fungus gnats and shore flies may also spread these fungi. Many herbs, such as **lavender**, **parsley**, **dill**, **Corsican mint**, **basil**, **rue**, **sage**, **thyme** and **rosemary** are susceptible to fungi that cause crown and root rots.

Management:

1. Use pasteurized soil, compost-based or soil-less mixes.
2. Disinfect all used flats, cold frames, pots and tools between crop cycles.
3. Use bottom heat to promote rapid germination of seed.
4. Avoid over-watering, excessive fertilizer, overcrowding, planting too deeply and careless handling.
5. Provide adequate light for rapid growth.
6. Promptly rogue out infected plants.
7. Manage fungus gnats and shore flies to reduce the potential for spread, especially during propagation.
8. Use appropriate biofungicides (see table 4).

Powdery Mildew

Most growers are familiar with the white, powdery growth that is characteristic of powdery mildew. Powdery mildew, unlike many foliar diseases, does not need free moisture on the leaf for spores to germinate. Favorable environmental conditions include high relative humidity (greater than 70%) and temperatures between 68 to 86°F. Fungal spores are easily spread by air currents and splashing water. Once a spore lands on a plant, it may take as little as 3 days, but more often 5 to 7 days, for the infection to develop into a visible colony.

Symptoms: Powdery mildew develops first on older leaves and is often overlooked. Scout weekly for early detection. Inspect susceptible crops and scout areas near vents, hanging baskets or any location with a sharp change between day and night temperatures. Look on both the upper and lower surfaces of leaves for signs of the white, powdery fungal growth. Use a hand lens to see the white fungal threads radiating from a central point and the chains of powdery mildew spores. These structures distinguish this disease from the whitish-spray residue, which has a droplet-like outline. Many herbs such as **rosemary**, **sage**, **mint**, **St. Johnswort** and **bee balm** are susceptible to powdery mildew.

Management:

1. Remove infected plants. Place affected plants in a plastic bag to avoid spreading the airborne spores to uninfected plants as you remove infected material.
2. Use proper spacing to increase air movement around plants and for better spray coverage.
3. Keep relative humidity levels below 70% in the greenhouse.
4. Use wire mesh or other benching that facilitates air movement.
5. Clean the greenhouse between crops. Powdery mildew may overwinter on certain weed hosts.
6. Use resistant cultivars whenever possible.
7. As soon as powdery mildew is detected, use appropriate biofungicides or fungicides (see table 4).

Rusts

Rust fungi are highly specialized fungi with complex life cycles. Some types of rust may need two different hosts to complete their life cycle, whereas other types only need one host. Cool temperatures and free moisture on leaves favor their development.

Symptoms: Rust diseases are easy to identify by the reddish-brown spores found in masses on the undersides of leaves. Rust caused by *Puccinia menthae* may infect spearmint and peppermint. This type of rust does not need an alternative host to complete its development. Look for yellow leaf spots on the upper surface and cinnamon-brown rust pustules on the undersides of the lower leaves. A rust disease caused by *Puccinia nakanishikii* may occur on lemon grass. Elongated, stripe-like rusty-brown lesions occur on the undersides of leaves.

Management: Destroy infested plants promptly. Do not take cuttings from infested plants. Discard plants and try a more resistant variety. The improved spearmint or Kentucky Colonel mint is less susceptible than the stan-

dard spearmint. The peppermint cultivars 'Murray Mitcham' and 'Todd's Mitcham' are also resistant to rust under moderate disease pressure. As soon as rust is detected, use appropriate fungicides (see table 4).

Fungal Leaf Spots

Fungal leaf spots caused by *Alternaria, Septoria* and other fungi may occasionally be seen on herbs. Alternaria leaf spots are generally dark brown to black with a yellow border. Septoria leaf spots are small and grayish brown with a dark brown edge. With a hand lens, you may see the dark fruiting bodies of septoria (which look like pepper) in the center of the leaf spot on **lavender**. Splashing water spreads fungal spores. These diseases may be carried over from season to season on infected seed or plant debris in the field.

Anthracnose caused by *Colletotrichum* causes reddening of the foliage and dieback on **St. John's-wort** (*Hypericum*). It can spread by contaminated seeds and then by water splash via overhead irrigation. *Hypericum perforatum* 'Helos' has shown tolerance to the disease. Some seed companies test their seed for this disease.

Management: Growers should select the healthiest and most disease resistant cultivars that are available. Cultural practices used to manage *Botrytis* will also help to manage leaf spots.

Fusarium Wilt of Basil

Vascular wilts are diseases in which the vascular tissue is systemically invaded by pathogens. As the vascular system is clogged, plants wilt. *Fusarium oxysporum f. sp. basilicum* causes fusarium wilt of basil. This disease was first reported in the United States on infected basil seed in the early 1990s.

Symptoms: A downward bending or cupping of the leaves is often the first symptom of fusarium wilt. Sometimes the top of the stem bends like a shepherd's crook. On large-leafed cultivars, defoliation may occur. If young basil plants become infected, stunting is usually evident before wilting occurs. In later stages of fusarium wilt, brown streaks can be seen on the stem. Basil can also wilt due to water stress, root rot diseases, or *Botrytis* stem canker, so confirmation is recommended by sending samples to a diagnostic laboratory. Above ground symptoms of fusarium wilt may be similar to those caused by root rot pathogens. However, plants infected with fusarium wilt generally have healthy roots compared to plants wilted due to a root rot disease.

Management: Fusarium wilt is very difficult to manage. Begin with disease-free seed and request that your seed suppliers test their seed. However, testing is not 100% guaranteed because conventional testing methods are not very sensitive. The varieties 'Aroma 2', 'Green Gate' are 'Nufar' have resistance to Fusarium wilt.

Fusarium is a soil inhabitant that can become established in the field. Crop rotation should exclude members of the mint family, for some mints can be symptomless carriers of *Fusarium*.

Bacterial Diseases

Herbs, like other greenhouse crops, are susceptible to bacterial diseases. Bacterial diseases generally survive in infected plants, in debris from infected plants and, in a few cases, in soil. Bacteria require a wound or natural opening in the plant to gain entry. Bacterial diseases of herbs include bacterial blight on scented geraniums, Pseudomonas leaf spot on basil and bacterial fasciation. Symptoms caused by bacteria are often indistinguishable from those caused by fungi and must be accurately identified by a diagnostic laboratory.

Scented geraniums are susceptible to bacterial blight caused by the pathogen *Xanthomonas campestris* pv. *pelargonii*. Characteristic symptoms associated with this disease are wilting, small leaf spots and V-shaped angular lesions. However, infected plants may not show any symptoms. These infected plants appear healthy and can serve as a source of this disease for the more susceptible zonal and seed geraniums. Keep scented or specialty geraniums away from seed and zonal geraniums to reduce the potential for infection. Bacteria are easily spread by splashing water and by handling plants. Protect plants from water drip from hanging baskets and water condensation on the inside of the greenhouse.

Pseudomonas leafspots are generally water-soaked and dark brown to black and angular in shape. Plugs may be especially vulnerable to infection due to the moist, wet conditions.

Bacterial fasciation results in abnormal branching and stem development near the base of infected plants of scented geraniums. Shoots are short, swollen, fleshy and produce misshapen leaves. Plants are not killed, but their growth is stunted. The bacterium (*Rhodococcus fascians*) is carried on infected cuttings. To manage, discard infected plants.

Management:

1. Disinfect all benches, equipment and pots.
2. Purchase culture-indexed plants known to be free of the most important bacterial pathogens.
3. Do not use overhead irrigation. Keep the foliage dry at all times.
4. Discard infected plants.
5. At the end of the season, do not hold over any plants. Rake up any plant debris, as the bacteria can survive in dead leaves.

Viruses

Viruses are ultra-microscopic infectious particles that multiply only within living host plant cells. Viruses can spread systemically throughout the host plant and some

plants may be infected even when symptoms are not apparent. Some, like tobacco ringspot virus on rosemary, have a narrow host range, while others, like cucumber mosaic virus (CMV), tobacco mosaic virus (TMV) and topsoviruses (such as impatiens necrotic spot virus), can infect a wide variety of herbs as well as other plants. There is no cure for infected plants. Virus infections are usually systemic and are often transmitted through vegetative propagation. Plants vegetatively propagated from stock plants infected with a virus also carry the virus. Depending upon the type, transmission can occur in a number of ways. Tobacco mosaic virus can be transmitted through the handling of plants or the use of contaminated tools, but not by insects. However, insect vectors can transmit a number of viruses. For example, aphids transmit cucumber mosaic virus and thrips vector tospoviruses.

Symptoms: Symptoms include mosaic patterns on the foliage, leaf crinkle or distortion, chlorotic streaking, ringspots, line patterns and distinct yellowing of veins. Plants may also be stunted. However, remember that plants can be infected and not show any visible symptoms.

Management: Submit potentially infected plants to the plant diagnostic laboratory for accurate identification. Management includes starting crops with virus-free seed or cuttings, eradication of weed hosts, reducing insect vectors and discarding infected plant material.

Foliar Nematodes

Foliar nematodes (*Aphelenchoides spp.*), microscopic roundworms that live in plant foliage, can occasionally occur on herbs. These nematodes enter plant tissue through stomates and then feed and reproduce within the plant. Foliar nematodes can be spread by splashing water. Affected leaves may turn pale green, yellow or brown. Symptoms are easily confused with those caused by fungal or bacterial leaf spots, so samples need to be submitted to a diagnostic laboratory for confirmation.

Insect and Mite Pest Management

A regular monitoring program is the basis of all pest management programs. Establish a monitoring and record-keeping system for all crop production areas including stock plants, propagation areas and outdoor yards. Conduct a regular, routine scouting program that consists of sticky cards, random plant inspections and using key indicator plants to detect problems early. This early detection and treatment, when plant canopies are still small, results in better spray coverage and better pest control. With limited pesticides available for use, spray applications need to be as effective as possible. Use a sprayer that can generate a very fine droplet size. Many insecticides registered for use on herbs work by contact, so achieving good spray coverage is essential to obtaining good control. Water-sensitive cards can be used to determine your spray coverage.

Insect screening can be used to exclude insects from the greenhouse, especially from propagation areas. Before installing screening, determine which insects you need to exclude and how to use the screening. Insect screening is only effective if the screened area is the only access point for insects. Proper design is needed for adequate ventilation. If improperly designed, the fans may become overheated. See reference listed at the end of this publication for additional information.

Sticky Cards

Use yellow sticky cards to detect adult whiteflies, aphids, thrips, fungus gnats and shore flies (see figure 1). Place 1 to 4 cards per 1000 square feet. Space cards equally throughout the greenhouse in a grid pattern, with additional cards placed near doorways and vents. Inspect cards each week, identifying and counting the insects. Record the information on a scouting form (forms are available at the University of Connecticut IPM Web site at ***http://www.hort.uconn.edu/IPM/***). Replace the cards weekly to keep track of population trends. In crops that

Figure 1: Identifying insects on sticky cards. [From: Baker, J.R. 1986. Insects on *Sticky Traps* 30(1)5-9.]

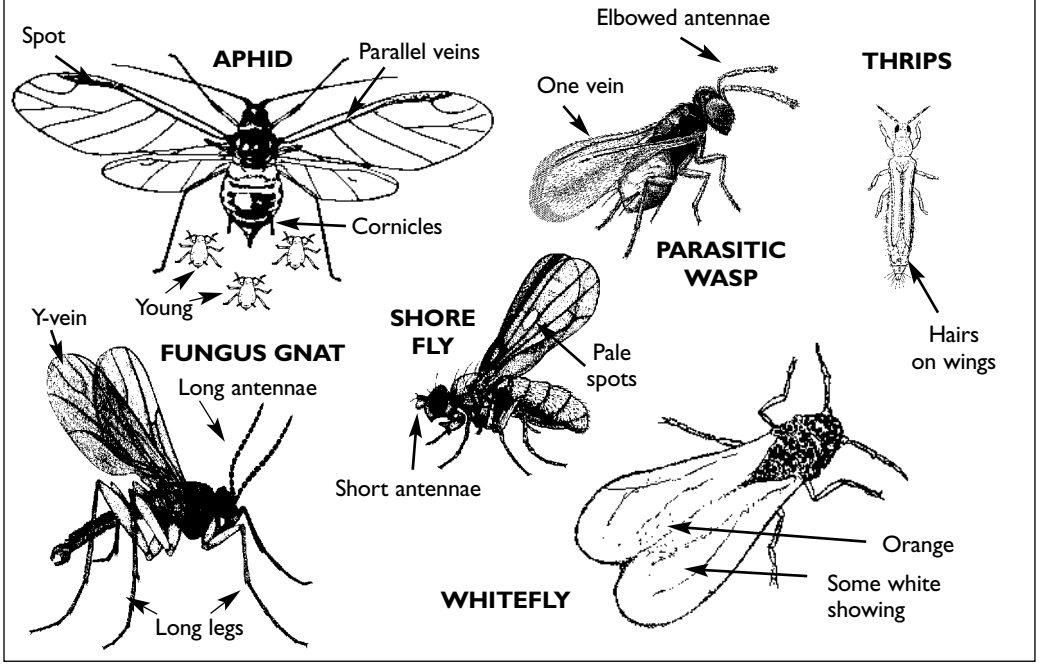


TABLE 1: SOME KEY PESTS OF HERBS.	
Plant	**Pest(s)**
Basil	Primarily thrips, also aphids, whiteflies. Botrytis blight, Fusarium wilt, Pythium and Rhizoctonia root rots, Rhizoctonia web blight, Impatiens necrotic spot virus.
Lavender	Aphids, whiteflies, mites, mealybugs. Primarily crown and root rots, also Botrytis blight, Septoria leaf spot.
Lemon Balm	Primarily mites, also aphids, whiteflies. Botrytis blight.
Lemon Grass	Mites, thrips, rust.
Lemon Verbena	Aphids, mites and whiteflies.
Marjoram	Whiteflies, Botrytis blight.
Mint	Primarily whiteflies, mites, also aphids, thrips Crown and root rots, Rhizoctonia web blight, powdery mildew, rust (peppermint and spearmint).
Parsley	Primarily root rots, also Botrytis blight, Rhizoctonia web blight.
Rosemary	Whiteflies, aphids, and thrips. Primarily powdery mildew, also Pythium and Rhizoctonia root rots, Rhizoctonia web blight.
Rue	Aphids, whiteflies. Crown and root rots.
Sage	Primarily whiteflies, also mites and aphids. Primarily powdery mildew, also Phytophthora root rot.
Scented Geranium	Primarily whiteflies. Bacterial blight (Xanthomonas), Bacterial fasciation.
St. Johnswort	Anthracnose, powdery mildew.
Thyme	Aphids, thrips. Crown and root rots, Rhizoctonia web blight, Botrytis blight.

are especially prone to thrips, growers may consider using blue sticky cards which are more attractive to thrips than the yellow cards.*

*If using parasitic wasps for biological control, discontinue the use of sticky cards for monitoring. Parasitic wasps are attracted to the sticky cards.

Plant Inspection

In greenhouses and outdoor production areas, plant inspection is needed to detect cultural problems and diseases, and to assess general plant health. Plant inspection is also needed to detect aphids, fungus gnats and thrips larvae, immature whiteflies and mites. Use a 10 to 20x hand lens or a hands-free magnifier (Optivisor) to identify these key pests and their life stage. When scouting, avoid wearing light colors (especially yellow), so insects are not attracted and then carried on clothing from one area to another. Based upon your scouting records, monitor least infested areas first and the most heavily infested areas last. Examine stock plants before cuttings to reduce

Use a 10x hands-free magnifer or hand lens to identify insects and their life stage. (Photo by Tina Smith)

the possibility of infesting the stock plants. When stock plants are held at lower temperatures, insects are less active, so plant inspections are more important than card counts during the winter months.

Randomly select plants at 10 locations in an area of 1000 square feet, examining plants on each side of the aisle. Start this pattern at a slightly different location each week, walking through the greenhouse in a zigzag pattern down the aisles. Look on the undersides of leaves for insects and mites, and inspect root systems. Become familiar with key plants and their associated pests so you know which insects and diseases are most likely to cause problems. Key plants are those herbs most likely to have pest problems (see table 1).

Record Keeping and Decision Making

Each time the crop is scouted, record pest numbers and location and number of plants inspected. This helps you identify population trends and indicates if initial control measures were successful or if they need to be repeated. Tables 3 and 4 provide a list of selected materials for use on herbs. The product must be used only for crops on which the compound is registered.

Biological Control for Insects and Mites

Biological control can be an option for aphids, mites, fungus gnats, thrips and whiteflies. Natural enemies are living organisms that need to be released when pest populations are low. They do not act as quickly as pesticides, so cannot be used as a rescue treatment. Some herbs may have such fast turnover that the natural enemies need to be established on longer-term crops. It takes commitment and time to learn the biology and life cycles of the insect pests and their natural enemies. Start in a small isolated area or separate greenhouse to learn how to use natural enemies.

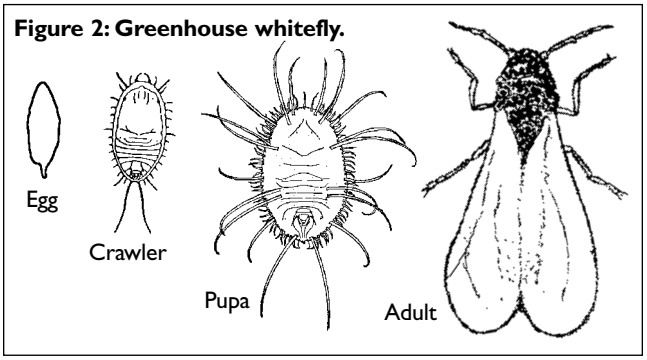
Before beginning biological control, you need to have a regular scouting program established. Natural enemies, especially parasites, are often specific to a pest or may be shipped in a stage that does not attack the targeted pest. Careful planning is needed before starting a biological control program. Many insecticide residues can adversely affect natural enemies for up to three months after their application. For example, pyrethrins may be very harmful to the adults of certain species of natural enemies.

In general, horticultural oils and insecticidal soaps once they have dried are fairly compatible with natural enemies. However, any adult beneficial insects contacted by these sprays will be killed. Many insect growth regulators, such as azadirachtin, are also fairly compatible to certain natural enemies but further research is needed. Koppert Biological Systems has compiled a list of pesticides and their effects on natural enemies (see the web site ***www.koppert.com*** and click onto "side effects").

A useful directory for choosing a natural enemy supplier is "Suppliers of Beneficial Organisms in North America" by Charles Hunter (See the web site ***www.cdpr.ca.gov/docs/ipminov/ben_supp/contents.htm***). This directory is also available from the California Environmental Protection Agency, Department of Pesticide Regulation, Environmental Monitoring and Pest Management Branch, 830 K Street, Sacramento, CA 95814.

Research in biological control is ongoing, so check with your university specialist on new developments before beginning a program. Work with your supplier and university specialist to determine specific release rates and timing. Become familiar with the environmental conditions needed by the natural enemies when they are released in the greenhouse. Be sure that the natural enemies are received quickly (1 to 2 days) and kept cool during shipment. Inspect them for viability and quality when they are received.

Figure 2: Greenhouse whitefly.



Specific Insect Pests and Mites

Whiteflies

Whiteflies are powdery-white insects approximately 1/16 of an inch long with piercing-sucking mouthparts. The most common species found in greenhouses are the greenhouse whitefly (*Trialeurodes vaporariorum*) and the silverleaf whitefly (*Bemisia argentofolii*). Whiteflies may attack a wide range of herbs including **mint, lavender, pineapple sage, lemon balm, rosemary, marjoram, oregano, sage, rue, scented geraniums, basil** and **lemon verbena**. When high populations develop, honeydew and sooty mold may be seen. Adult whiteflies lay their eggs on the tender young growth. The immature scale-like crawlers can be found on the undersides of the leaves. Their life cycle from egg to adult takes from 3 to 5 weeks depending upon greenhouse temperatures.

Monitor adult whiteflies using yellow sticky cards. Monitor immature stages on the undersides of leaves during weekly foliage inspections. Adults are found on the tender young growth and the pupae tend to be found on the 3-week-old leaves. See figure 2.

Management:

1. Eliminate weeds.
2. Inspect incoming plants.
3. Use insecticides. Repeat applications are often needed.

When using contact materials, be sure to obtain thorough coverage to the undersides of the leaves where the immature and adults stages are found.

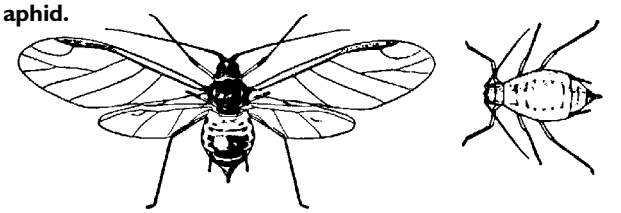
Several natural enemies are commercially available. *Encarsia formosa* is a small, parasitic wasp that attacks both greenhouse and silverleaf whiteflies. However, it is more effective against the greenhouse whitefly. *Encarsia* is sold as parasitized greenhouse whitefly pupae that are glued onto small cards. These cards can be hung on lower leaf petioles. *Encarsia* needs to be released as soon as the first whiteflies are detected and repeated releases are often needed. The adults are especially sensitive to many different pesticide residues.

Eretmocerus eremicus is a small, lemon-yellow wasp with green eyes and clubbed antennae. It is more effective than *Encarsia* against the silverleaf whitefly. *Eretmocerus* is native to the desert regions of Arizona and California, and appears to be better adapted to high temperatures in greenhouses. Whitefly nymphs can be killed by feeding or by parasitization.

Delphastus catalinae is a predatory lady bird beetle that can feed on all stages of whiteflies. Both immature and adult beetles are predacious. *Delphastus* is most likely to establish in hot spots and may be used to supplement other natural enemies.

Beauveria bassiana, the insect pathogen, is most effective against whitefly nymphs. Thorough coverage is necessary on leaf undersides where whitefly nymphs are found.

Figure 3: Winged and wingless forms of green peach aphid.



Aphids

Aphids are small (less than 1/8 of an inch long) soft-bodied insects, with piercing-sucking mouth parts. Green peach (*Myzus persicae*), melon/cotton (*Aphis gossypii*) and foxglove (*Aulacorthum solani*) aphids are commonly found in the greenhouse. Many herbs, including **lemon verbena, curry plant, rosemary, oregano, lemon balm, dill, basil, lavender, mint, thyme, sage** and **rue** are susceptible to aphids. Look for wingless aphids on the young, tender growth. Signs of aphid infestation include whitish, cast skins, honeydew, and sootymold. The foxglove aphid may cause more leaf distortion on tender new growth than the green peach aphid. Winged aphids appear when the colony becomes overcrowded or when they migrate to new hosts.

Aphids give birth to live young (100 to 200 nymphs) in the greenhouse. They can, in turn, give birth to young in as little as 7 to 10 days. Therefore, populations can increase rapidly. Aphids may enter greenhouses on incoming plants, on worker's clothing or through vents. Weeds are often an overlooked source of continuing aphid infestations. See figure 3.

Management:

1. Eliminate weeds.
2. Inspect incoming plants for signs of aphids.
3. Use chemical controls. Repeat applications are often needed (see table 3).
4. Use biological control.

Several different biological controls are commercially available for use in the greenhouse. A predatory midge, *Aphidoletes aphidimyza*, is sold in the pupal stage and packed in moist vermiculite. The short-lived adults are rarely seen, as they search for aphids at night. The bright orange larvae kill aphids by biting their knee joints, injecting a paralyzing toxin and sucking out body fluids. The larvae drop to the ground to pupate, so sawdust, peat or holes in the weed mat barrier are helpful, but not essential to provide pupation sites. Aphid midges complete their life cycle from egg to adult in 3 to 4 weeks. They are most effective in the summer and will go into a diapause (dormant period) during cool, short days unless supplemental lighting is provided.

The green lacewing, *Chrysoperla rufilabris*, can be purchased in the egg or larval stage. Adults feed on nectar, pollen and honeydew. The larvae (also known as aphid lions) prefer to feed on aphids but also eat some mites and whiteflies. Aphid lions, which grow to 1/2 inch long, are light-colored and mottled, with large sickle-shaped mouthparts. Lacewings can also feed upon each other, so they must be released as far apart as possible to discourage cannibalism. Their life cycle from egg to adult takes about 4 weeks.

The convergent lady beetle, *Hippodamia convergens*, feeds upon many different types of aphids and other soft-bodied insects. Eggs are laid near abundant prey. Their life cycle from egg to adult takes about 4 weeks. Ladybird beetles will not establish in the greenhouse. Continued releases every 3 to 4 days are needed to assure coverage over time.

Different species of parasitic wasps are also commercially available. *Aphidius matricariae* attacks green peach aphids, whereas A. *colemani* attacks both green peach and melon aphids. These small parasitic wasps lay their eggs inside the aphid. The aphid is killed as the developing larvae first feed upon it and then spin their cocoons. The brown, swollen exoskeleton of the aphid remains, resembling a sesame seed with small, round exit holes where the parasitic wasp emerged. Parasitic wasp adults feed on nectar and honeydew. Avoid using yellow sticky cards if using parasitic wasps for they will be trapped on the cards. Do not release in bright sunlight, as they will get

trapped in any condensation on the glazing. During the summer, certain species of parasitic wasps commonly enter greenhouses from outdoors and attack aphids. In display beds outdoors, natural enemies, including ladybird beetles, lacewings, flower flies (also known as hover flies) and fungal diseases also help to manage aphid populations.

Beauveria bassiana is an insect-killing fungus that can be used at the first sign of aphids. Repeat applications are needed to contact those aphids that may have shed their skins before becoming infected by the fungus.

Two-spotted Spider Mites

Adult female two-spotted spider mites (*Tetranychus urticae*) are approximately 1/50 of an inch long and whitish to slightly orange in color. When mature, they have two dark spots on either side of their bodies. Their life cycle from egg to adult can be completed in 7 to 14 days depending upon temperature. Females may lay up to 100 eggs during their 3 to 4 week lifespan.

Mites have piercing mouthparts. As they feed, chlorophyll is removed and leaves become flecked or stippled. Leaves may also turn yellow and drop, and webbing may be seen when outbreaks occur. Many herbs are susceptible to mites including **lemon balm, lemon verbena, lemon grass, mint, pineapple sage, sage** and **oregano**. Scout for mites and signs of their damage in hot, dry areas of a greenhouse. A 10 to 20x hand lens is necessary to see the eggs, nymphs and adults of both the two-spotted spider mites and the predatory mites. Turn leaves over and look for the mites along the veins, or tap foliage over a white sheet of paper, to look for both the two-spotted spider mites and the faster-moving predatory mites.

Management:

1. Eliminate weeds in and around the greenhouse.
2. Sprays can be applied to locally infested areas. Many of the miticides labeled for herbs work by contact and have no residual activity. Follow-up inspections are needed to determine if repeat treatments are needed. When using contact materials, be sure to obtain good coverage to the undersides of the leaves.

Several different species of predatory mites are commercially available. They can drive down an outbreak, but can only prevent leaf damage if they are released when spider mite populations are low.

Phytosieulus persimilis feeds on all stages of the two-spotted mites and is the most commonly used predatory mite in greenhouses. This hungry predator can quickly gain control of a spider mite outbreak. It does not hibernate and dies when its prey is eliminated. *P. persimilis* performs best under humid conditions and moderate temperatures. Relative humidities greater than 60% are needed for this predatory mite to survive, especially in the egg stage. *Neoseiulus californicus* is slower acting than *P. persimilis*, but can survive longer in the absence of prey. It is useful for keeping low mite populations under control. *Amblyseius fallacis*, is native to the North, so this mite species may be useful in outdoor applications. Combinations of different species are also available and may be more effective under changing environmental conditions and pest densities.

A tiny predatory midge larva, *Feltiella acarisuga*, also feeds on two-spotted mites. This midge prefers humid conditions and is able to forage on hairy leaves. It is commercially shipped in the pupal stage and hatches into midge adults on arrival. These adults lay eggs near spider mite infestations.

Thrips

Thrips are small and tend to feed in plant buds and flowers, so considerable damage can occur before they are detected. The most common and destructive thrips species in greenhouses is the western flower thrips (*Frankliniella occidentalis*). This species also transmits tospoviruses (impatiens necrotic spot virus and tomato spotted wilt virus). Adults are about 1/16 of an inch long with narrow bodies and fringed wings. The small yellow larvae can be found on the foliage. Thrips feeding damage results in white scars on expanded leaves or flowers. After thrips feed within developing buds, the leaves or flowers become distorted. Many herbs including **basil, French tarragon, mint, lemon grass, rosemary, sage** and **thyme** are susceptible to thrips. The life cycle from egg to adult varies from 8 to 44 days depending upon greenhouse temperatures.

Use yellow or blue sticky cards to detect adult thrips. Look for feeding damage during routine foliage inspection. Tap foliage over a sheet of white paper and use a 10 to 20x hand lens to see the adult or larval thrips.

Management:

1. Eliminate weeds inside and outside the greenhouse.
2. Inspect incoming plants.
3. Several insecticide treatments are suggested at 3 to 5 day intervals (depending upon temperature) using spray equipment that produces very small-diameter spray droplets which can penetrate growing points, flowers and other areas where thrips feed.
4. Thrips populations on cards tend to peak every 2 to 3 weeks. Apply insecticides before this peak, so the adults are killed before they lay eggs. Rotation between classes of insecticides may help to delay the development of resistance to certain insecticides.

Several biological control options are commercially available. *Neoseiulus cucumeris*, is a small predatory mite that feeds upon the small, first instar thrips larvae and can also feed upon pollen. It is sold in bulk (mixed with wheat bran) or in sachets containing both the mites and grain mites as live prey. *Hypoaspis miles* feeds upon thrips

pupae in the soil.

Orius insidiosus, the minute pirate bug, attacks all stages of thrips by sucking out their body fluids. *Orius* feeds upon pollen, as well as spider mites and aphids.

The insect pathogen, *Beauveria bassiana*, may help to suppress thrips populations. This biopesticide creates an infection as the fungal spores penetrate the host insect. Good coverage is needed to contact the thrips.

Plant Bugs

Four-lined (*Poecilocapsus lineatus*) and tarnished plant bugs (*Lygus lineolaris*) are common on herbs grown outdoors and may enter greenhouses through vents, especially from weedy outdoor areas. Four-lined plant bugs are 1/4 of an inch long, yellow or greenish in color with 4 characteristic black lines, and are commonly found on mints. Feeding damage results in leaves with brown, dead spots that are often confused with a fungal leaf spot disease. Four-lined plant bugs are timid insects and hide under leaves when disturbed.

Tarnished plant bugs are 1/5 of an inch long and bronze in color with yellow and black dashes. Adults and nymphs feed on plant sap using long sucking mouth parts. They also inject a toxin that causes death of the tissue. Symptoms may include death of tender young growth, dead spots, and badly distorted buds. The life cycle from egg to adult takes 3 to 4 weeks.

Monitor feeding damage through routine plant inspections. Management includes removal of trash, debris and weeds from production areas, and treating plants with an insecticide. Naturally occurring predators include big-eyed bugs and damsel bugs. The big-eyed bug, *Geocoris punctipes*, is available commercially.

Scales and Mealybugs

One of the more common types of scale insects found in greenhouses is the brown soft scale, *Coccus hesperidum*. Adult females are oval in shape, 1/10 of an inch long, yellowish brown when young and becoming darker brown as they age. Crawlers are yellow and flat. Scale insects are often found along the veins and on the stem. Brown soft scale can produce large amounts of honeydew, resulting in the growth of sooty mold. This scale, as well as many others, may be found on sweet bay (*Laurus nobilis*). The parasitic wasp, *Metaphycus helvolus*, is commercially available as a natural enemy for brown soft scale.

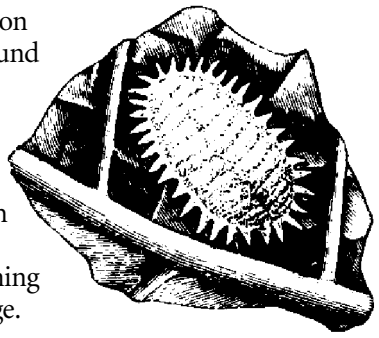


Figure 4: Adult mealybug.

Mealybugs may be occasional pests of herbs that are carried over or those herbs propagated by cuttings such as rosemary. Mealybugs are small, oval soft-bodied insects covered with a white, cottony wax-like layer. They can affect all parts of a plant, some types even feed upon roots (see figure 4). The Australian ladybug, *Cryptolaemus montrouzieri*, consumes all stages of the citrus mealybug and is released as an adult. Both adults and larvae will feed upon mealybugs. It prefers warm temperatures and a relative humidity between 70%-80%.

Fungus Gnats

The moist greenhouse environment favors both fungus gnats (*Bradysia spp.*) and shore flies (*Scatella stagnalis*). Fungus gnats are common pests in propagation areas. Adult fungus gnats are small (1/8 of an inch long), mosquito-like flies with long legs and antennae. They are often confused with the shore flies that feed upon algae growing in moist areas in the greenhouse. Adult shore flies are 1/8 of an inch long, robust, with short legs and antennae and 5 light spots on their wings. Shore flies are primarily an annoyance and are not believed to cause direct plant damage. They are best managed by controlling algae, their food source. See figure 5.

Female fungus gnats lay up to 300 eggs in the upper surface of moist growing media. Eggs develop into translucent legless larvae with shiny black heads. Fungus gnat larvae feed upon the developing callus of young cuttings and can delay rooting. They also feed upon young roots and cause wilting and plant death. Their life cycle from egg to adult takes 3 to 4 weeks. Overlapping generations can occur in the greenhouse.

Figure 5: Adult fungus gnat compared to shore fly.

Fungus gnat larvae. (Photo by Richard Lindquist)

Monitor for adult fungus gnats by placing yellow sticky cards at the soil line at the base of plants. Monitor for larvae by placing raw, peeled potato chunks on the soil surface and checking them after 48 hours for the larvae.

Management:

1. Use proper watering techniques. Avoid overwatering, which contributes to high moisture levels in the potting media as well as to puddling on the floor.
2. Store media in a dry location.
3. Keep floor as dry and weed-free as possible.

Soil treatments are directed toward the larval stage and are most effective against the young larvae early in the production cycle. Several biological control options are available.

Certain species of insect-killing nematodes (*Steinernema feltiae*) can be applied as a soil drench against fungus gnat larvae. These beneficial nematodes enter the insect's body through openings in their exoskeleton. The nematodes multiply inside the host and release a bacterium that is toxic to the host insect. They reproduce within the fungus gnat larvae, exit the dead body and will search for new hosts to infect.

Bacillus thuringiensis subsp. *israelensis*, is an insect pathogen sold under the name of Gnatrol. This bacterium consists of viable endospores and crystals that must be ingested by the larvae. Gnatrol is most effective against young, actively feeding larvae. It is applied weekly as a soil drench to pots or under the benches where the larvae are found. Gnatrol is labeled for leafy vegetables. Some herbs, such as fresh chervil and parsley, are listed by the EPA under the crop heading of leafy vegetables.

Hypoaspis miles is a small predatory mite which is shipped in shaker tubes with all stages of the predatory mites in a vermiculite/peat carrier. These predatory mites may be sprinkled over the soil surface or mixed into the media before planting. *H. miles* is a scavenger that can survive in the absence of fungus gnats. It also feeds upon thrips pupae in the soil. It may take several weeks for the predatory mites to reach an effective level, so they are often used in conjunction with either insect-killing nematodes or *Bacillus thuringiensis* subsp. *israelensis*.

Slugs

Slugs are mollusks and are covered by a coating of slime, which helps protect their bodies from desiccation. Slugs leave shiny patches of dried slime and tend to be found in cool, moist locations. Slugs are most active at night, and feed by chewing or rasping holes in leaves and stems. This damage can sometimes be confused with damage caused by caterpillars. Caterpillars usually leave pellet-like droppings. Management requires improved sanitation (removal of debris under benches) and hand-removal of the slugs at least in small areas. A copper barrier or strip may be wrapped around greenhouse bench legs or placed on raised beds as a barrier. The copper emits a small electrical charge that repels slugs.

Caterpillars

Many different types of caterpillars, including cabbage looper (*Trichoplusia ni*), imported cabbageworm (*Pieris rapae*) and black cutworm (*Agrostis ipsilon*) may occasionally feed upon herbs. Winged moths or butterflies may enter greenhouses through openings and lay eggs on plant foliage. The eggs hatch into caterpillars that feed on herbs with their chewing mouthparts.

When inspecting foliage, look for bites taken out of leaves and droppings left behind by caterpillars. Cutworms can be found at the base of the plant during the day. Other species can often be found hanging from the underside of the leaf.

The insect pathogen, *Bacillus thuringiensis* subsp. *kurstaki* can be used against many different species of caterpillars. It is most effective against young, actively feeding caterpillars.

Beetles

Beetles are a large group of insects in which both adults and larvae have chewing mouth parts. Herbs grown outdoors are especially prone to beetle damage. Early in the growing season, flea beetles can injury some types of herb seedlings. Adults overwinter in leaf litter and emerge from late April to early May. Look for small adult flea beetles feeding on plants early in the season, perforating foliage with tiny shot holes. They characteristically jump when disturbed.

Asiatic garden beetle (*Maladera castanea*) is a 1/2 inch long, rounded, chestnut-brown beetle which is active from late spring through mid-summer. They feed at night and hide during the day in the soil or debris around the base of plants. Asiatic garden beetles are sometimes attracted to porch lights at night. Japanese beetles (*Popillia japonica*) are familiar to nearly everyone as a brown and metallic- green species active in the daytime during the summer. Basil is one of the favored hosts for both of these beetle pests. Controls include screening or rowcovers, and certain insecticides (See table 3).

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Designed by Karen J. Havens and Poshen Wang, Graphic Designer/Illustrator, Communications and Information Technology, College of Agriculture and Natural Resources, University of Connecticut.

Basil plant suffering from leaf scorch when grown in full sun. Non-infectious disorders can often mimic infectious diseases.

Root injury and eventual death of lavender due to high soluble salts. Note application of slow release prills. Herbs are light feeders compared to most bedding plants.

Botrytis canker on rosemary. (C. Smith, UNH Extension)

Use separate greenhouses for herb production. Keep stock plants separate from production areas to help keep stock plants clean.

Botrytis stem canker on basil.

Powdery mildew on rosemary. (C. Smith, UNH Extension)

Damping off of basil due to *Rhizoctonia.* (C. Smith, UNH Extension)

Seedling flat of parsley affected with damping off. Infected seedlings were removed. Infection often starts from a central point.

Fusarium wilt on basil. Note wilting and brown streaks on stem. Defoliation can occur on larger-leaved cultivars. (R. Wick, UMass Ext.)

Rust on lemon grass. Note elongated stripe-like rusty-brown lesions.

Rhizoctonia web blight on lavender. Dense, lush canopies and humid conditions favor web blight.

All photos are by L. Pundt, UConn, except where otherwise noted.

Bacterial leaf spot on basil. Note dark brown, angular, water-soaked lesions. (R. Wick, UMass Ext.)

Impatiens necrotic spot virus on basil. Leaves are mottled with brown, necrotic areas. Plants may be stunted.

Ringspots and unusual line patterns are often symptoms of viral infections.

Use yellow sticky cards in greenhouse to detect adult whiteflies, thrips, fungus gnats and shore flies.

Greenhouse whiteflies on underside of leaves of costmary.

Whitefly nymphs treated with *Beauveria bassiana*.

Aphids on young growth of basil. Note signs of aphid infestation, whitish cast skins, honeydew and sooty mold.

Feeding damage from foxglove aphid on sage.

Green lacewing larva feeding on aphid. (NY State Ag Research)

Aphidoletes midge larvae prefer to feed on aphids. (L. Los, UConn)

Aphid mummy on lemon verbena. See exit hole where small, parasitic wasp emerged. The shed, white skin of aphid is above aphid mummy.

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