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Vegetable Insect Identification and Management - Florida Greenhouse Vegetable Production Handbook, Vol 3[1]

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Introduction

The management and control of insects in a greenhouse can be challenging, even under optimum conditions. Integrated pest management (IPM) is a useful approach for producing greenhouse vegetables. It involves integration of cultural, physical, biological, and chemical methods to maximize productivity in a way that is ecologically sound and safe. Often, but not always, it means limiting the use of broad-spectrum insecticides. IPM implies management of of all crop pests, including insects, mites, diseases, nematodes, and weeds, but only insects, mites, and nematodes will be considered in this chapter. Where possible, the effects of measures to control diseases and weeds should enhance or, at least, not interfere with the management of insects and mites.

Many of the general IPM principles and tactics that apply to the control of plant diseases apply to the management of insects and mites. These include regular scouting or monitoring for problems, identifying pests and life stages of the pests, keeping good records of pest management practices, using exclusion techniques, practicing good sanitation, testing soil or plants for nutrients, using biological controls when possible, and using selective pesticides, properly timed and applied.

Crop Scouting and Monitoring

In order to detect pests and the damage they cause before a problem becomes serious, growers must visually inspect plants at least once a week. Yellow and blue sticky cards are also helpful for detecting insects flying into or around the greenhouse and should be part of any pest management program. As a first step, growers should observe the overall plant, looking for stunted growth, breaks in leaf color, distorted leaves, and irregular-shaped or off-color fruit, and compare the plant to a normal, healthy plant. The next step is to carefully inspect all plant parts from ground or stem level up to the growing tip. Some insects will feed on roots, others on stems, leaves, flower blossoms, and fruit. The

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grower must become proficient at quickly examining these plant parts and recognizing the presence of pests and the damage they cause.

Both the upper and lower leaf surfaces must be thoroughly inspected. Most insects, as well as a large number of diseases, start their infestation or infection from the lower side of the leaf. Many insects and mites only feed on the underside of the leaf and may never move to the upper leaf surface or other plant parts until populations become so great that overcrowding forces movement. Attention should be given to the midrib area under the leaf and along large, lateral, lower leaf veins. The leaf axils, the growing tips and terminal buds should be carefully inspected. Weeds, both in and around the greenhouse, should also be examined. Often weeds serve as hosts for pests that can move to greenhouse crops and should be removed (see section on sanitation).

Some insects, particularly thrips, will be found within the blossoms, so these should be included in the inspection. The area under the calyx or stem end of tomatoes and cucumbers can also be an attractive hiding place for insects. Generally speaking, insects inhabit secluded areas of the plant that provide protection for them.

Although there are few specific rules to follow in sampling or selecting greenhouse plants, inspection should be increased in chronic problem areas such as around doors, vents, lights, and in hard-to-reach areas where spray is likely to miss. A random plant selection process should be used. It is best to use a different selection pattern each sampling time, not including the same plant in two successive inspections. Growers should be sure to examine plants in all areas of the greenhouse operation, including border plants and sampling a reasonable number of plants to get a feel for the pest situation. A good number would be at least two plants per 100 row feet.

Yellow sticky traps are useful for monitoring the adult (flying) stages of many insects. Blue is more attractive to thrips but yellow works well also. Traps are usually placed vertically at or just above the plant canopy. Some insects, such as thrips and leafminers can be caught just above the surface of the growing medium. A minimum of 4 to 5 traps per acre is recommended. Traps should be inspected weekly and replaced regularly. A system of numbered traps can simplify record keeping and locate infestations. Yellow sticky tape can be used on a larger scale to reduce insect populations by trapping.

Many of the insect pests that infest greenhouses are very small organisms. Mites are 1/50 to 1/60 of an inch long. Thrips, aphids, whitefly crawlers, and the eggs of other harmful insects are not much larger. Growers should have at least a 10x hand lens (jewelers' hand lens) and preferably a 16x to 20x hand lens. With a hand lens, one quickly can identify many of the insect pests that are otherwise difficult to see. If at all possible, growers should buy and learn to use a common dissecting microscope. These microscopes can be purchased either as monocular (one barrel) or binocular (two barrel) types. They allow from approximately 10 to 200 power magnifications. With these scopes, one can see small mite and disease lesions clearly. This tool can be very helpful in detecting and diagnosing problems early.

Identification of Insects and Mites

Proper identification of insects and mites and the damage they cause is absolutely critical. If the grower knows exactly what insects are present, he or she can choose the proper chemical or biological controls and take steps to exclude or limit further introductions. In Florida, Cooperative Extension Service offices in each county are able to help with identification. Workshops may be offered on pest scouting and identification and there are many publications and online resources available.

Record Keeping

Good records can help growers see trends in pest infestations, keep track of the success or failure of control efforts, and determine how the greenhouse environment affected the crop. Of course, pesticide application records are essential. Some things that general records should include are: daily minimum and maximum temperatures, measurements of plant growth and development, pH of growing medium, soluble salts, general root health and other specific crop observations. Insect counts from monitored plants and sticky cards are also useful for seeing trends over time and for determining the success of control efforts. Details of releases of beneficial insects should be recorded.

Managment Strategies and Tactics

Exclusion

Growers need to make every effort from the beginning of a crop until the final harvest to prevent the introduction of insect pests into the greenhouse. The old saying, ”An ounce of prevention is worth a pound of cure” certainly applies to greenhouse operations. Insects reproduce quickly. For instance, a single melon aphid in a greenhouse can produce at least 5 offspring a day for a week (35 aphids). These 35 aphids will begin reproducing within a week, leading to 700 aphids by the end of the second week (on day 8, the first group of 5 produces 25 aphids, on day 9, the first and second groups produce 50 aphids, etc.). If all 700 produce 5 aphids a day for another week, they will produce over 10,000 aphids by the end of three weeks.

Openings, including those in cooling pads and ventilation units, can be screened to prevent entry of even the smallest insects. The small pore size can restrict the movement of air so the area screened may need to be three times that of the area covered (consult suppliers for exact recommendations). This can be accomplished by constructing a screen house to enclose the cooling pads and entryway.

Research in Israel and the United States has shown that covering the greenhouse with plastic films that absorb high amounts of ultraviolet light (UV) deters entry by whiteflies, aphids, and thrips. High UV-absorbing films also appear to suppress some fungal diseases. One company currently selling a high UV-absorbing film in Florida is Florikan (1523 Edgar Place, Sarasota, 34240).

Sanitation

Sanitation is closely related to exclusion and should be practiced to manage insects and mites as well as diseases. The following practices are strongly recommended:

1. A greenhouse should be thoroughly cleaned before planting a new or first-time crop. This means burning, burying, or hauling away all leftover roots and other plant parts so that there is no chance that insects in the egg, larval, nymphal, pupal, or adult stages could remain inside the greenhouse. Crop residues must be removed immediately after the final harvest.

2. In addition to removing all plant debris, growers should thoroughly clean or sterilize the greenhouse to make it as insect-free as possible. Workers will need to wash walls, steam cracks and crevices, and fumigate with appropriate insect bombs, or use space sprayers or foggers. One could also use an approved broad-spectrum insecticide to spray cracks, crevices, walls, and other potential hiding places. Attempts should be made to spray around doors, windows, and other possible points of entry. In hot weather, closing up the empty greenhouse for a week will help eradicate pests (as a result of high temperatures and starvation).

3. Sanitation must be practiced not only during preplant times but also throughout the growing period. Workers should immediately dispose of plant parts generated by pruning, such as leaves and stems. Culls (undesirable) or overripe fruit should be removed from the greenhouse and surrounding areas. Insects are often attracted to and can live for long periods on these plant materials.

4. Avoid planting outdoor crops near greenhouses. These may serve as host plants for insect pests and may be a source of diseases as well. Weeds should not be allowed to grow within the greenhouse or to become established around the greenhouse. A 10 to 30-foot vegetation-free zone around the greenhouse can be created with a heavy-duty geotextile weed barrier covered with gravel.

5. A clean stock program will aid in keeping pests out of the greenhouse. Plants coming from other greenhouses should be carefully inspected for insects and diseases and temporarily quarantined until it is clear that the plants are free of pests. Workers should avoid wearing yellow clothing because it is highly attractive to insects, which may land and hitch a ride

into the greenhouse or from one greenhouse to another.

Biological Control

Biological control in the greenhouse environment means purchasing and releasing insect predators, parasitoids, nematodes, or disease organisms that attack insect pests. Reducing or eliminating chemical pesticides leads to a safer working environment and, in the case of organic production, can result in premium prices for the crop. Biological control, however, is much more management-intensive than using conventional pesticides and requires a greater knowledge of pest biology and pest numbers. Many factors contribute to success or failure of biological control: release rates, timing, placement, temperature and humidity, previous use of pesticides, and quality of the biological control agents.

Suppliers will provide technical advice on the optimum use of their products. Some have detailed web sites. In general, releases need to be made when the pest population is first detected. High pest populations will be difficult to control biologically. Some predators and parasites are better adapted to particular temperature and humidity conditions than others, and some do better on some crops than others. The life span of the parasite or predator will determine how often it has to be reintroduced. If all the pests are eliminated, the beneficial insects will be also. Providing nectar sources (flowering plants) may prolong the life of parasitoid wasps. Yellow sticky cards may have to be temporarily removed to avoid trapping beneficials.

Insecticides

Even when a good biological control program has been established, there may be times when a conventional pesticide is needed. Biorational pesticides, such as insecticidal soaps, oils, neem products, and *Bacillus thuringiensis* (Bt) can be much less harmful to beneficial insects, although active against pest species. Systemic insecticides, insect growth regulators, and pheromones used for mating disruption also fall into this category. Some products are harmful to some stages of some beneficial insects and not others. Oils, for example, are toxic to lacewing eggs and adult parasitoid wasps, but have relatively little effect on adult ladybeetles and lacewings. Soaps are toxic to young lady beetle larvae. Neem and Bts are generally safe. Other advantages of biorational pesticides are shorter re-entry intervals and safety for workers.

Conventional insecticides also have a place in IPM. If it is not feasible to use biological controls and if biorational pesticides do not offer sufficient control, more toxic options must be pursued. These options are limited, however, to only a few insecticides and miticides.

The following steps are suggested when using any pesticide.

Step 1: Choose the right insecticide.

Only after the grower has properly identified the pest can he or she select the best insecticide. Insecticides are sometimes effective against one pest but useless against other closely related pests. Also, one pesticide may be effective against a specific developmental stage while alternative pesticides may be effective against a different or perhaps all developmental stages. Making the proper identification of the pest and understanding its biology and life cycle allows the grower to make wiser decisions in choosing the best insecticide. Growers should consult their Cooperative Extension Service, pesticide companies and dealers, published literature, and ultimately, the pesticide label, for helpful information.

Step 2: Use the correct amount of insecticide.

After choosing the insecticides, growers must carefully read the label to determine the correct amount to use. Sometimes this decision will be based on the size or stage of the pest and whether the population is high or low. For example, small worms may require the lowest recommended label rate while large worms may require the highest.

Greenhouse growers frequently have smaller areas to spray than field growers do and therefore need smaller amounts of insecticide to do the job. For example, a field tomato farmer may use 1 quart (32 ounces) of a material per acre in 100 gallons of water.

However, in a greenhouse, only 1 gallon of spray might be needed to do the greenhouse block. This means one must measure out 0.32 ounces or 9.3 milliliters (or cubic centimeters), which is less than 1 tablespoon. It is critical that this measurement be accurate so growers should buy a set of graduated cylinders that are marked in ounces (oz.) and milliliters (cc or ml), as well as a set of good quality measuring cups. A scale is essential for weighing dry flowables, wettable granules, and other dry formulations. Measuring devices, such as graduated cylinders, should have pouring lips and graduated markings that allow one to measure accurately. Plastic is probably safer than glass. Accurate measurement is essential for efficacy against the target pest, a safe range of pesticide residues on the crop, efficient use of chemicals and money, and the reduction or elimination of phytotoxicity.

Proper measuring devices also play an important role in the overall safety and handling of pesticides. They aid in preventing spills of concentrated materials. Insecticide concentrates are usually handled when the sprayer is loaded and dilute sprays are being prepared. Special handling precautions are necessary at this time. The applicator must be particularly careful in handling finished sprays but even more so in dealing with the more dangerous and concentrated material. Workers must be mindful, cautious, and use all pesticides according to the label.

If applicators use too much pesticide, the following problems can result:

1. The crop can have more residue than the law allows which can pose health hazards to consumers and could prevent the crop from entering the market until it has undergone special cleaning or washing.

2. The crop can be confiscated by authorities for excessive residues and destroyed without any compensation to the grower. Resulting negative publicity can harm the future markets for that commodity.

3. Re-entry by workers into overdosed areas could be dangerous and lead to illnesses, medical costs, and liability to the grower.

4. Production costs increase without the benefit of added profits.

5. Phytotoxicity is more likely to occur.

It is important not to exceed the label rates. If the maximum labeled rate is not achieving the desired results, look for other reasons for failure. Chances are that additional amounts of the same material will not improve the situation.

Step 3: Apply insecticides at the right time

The chosen insecticide should be applied at the correct time. This is one of the most difficult tasks that any grower faces. Determination of the best time to apply chemical control is a very dynamic and comprehensive undertaking. The failure to treat at or near the correct time is one of the major reasons for unsuccessful pest management.

1. Growers should regularly and thoroughly inspect the crop so that they are aware of the presence of insects as well as their increase in numbers.

2. Growers should know the pest, its behavior, and its ability to damage the crop.

3. Growers should be aware of the number of insects that constitute an economic or action threshold. Thresholds are discussed in this chapter for each individual pest where information is available.

4. Growers should know the biology of the pest so that pesticide application can be aimed at the weakest, most vulnerable stage or size. Some stages of insects and mites, such as the egg stage, can seldom be controlled. Young larval or nymphal stages are more easily controlled and require less insecticide than older stages. Insecticides generally do not affect pupae (large larvae nearing this stage are also difficult to control).

It is generally best to apply insecticides in the late afternoon or evening hours when temperatures start to decrease. This also allows for maximum time of exposure before "airing" out the sprayed area for employees. Also, many insects are most active at night. The risk of phytotoxicity (burning) is greater when applications are made during the middle of the day when temperatures are high. However, it has been reported that better mite control can be obtained by spraying early in the morning hours. As a rule, insecticide or miticide applications should be made while temperatures are low. Insecticides should not be applied when plants are water-stressed.

Step 4: Apply insecticides correctly.

Proper application, like the proper timing, is one of the most important steps in pest control efforts. It does little good to complete the first three steps properly and then fail to deliver the material to the target area. There are many factors and components of spray methods that add up to proper application of insecticides.

Spray equipment must be properly calibrated. A calibration mistake can result in applying too little pesticide and not obtaining control, or applying too much, which is illegal.

Growers should purchase the proper type of equipment to meet the needs of the operation and use the proper equipment designed for the target pest. Each pest differs in habits and behavior and a single piece of equipment may not meet all needs. For instance, tests involving equipment geared to control greenhouse mites varied widely in results. High volume sprayers provided 59% control, rotary atomizers provided 67% control, and pulse-jet applicators provided 8% control.

High volume sprayers have been used for years in greenhouses. They are popular, can accommodate a wide range of pesticide types, and offer flexibility in the operation. However, high volume sprayers require a great deal of labor, are time-consuming to use, and are considered to be low in application efficiency. It has been estimated that less than 10% of the active ingredient reaches the actual target using high volume systems. However, most insecticides are labeled for high volume application. As previously discussed, most greenhouse insects and mites are found on the underside of the leaves making it difficult for the spray to reach the pest.

Much work has been done on various low volume methods of applying pesticides in greenhouses. Aerosol generators, thermal foggers (hot), cold foggers, rotary atomizers, electrostatic applicators, mist blowers, and pulse-jet applicators have been used. The drawback is that some low volume systems require special formulations and special accessory equipment The low volume equipment may use just as much active ingredient per acre as high volume units, but they use less carrier to apply the material. Low volume systems can be quite efficient in delivering pesticides as they provide contact, fumigant, or residual control. Their greatest advantage is saving time. However, each piece of equipment, whether it is a high or low volume type, has advantages over other types of equipment for a particular job. There is no perfect piece of equipment, so growers need to look carefully at all available options. It is illegal to use certain low volume spray equipment to apply insecticides in greenhouses. The grower should thoroughly be aware of all rules, regulations, and laws applicable to spray equipment before the purchase of equipment is made.

For the best results, knowledge about the pest and its biology should be coupled with the capabilities of the equipment. To reach the bottom side of the leaves in thick canopy crops, a driving, directed spray maybe required. If the canopy crop is thin, a rolling fog, atomizer or electrostatic applicator may be very successful. Many insecticides can produce vapors that aid in controlling insects even when the coverage is less than desired. However, proper coverage can further enhance the fumigating properties of a pesticide.

Another area in the overall correct way to apply insecticides is the proper maintenance of spray equipment. Many spray operations are hampered and effectiveness drastically reduced because the spray cannot be delivered at the proper pressure, droplet size, or pattern due to excessive wear, improper adjustment, or broken or improperly working parts. Growers should regularly check nozzles and discs for wear and tear and replace them when they do not deliver up to specifications. Discs and nozzles wear fast when flowables, suspensions, and wettable powder formulations are used. Workers should be aware of spray pressure and have accurate gauges. Inaccurate pressure, even small errors, can result in improper droplet size and failure to deliver the desired coverage. Sanitation also factors heavily in the overall success of spray operations. Most insecticides are highly corrosive and will react with hoses, lines, nozzles, tanks, and other components. They cause corrosion, which affects the spray patterns and also leads to the formation of foreign particles that clog the equipment. Applicators should use the spray as soon as it is mixed and thoroughly clean and rinse the equipment as soon as they are finished spraying.

Workers must mix only the spray that is needed for the job. Leftover spray allowed to sit in the sprayer can quickly destroy it and other sprayer parts, lines, and components. Leftover spray also must be carefully and legally disposed if not used on the crop. Disposal of pesticides is becoming a growing concern with liabilities becoming more of a problem. Therefore, growers need to plan carefully what they need, use what is mixed, and clean up properly afterward.

Spray equipment must be properly stored after cleaning to keep it free of dust, dirt, and other foreign materials that may enter the system. Rust particles, pieces of rubber lines, and other unwanted particles quickly stop up the system or cause poor spray patterns particularly when pressure is applied.

Clean water should be used for spraying. Water is the most commonly used diluent (carrier) for pesticide sprays. Water frequently has dirt, sand, or corrosion from the pipes or lines that may enter the spray tank. Loading hoses or pipes can be dirty. These contaminants can cause severe problems to operations. Growers should filter water as many times as possible to ensure freedom from contamination. Filters should be used between the source of water, the spray tank, and where the water enters the tank. Filters are also needed between the tank and the final nozzle. This allows the spray to flow and be delivered in the pattern needed to meet the capabilities and specifications of the equipment.

Insecticides should be used as soon as they are mixed. Once mixed with water, the insecticide begins to change. The effective life of certain insecticides can be only hours once they are mixed with water. Water with a pH over 7.0, which is neutral, can be particularly detrimental to many insecticides. Generally speaking, the higher the pH, the faster the insecticide is broken down and rendered useless. Under Florida conditions, where the underground water is frequently high in calcium carbonate with resulting water pH of 8.0 to 8.5, it is even more important not to allow finished spray to sit any longer than necessary.

Storage of Insecticides

In storing insecticides growers should follow these rules:

1. Growers should try to purchase only those needed pesticides with plans not to store materials longer than a single season. Consult the pesticide label or the manufacturer for specific information on the shelf life of a product.

2. Insecticides must be stored in a safe, dry location. The best storage temperatures are generally room temperature (70 to 80F). Temperatures over 90F are not recommended. Certain insecticides also undergo undesirable changes if storage temperature drops below freezing (32F).

3. Applicators must follow local and state laws as to storage sheds, locks, and warning signs.

Safety

Pesticides can create serious problems when good rules of common sense and of safe use and handling are not used. The pesticide label is considered a legal document and "the label is the law." It is the duty and legal responsibility of the user to read and understand all the directions and information on the label. If the user does not understand any part of the label, it is the user's duty to seek interpretation of the information. The pesticide dealers, manufacturers and their representatives, and the Cooperative Extension Service can aid in interpreting pesticide labels. Most pesticide labels can be found on the Internet. One general site is http://www.cdms.net/

Lack of understanding or the use of a pesticide inconsistent with the label can have serious consequences. The label contains statements concerning the safe use of its contents, protective clothing, worker contact, poisoning symptoms, and other information, such as the disposal of containers.

The user is encouraged to become familiar with all safety and other aspects of the label in advance of use.

Growers should be completely familiar with Worker Protections Standards and record keeping requirements.

Specific Greenhouse Pests

Many insects that will feed on a plant grown under field conditions will feed on that plant in a greenhouse. However, several insect and mite pests seem to be habitual problems for greenhouse growers. These pests are very difficult to control and can mean a loss of both quantity and quality of fruit and foliage.

As previously indicated, growers need to be thoroughly aware that the same pesticides registered, labeled, and recommended for field conditions are not automatically legal in the greenhouse for the same crop and pest. On the contrary, growers are restricted by law to only a small number of insecticides for greenhouse use. The reasons for this are thoroughly discussed in the Introduction of Disease Control in this volume.

Gaining control or successfully managing insect problems in the greenhouse can be more difficult than under open field conditions. Therefore, the grower must know tactics, schemes, and methods that are legal and play a role in the overall reduction or control of a pest.

One of foremost factors in insect management is to know how to identify the insect pest and to understand the biology, behavior, feeding habits, and other information on how the pest enters the greenhouse, reproduces, and ultimately damages the crop. It is very important to understand the clues to insect or mite presence and identify crop damage caused by the pest early in its life cycle. Early detection of these pests frequently makes the difference between whether they are controlled and a crop is grown successfully, whether the crop is lost, or whether the grower faces the entire season with chronic insect problems.

Aphids

Aphids, also called plant lice, are pear-shaped, soft-bodied insects about 1/10 of an inch or less in length. They may be found in a variety of colors such as green, brown, black, yellow, or pink. Aphids have a pair of tubes that protrude from the rear of the aphid's upper abdominal surface. These tubes (cornicles) can be seen easily with a hand lens or dissecting microscope. When plants are heavily infested or deteriorating, winged aphids develop. The presence of a winged aphid on a sticky trap when plants are not yet infested signals the possible beginning of a problem.

Aphids prefer to feed on the underside of the leaf and on the young terminals or growing tips of tomatoes, cucumbers, lettuce, and a wide range of other host plants. Aphids have piercing-sucking mouthparts called stylets that look like a hollow needle. The aphid inserts its stylets into a plant vein and sucks the fluid. Aphid damage can appear in the following four ways:

1. As the aphid populations increase, they suck nutritional fluids (sap) from the plant and create stress problems such as stunting.

2. The aphids inject enzymes through their needle-like mouthparts as they feed causing physiological changes in the plants. These changes result in distorted plant growth, such as leaves that are twisted and abnormally thick with leaf edges cupping downward.

3. Aphids ingest plant fluids and excrete excess sugars as a waste product. The honeydew collects on fruit and leaves and serves as a medium for the growth of a black fungus known as sooty mold. The collection of mold and sticky honeydew can lower the quality of the fruit and leaves.

4. Aphids are also capable of vectoring (carrying and transmitting) certain viral diseases, which can spread quickly through a crop and result in severely stunted plants or the death of the infected plants.

Aphids are particularly dangerous pests because they reproduce rapidly. There are several reasons for this quick buildup. First, under Florida conditions, most aphids are female; therefore, most of the population is capable of reproducing. Second, aphids give birth directly to nymphs rather than laying eggs. Three to ten young aphids are born per female per day and they start to feed immediately after birth. Third, the young aphids usually reach maturity within 5 to 7 days and at this time begin giving birth themselves. Aphids can live for 30 to 45 days and continue to give live births daily. Due to this biological process, aphids can have 30 or more generations per year in Florida and populations can explode in short periods.

Aphid Control

In outdoor conditions, aphids frequently are kept under control by a multitude of beneficial insects such as lady beetles, wasps, syrphid flies, lacewings, and other insects. Also, fungal diseases of insects reduce aphid populations in the field. The grower can mimic this situation in the greenhouse by purchasing and releasing some of the many biological controls for aphids, including parasitoid wasps and lacewing larvae and ladybeetles. A predacious midge, *Aphidoletes aphidimyza*, can be effective. Beneficials should be introduced early, before aphid populations grow large.

In the greenhouse, aphids are protected from these natural enemies (unless introduced). Aphids, particularly the green peach aphid, are quite difficult to control with insecticides. The aphids must be contacted directly by the spray. Since they primarily feed underneath the leaf, they are protected unless extra efforts are made to deliver the insecticide to this area. Any aphids that are not controlled by a given spray application continue to multiply rapidly and, within a few days, populations can return to original levels. To gain control, every effort must be made to cover the entire plant thoroughly with spray. Insecticides with systemic activity (the plant sap is toxic to the aphids) are limited for greenhouse use.

Whiteflies

The adult whitefly is about 1/32 of an inch long. It is a very active flyer with four wings and a yellowish body. The whitefly looks like it has been dusted with a fine white powder. Growers may first notice plants that have numerous tiny white "moth-like" looking flies or flecks of dandruff on the underside of the leaves. Generally, the whiteflies seem to prefer the leaves in the upper part of the plant. If the plant is shaken or tapped, the whiteflies will move from their resting sites and fly vigorously around the plant.

At least two species of whitefly may be found in greenhouses. The greenhouse whitefly was the most commonly encountered species in the past, but the silverleaf whitefly has become the dominant species in the last 10 to 15 years. The silverleaf whitefly has been an especially important pest of greenhouse tomatoes in Florida since the late 1980s. The two whiteflies look similar, except that adult silverleaf whiteflies hold their wings more tightly against their body and appear to be slightly smaller than the greenhouse whitefly. The different whitefly species are difficult to identify and separate conclusively in the adult stage. When positive identification is needed, growers must collect the leaves harboring the nymphal and pupal stages.

The silverleaf whitefly female lays approximately 100 or more eggs at a rate of 6 to 12 eggs per day. The eggs are generally yellow, very small (1/132 of an inch) and are attached to the underside of the leaves by a short stalk. Eggs may be placed unevenly or arranged in small, circular patterns. Eggs hatch in 3 to 7 days, giving rise to tiny, pale green first nymphal instars, also called crawlers. This stage is approximately 1/95 of an inch long. The crawler moves a slight distance from where it hatched, finds a suitable a pot on the plant, inserts its mouthparts, and begins to feed. Whiteflies have piercing-sucking mouthparts and, like aphids, feed on plant sap.

The second, third, and fourth nymphal instars are approximately 1/75, 1/50 and 1/40 of an inch long, respectively, and they feed until reaching the pupal stage. The nymphs are immobile, flat, oval, and transparent and are green to greenish-yellow. The pupae is a non-feeding stage and is oval-shaped but more convex (mounded), approximately 1/35 of an inch long and, in the case of the silverleaf whitefly, has conspicuous red eyes. Whitefly pupal stages develop eyespots. A 10x hand lens is very useful for examining whiteflies.

The length of the whitefly life cycle varies depending on the species. In the silverleaf whitefly, the egg stage generally lasts less than a week. The nymphal stages last for 6 to 12 days. The pupal stage takes from 6 to 12 days, and adult females lay eggs for 10 to 14 days. The average life cycle from egg to adult ranges from 18 to 30 days depending on the temperature. In Florida, there may be from 12 to 15 or more generations in a year.

The life cycle for the greenhouse whitefly is reported to be longer than the silverleaf whitefly with the nymphal stages lasting 28 to 30 days. Adults are thought to live and feed for 30 to 40 days under greenhouse conditions.

Whiteflies feed on a wide range of cultivated crops and weeds. Both species feed on cucumbers, tomatoes, and lettuce. They cause damage by piercing the foliage and sucking the nutrients from the plant. Chlorotic (yellow) spots appear on the upper leaf surfaces and heavily infested plants appear stunted or sickly. Indirect damage is caused by the excretion of the waste product honeydew, upon which sooty mold grows.

The silverleaf whitefly is the vector for a new closterovirus that had been affecting Florida greenhouse tomatoes since 1989. This disease was called “yellow leaf disorder” before the causal agent was identified, but has since been named tomato chlorosis virus (ToC). Silverleaf whitefly also vectors a recently introduced geminivirus, tomato yellow leaf curl virus (TYLCV) as well as tomato mottle geminivirus.

Silverleaf whitefly is associated with a tomato ripening disorder known as irregular ripening. Even if the tomato looks completely red on the outside, there can be tough, white areas internally. Only a few silverleaf whiteflies are required to cause this problem, which is apparently due to some enzyme or other chemical in whitefly saliva. This disorder makes the silverleaf whitefly particularly dangerous in a greenhouse.

Whiteflies can be detected by several methods, such as observation, shaking the plants, or using traps. The method that is thought to be most successful is the use of yellow plastic sticky traps. Whiteflies are highly attracted to yellow. Research indicates solid or brighter yellows seem to be better than duller or pale shades of yellow. Sticky traps also can be purchased from most greenhouse supply companies. Bright yellow, plastic, picnic type plates or cups coated with STP (automotive oil additive) have been reported to also work well as an attractant. Yellow sticky tape can be used as a trap to reduce the number of adult whiteflies.

Whitefly Control

The following are some cultural applications that may help in managing whiteflies:

1. New crops should not be planted in or near greenhouses that currently have a whitefly problem.

2. All growers should try to cooperate in dealing with the problem. This can be accomplished by joint efforts in prevention measures such as sanitation, use of clean plants, and overall control measures.

3. Greenhouse owners that grow transplants should take extra precautions to keep the transplants free of whiteflies. One of the major means of infestation into clean houses is through infested transplants.

4. Workers should not wear yellow clothing. Since whiteflies are attracted to yellow, they may hitchhike on clothing and be moved to other houses.

5. Workers must control or destroy volunteer host plants, including weeds, both during production and in the off to season.

6. All transplants should be inspected before they are planted. A dissecting microscope will clearly reveal nymphal, pupal, and egg stages. Transplants should be purchased from known, reputable greenhouse growers or suppliers.

7. Sanitation should be practiced at all times and infested plants and parts should be destroyed as soon as the crop is harvested.

Whiteflies are very difficult to control with insecticides even with the best available spray equipment and under ideal field conditions where there are more legal materials available than under greenhouse conditions. The following are reasons for this difficulty, particularly on tomatoes:

1. Tomato plants have thick canopies, which make it difficult to penetrate them with spray and reach the inner plant parts. The situation is further compounded by the fact that whiteflies in all developmental stages are found on the underside of the leaves.

2. Whiteflies are covered with waxy materials that reduce the adherence of spray to their bodies.

3. Whiteflies suck the juices from the plant and, therefore, they do not eat or consume the insecticide like a chewing insect. Only systemic insecticides are consumed by whiteflies.

4. Egg and pupal stages do not feed and are protected from systemic insecticides.

5. Only the adult and crawler stages (short time period only) move and come into contact with spray residues. Eggs, nymphal stages, and pupae do not move and thus avoid spray residues.

6. The immature whiteflies must be hit directly with contact insecticides in order to kill them. This requires strategic and careful application of the available insecticides.

7. Whiteflies appear to have become resistant or are more difficult to control with many once popular and effective insecticides. Because of this, chemical controls are limited.

To maintain and produce greenhouse crops at a profitable level, growers must use all available efforts to prevent and control the whitefly. For chemical control to be successful, growers must concentrate on the adult, crawler, nymphal, and pupal stages. Some others are effective only against adults while others are effective only against adults while others are effective against the immature stages. A good management program includes a spray against each stage. The spray program must be started as soon as adults appear and continued on a 4-day cycle until the whiteflies are controlled; failure is common when spray intervals are lengthened. Field and greenhouse observations show that it is imperative to start a spray program early (when pests are first observed) and not wait until populations are established before taking action.

The greenhouse whitefly has been successfully controlled biologically on tomatoes throughout the world by using the parasitic wasp, *Encarsia formosa*. These beneficial wasps are readily available from many suppliers of biological controls. Trials using parasitic wasps against the silverleaf whitefly in Florida greenhouse tomato crops have not been nearly as successful. Trials conducted at Suwannee Valley Research and Education Center in 1994 and 1995 tested *Encarsia fo*rmosa as the control program for silverleaf whitefly. Control could be achieved, but release rates of 28 per square meter were required. This is 6 to 7 times higher than the release rate recommended for control of the greenhouse whitefly. Other species of parasitoid wasps are more effective against silverleaf whitefly. One of these, Eretmocerus eremicus (=californicus) is now readily available.

In addition to trials with *Encarsia*, research has also been conducted at Live Oak on the whitefly predator beetle, *Delphastus pusillus*. This beetle is known to feed on silverleaf whitefly in several ornamental crops. However, *Delphastus pusillu*s was unable to live in the tomato crop even though plenty of whiteflies were available as food. It is speculated the hairs on tomato leaves and stems make it impossible for *Delphastus* to become established in the tomato crop.

Spider Mites

Spider mites, a major pest under greenhouse conditions, are also referred to as spiders and red spiders. The most common spider mite in the greenhouse is the twospotted spider mite, which is a major pest of both vegetable crops and ornamentals. Spider mites are very small, with adults being 1/50 of an inch long. The mites are pale green to light green with a large dark spot on each side of the body.

Spider mites have five developmental stages: egg, larva, protonymph, deutonymph, and adult. The females lay spherical eggs, approximately 1/8 to 1/4 the size of the adult, on the underside of the leaf usually along the sides of the midrib or large veins. The small, whitish larvae have three pairs of legs. The larval stage is short and the mite soon becomes a protonymph and then a deutonymph. In both nymphal stages, the mites have eight legs. The deutonymph matures into an eight-legged adult spider mite.

With the exception of the egg stage, all stages feed on the host plant. The length of the spider mite life cycle is dependent upon temperature, with a shorter life cycle corresponding to higher temperatures. It is thought that under the warm temperatures of the greenhouse, spider mites go from egg to adult in 5 to 7 days. Recent research indicates that the life cycle can be completed in as little as 3.5 days at 90F.

The adult female will start laying eggs within 36 hours and will lay five to seven eggs per day. Spider mites can go through 30 to 50 generations, or perhaps more, in a year, if the temperature and humidity conditions are favorable. With the ability to lay a relatively large number of eggs combined with its short life cycle, spider mite populations can explode.

Spider mites prefer to lay their eggs and feed on the undersides of the leaves. Most infestations begin along the midrib of the underside of the leaf. As populations increase, the mites feed along the lateral veins as well as other parts of the undersides of the leaves. They move to the top of the leaf only after populations reach extremely high numbers.

The mites rupture plant cells with piercing, style-like mouthparts and suck the cell materials that give the leaf its green color. Each feeding site is very small but soon the feeding marks become so numerous that they group together, causing the leaf to turn yellow and to appear dusty. Severe damage to the foliage reduces photosynthesis. This leaves the plant unable to manufacture food. The plant literally dries up regardless of the presence of adequate water and nutrition. The leaves often shrivel and die before the grower realizes spider mites are causing the problem. The reason is that even the adult mites are generally too small to be seen without a hand lens or a microscope. The eggs and feeding marks are even smaller and can be observed only with the use of magnification.

As the number of spider mites becomes excessive, they move to the upper surface of the leaves. The mites continue upward to the apical or terminal leaves where they produce silken webs. Individuals may then drop down several feet on a silken thread, which other mites will climb, creating a rope of mites. The spider mites use these ropes as leaf bridges to cross to other plants. Spider mites spread long distances by using the webs to parachute through the air. Greenhouse workers and equipment also easily spread the mites both long and short distances.

Spider mites are particularly damaging to tomatoes and cucumbers. Although it is often hard to determine specific economic damage thresholds under all conditions and crop prices, research has established some good guidelines for damage indexes for cucumbers and tomatoes.

The number found per square inch of leaf determines the severity of spider mite infestations. On cucumbers, slightly less than 12 mites per square inch will start causing crop losses. At this infestation level, 40% of the leaf area is going to be affected. Approximately 55 to 60 mites per square inch can result in 40% yield loss when this number is reached after the plants are 5 weeks or older. On tomatoes, the threshold is similar with 12 mites per square inch meaning approximately 30% of the leaf photosynthetic area is affected. This level initiates crop loss. Mites can easily build to over 600 mites per square inch in a short time. For example, in a glasshouse test involving cucumbers, mites increased from 12 to approximately 107 per square inch in 12 days. For tomatoes, the glasshouse test showed a mite population increase from 12 to approximately 413 mites per square inch in 16 days. These tests were also run at 61F and 70F. At warmer temperatures, the mite populations would be expected to be even greater for a given time period.

Spider Mite Control

Prevention and sanitation are of utmost importance. Many mite infestations are started from contaminated transplants. The mites are so small they can easily enter standard screens. Mites also affect ornamentals and wild hosts that are often found around greenhouses. The mites easily climb or move from infested outside sources to enter the greenhouse. Mites also may be blown by the wind and often are intercepted by the highest structure, for example, trees, a barn, or greenhouses. Then, they simply move down to the nearest host plant and start a new infestation.

Rainfall and sprinkler irrigation are detrimental to mites and aid in control and in delaying buildup of mite populations. Mite problems are encouraged by high temperature and dry weather conditions. Sprinkle irrigation of cucumbers has been used effectively to prevent spider mite populations from increasing when the sprinklers were activated more than 30 times on hot afternoons. Before using irrigation or misting as a supplementary control measure the grower should discuss the program with a plant pathologist or seek out expertise concerning the chance of increasing certain plant diseases.

Once mites are found, miticides need to be applied three times at 5-day intervals. The reason for this tight spray schedule is the short life cycle (egg to adult) of 5 to 7 days. Within a 5-day period you must try to kill all adults and immature stages that would otherwise become egg-laying adults. The eggs cannot be killed with spray. Therefore, failure to repeat application in 5 days will allow today's eggs to reach adulthood shortly after 5 days and the life cycle remains unbroken. Take care to direct sprays to the underside of the leaves where the mites live. Control measures will fail if the spray does not hit the mites directly. Once mites become established in the greenhouse it maybe impossible to gain control for the entire season.

Predacious mites can be purchased and released to control mites if the infestation is light. Suppliers can recommend which species to use, depending on environmental conditions in the greenhouse. *Orius* spp., or pirate bugs, also feed on mites.

Leafminers

Leafminers are found throughout Florida but usually in greater numbers in the southern half of the state where they may reproduce year-round. They feed on a wide variety of vegetable crops and weeds, including tomatoes, cucumbers, and lettuce.

The adult flies are approximately 1/12 to l/20 of an inch long and have two clear wings with rounded tips. Three nearly straight veins run the entire length of each wing. The antenna, the front of the head, and the upper portions of the legs are bright yellow. The lower legs are pale yellow and the feet are light brown. The back, between the wings, is often shiny black but may also be grayish-black. The abdomen (stomach) is yellowish with brown and black markings.

The adult females lay eggs in puncture holes they make in the leaves. The eggs are about 1/75 to 1/100 of an inch long, oval, pale, and whitish. After 5 to 7 days, depending on the temperature, the eggs hatch. Tiny larvae (maggots) emerge and begin mining tunnels through the leaves by feeding on green leaf tissue between the upper and lower surfaces of the leaf. The larvae tunnel for 5 to 7 days in a winding or snake-like pattern. The tunnels are small at the point where the eggs hatched but enlarge as the larvae grow.

The larvae (maggots) are generally yellow and shaped like a flattened carrot. They use a set of black mouth hooks to feed on the plant tissue. The tunnels they make as they feed are clear or transparent and have dark trails and spots of fecal material located behind the feeding maggot. The full-grown maggot reaches a length of about 1/8 inch before it forms a pupa. The maggot chews its way out of the leaf and drops to the ground or ground cover to pupate.

The pupae, when first formed, are light yellow and are slightly shorter than the larval stage. They gradually darken to a golden brown with age. The pupal stage lasts about 10 days, depending on temperature. Under ideal conditions, the life cycle, from egg to adult, takes as little as 16 days. Adult females will start laying eggs after 1 to 5 days.

Under warm greenhouse conditions, leafminers can have numerous generations and overlapping developmental stages during a single crop season. Under field conditions there are many parasites of leafminer larvae and pupae. A great deal of parasitism is not expected under the protected environmental conditions of the greenhouse. However, if parasitism is taking place, the larval stage may lose its pure yellow color and translucency and become much darker (almost bronze). It will appear bloated and will never emerge from its tunnel. Pupae that are parasitized may become dark brown or glossy black (normal pupae are golden brown). The characteristic colors and descriptions can easily be seen with a dissecting microscope or a hand lens.

Leafminers can build to high populations in a short time. Numerous larvae may occupy one leaf and their combined tunneling can leave a leaf almost devoid of its green color (chlorophyll tissue). The plant can no longer manufacture food and the leaves eventually become almost clear. The leaves then dry up and die. In cases where the populations are high and remain uncontrolled, the plants look as if they have been burned with chemicals or herbicides. The mines (tunnels) are almost totally confined to the leaves but occasionally a mine will be found on the fruit.

There are no established thresholds for leafminers on tomatoes grown under greenhouse conditions. There are thresholds for field-grown tomatoes, but one should thoroughly understand that under field conditions natural control agents can be a tremendous factor in reducing leafminer populations. These natural control agents are not found in the greenhouse (although they can be purchased and released in the greenhouse). Furthermore, many insecticides available for field grown tomatoes are not legal for use in the greenhouse.

The following list covers scouting, sampling, and threshold levels for field-grown tomatoes. Greenhouse producers will need to carefully modify this for greenhouse purposes:

1. One random station is selected where samples will be taken for every 2 acres of tomatoes.

2. Six plants are selected at each station. The seventh leaf from the top of a main stem from the first sample plant is selected.

3. In the three terminal leaflets of the seventh leaf, the total number of mines and leaves (leaflets) with mines are counted. The terminal leaflet is called a” trifoliate”.

4. Step 3 is repeated for the other five plants being sampled.

5. Treatment is warranted under field conditions if the average population is 0.7 live larvae per terminal trifoliate leaf.

6. Controls are recommended after blooming if defoliation exceeds 10 percent.

The preceding list is for informational purposes only to enhance the basic understanding of how to effectively inspect and assess leafminer populations. These thresholds are not intended for greenhouse grown tomatoes. The greenhouse crop stays in production a great deal longer than field-grown crops and greenhouse thresholds have not been established. Be conservative in establishing action levels or economic thresholds for greenhouse crops.

Leafminer Control

As with other pests, it is best to prevent the establishment of leafminers. Many infestations are brought in on transplants in the egg and larval stages. Transplants should be inspected carefully for mines and maggots, which are easily seen. Eggs are usually too small to be seen and are inserted into the plant tissue below the leaf surface.

Transplants that have been exposed to adult leafminers have their leaves stippled with numerous feeding or laying sites. The stippled areas are composed of tiny spots smaller than a pinhead, scattered all over the upper leaf surface. Upon closer examination, the stipples appear as white spots. The female deposits an egg in only some of the spots. These plants probably bear leafminer eggs and can lead to a potential infestation. Growers should try to grow their own transplants and keep them clean of pests or buy from reputable transplant growers.

Leafminer larvae are difficult to control because they are protected in the mines (tunnels) by both the upper and lower leaf surfaces. To be successful, control measures should be aimed at all susceptible life stages. Certain insecticides will knock down the adults before they can lay eggs. The eggs are protected from insecticides. Systemic insecticides can kill the larvae with strong vaporizing action.

However, materials with these abilities are often not legal for use in greenhouses.

Insecticides are not effective against the pupal stage. Research with outdoor vegetables indicates that the larvae drop to the soil or bed covers before they pupate. Insecticide applications can be aimed at this area to kill some larvae before they can mature into the pupal stage. The best insecticides against leafminers have been the insect growth regulator (IGR) materials. However, the materials have been legal for use only on selected crops under outdoor field conditions.

Tomato Pinworm

Tomato pinworm larvae mine leaves and tunnel into the fruits of the tomato. Populations sometimes reach levels capable of causing economic losses. The mild climate of Florida is especially conducive to rapid buildup of pinworm populations.

The adult moth is mottled-gray with a total body length of about 1/4 inch. The antennae are about 2/3 the length of the body and are thread-like. The moth can be identified under a dissecting microscope by the antenna, which have alternating rings of yellow and gray along the entire length. It has a pair of banana-shaped structures that are located between the eyes and curve upward. The wings of the moth are folded tightly along the sides of its body when not in flight. The wings are narrow and are marked with gray and yellow flecks.

The moth's legs are gray, yellow, and black with small spines protruding from the surface. Frequently, the adult moth can be seen resting on the leaves of a host plant. They fly readily when disturbed. Of all the moths that may be in the greenhouse, the pinworm may be the most significant. It seems to prefer the greenhouse more than most other moths. Most infestations of pinworms can be traced back to greenhouse-grown transplants being introduced into either the field or greenhouse.

The tomato pinworm moths usually lay eggs singly (occasionally in clusters of two or three) on the surface of the tomato leaves. The eggs are very small, about 1/100 of an inch long, and less than 1/100 of an inch thick. The eggs are yellow when first laid and darken to yellowish-orange just before they hatch. They can be seen easily with a hand lens or dissecting microscope.

Upon hatching, the young larvae spin a silk-like tent over themselves and tunnel into the leaf. Further feeding produces an irregular-shaped blotch mine. The mines first appear as small "window panes" since the caterpillar eats away the chlorophyll-bearing tissue, leaving only the thin, clear upper and lower leaf surfaces (epidermis).

The pinworm larvae go through several instar or growth stages. The pinworm head is black in the early stages and may change to a green shade as it ages. The body also changes color with age. The body of the first and second instars is yellowish-gray. These stages create the blotch-like leaf mine. The third and fourth instars become gray to grayish-green with dark purple spots spaced along the back and sides of their bodies.

The feeding behavior is different as the caterpillar gets larger. The older caterpillars move out of the leaf mines and feed in the following ways:

1. They feed on foliage after tying the leaves together with silk.

2. They feed in newly developing unrolled or unfolded leaves.

3. They bore into the stem and feed.

4. They bore into the fruit and feed.

The larvae frequently enter the fruit in the region below the calyx or somewhere in this area where the stem joins the fruit. When pinworm populations are low, the calyx is the preferred point. When populations are high, the larvae will bore and burrow into any part of the fruit. The pinworm gets it name because of the pinholes it bores into the fruit. The holes may have some slight webbing at the entrance as well as a small quantity of black fecal material. The holes may be 1/2 inch deep.

The mature, fully-grown larvae (caterpillars) are approximately 1/4 inch long. They drop to the ground or soil and construct capsule-shaped cells with soil particles or trash cemented together. The capsule is lined with silk and this structure forms the cocoon. The pupa forms inside the cocoon and is about 1/4 inch long.

The initial feeding damage is slight and the plants can overcome the blotch-mine feeding. However, the major feeding damage results from the leaf tying and rolling that quickly can destroy a large portion of the plant's productive leaves. The plant appears as if it was scalded or fired.

Further boring into the fruit creates primary damage. The fruit becomes subject to secondary damage as plant disease agents enter the larval feeding sites. The plant also may become infected and die because of disease. The secondary diseases are further compounded by overhead irrigation. The general treatment threshold is to treat if any pinworms are found.

Pinworm Control

Tomatoes are the favorite host for the pinworm. Growers must make every effort to prevent the tomato pinworm from entering or becoming established in the greenhouse. Infestations commonly start in greenhouses where transplants are grown and subsequently are transferred to other greenhouses or the field where the infestation continues to develop and build.

Growers must keep transplants clean and free of pinworms. Transplants with pinworms present should not be used. Workers should burn or bury pruned plant parts as well as whole plants after final harvest. Research has shown that pinworm adult moths continue to emerge from open trash piles containing dead tomato plants for as long as four months.

Insecticides can be used as soon as pinworms are found. The early instar stages (first 5-10 days) are easier to control than the older instars. Pinworms are difficult to control because they mine and tie leaves together. This behavior protects the pest from the spray applications. Insecticide applications must thoroughly cover the leaves and developing fruit. Spray programs should be designed to keep the female from laying eggs and to control the young larvae before they migrate to the fruit.

Table 1. Duration of pinworm life stages.

Developmental Stage	Developmental Time (Days)	
	Minimum	Average
Egg (incubation)	4	9
1st and 2nd instar	5	12
3rd and 4th instar	4	17
Pupa	15	30
Egg to Adult	28	67

Thrips

Thrips have been found to infest most cultivated crops as well as many wild host plants. For years they were considered more a nuisance than a harmful pest and little attention was given to their activity. However, in the last several years their activity has caused great concern to growers of both greenhouse and field grown crops, including tomatoes. The western flower thrips has caused concern because it vectors the tomato spotted wilt viral disease (TSWV).

Although there are several species of thrips associated with greenhouse operations and the species vary in appearance, life cycle, and behavior, there is some commonality among them. Thrips are so small that in many cases they are overlooked. Their size ranges from approximately 1/25 to less than 1/10 of an inch in length. Adult thrips have two pairs of wings with fringes on the margins. Thrips can readily fly but also are able to rapidly move by running or hopping.

The adult female makes incisions in the leaf and lays about 25 to 75 extremely small, bean-shaped delicate eggs in the leaf tissue. She lays the eggs individually over a span of 2 to 7 days. Upon hatching, the eggs yield soft-bodied, wingless larvae. The larvae are very small when first hatched, about 1/100 of an inch long. The larvae go through two stages, increasing in size to about 1/20 to 1/25 of an inch in length. The larvae are much more sluggish than the adults are. They feed in colonies over a period of 10 to 14 days. Feeding sites are usually between two leaf veins. Larval stages are generally cream colored when first hatched and turn yellow as they develop.

The thrips pass through a prepupal stage that lasts only about 1 day. They then transform into the pupal stage, which lasts 4 to 5 days. During the pupal and prepupal stages, the thrips do not feed. Some species of thrips may pupate in secluded parts of the plant, but most are thought to fall to the soil, trash, or ground level to go through this stage of development. The entire life cycle depends on temperature and takes approximately 20 to 25 days to complete. There may be thrips activity in the greenhouse throughout the year, with as many as 12 generations per year. Adult thrips are the only winged stage. Depending on the species, adult thrips are yellowish, brown, or black.

The larval and adult stages feed by rasping the tissue surface, rupturing the epidermis and plant cells. After lacerating the tissue, the thrips suck the plant juices. Some thrips primarily feed on leaves but some feed almost exclusively on flowers, buds, and fruit. Thrips seem to prefer shady places to feed and are found feeding most frequently on the lower leaf surfaces on the inner plant leaves. As feeding increases and higher populations develop, the thrips (particularly adults) move to the upper leaf surfaces.

As a rule, thrips show up on the foliage of the middle to upper part of the host plant. Affected leaves become discolored and distorted. Leaves that have been under thrips attack frequently cup or curl. The leaves also become flecked and bleached with white spots. As the damage progresses, leaves appear silvery and paper-like. The leaf then dries out, appears burned, and dies.

Fruit damage is characterized by well-defined irregular depressed areas. The damaged fruit may appear as scaly, rough, silvery patches or russeting (scars) that resemble wind burn. Feeding early in the life of the fruit probably causes this damage. Western flower thrips transmit tomato spotted wilt virus. They also cause cucumbers to be curved and hooked. Thrips can reduce cucumber yields by 50%.

Thrips can be detected by several methods. As thrips feed, they deposit reddish droppings that turn black. This generally occurs on the underside of the leaves. The leaves can be distorted and twisted. If one opens the curled, damaged leaves, the colonies can be viewed. Thrips can also be detected by striking blossoms or leaves several times against a piece of stiff cardboard or heavy construction paper. Green or blue paper provides a good background on which to see the yellow and dark thrips.

If the grower waits until visible damage is observed, the young fruit may have already sustained serious damage. Thrips are often well established before these symptoms show up and regular inspection using the sampling technique described above will give early warning. Thrips are also attracted to yellow and blue and frequently are captured by sticky traps. Their presence can also be detected by accidental bites they inflict on people working in close proximity to infestations.

Cucumbers and tomatoes are favorite host plants of thrips. Thrips have also been found damaging greenhouse lettuce in Florida. Thrips usually become established in greenhouses in two ways. The most common is by the winged adults flying in from other host plants or crops. Thrips also may enter on boxes and equipment coming from packinghouses, fields, or other areas outside the greenhouse.

Thrips Control

Growers should try to prevent the thrips from flying or moving into the greenhouses. Small mesh screens, door protection, fan shrouds, and entry holding rooms (air-lock porch) may slow down or eliminate entry. Workers should thoroughly wash equipment using sweepers or compressed air guns. This may be helpful in preventing thrips from hitchhiking rides on buckets, boxes, and other equipment before they are brought into the greenhouse.

Research on cucumbers shows that daily misting and a relative humidity of 90% or higher reduces thrips and spider mite populations. More cucumbers were produced in misted tests and there were no problems with plant diseases. The wet leaves may interfere with the biology of the pests in some way. The daily misting also increased the incidence of an insect fungal disease that attacks whiteflies. This research is provided for informational purposes only, since misting may not work in every situation and may interfere with worker activity.

There is a shortage of registered pesticides for thrips. Thrips have become resistant to many of the available pesticides. Due to the habits of thrips, all spray efforts should be directed underneath the leaf surfaces and on the developing flowers, buds, and young fruit and leaf axils. A predacious mite, *Neoseiulus cucumeris*, can be very effective but must be released over a period of several weeks to control thrips. They attack larvae but not adults. Pirate bugs, *Orius* species, are very effective thrips predators. Biological controls cannot be used with most pesticides.

Other Insect Pests

Aphids, whiteflies, mites, leaf miners, pinworms, and thrips have created the most problems for greenhouse growers. These pests are associated mainly with tomatoes, cucumbers, and lettuce. However, there are other insects that can enter the greenhouse and cause problems. The discussion of these pests will be limited since they are not currently causing serious problems and because research concerning their presence in the greenhouse is lacking.

Caterpillars

Worms, caterpillars, and lepidopteran (butterflies and moths) larvae are all names for one group of pests that are frequently associated with vegetables. Although these pests are particularly troublesome under field conditions, they have not been as much of a problem in greenhouses. This is probably because the moths can easily enter open fields to lay their eggs. Most greenhouses offer reasonable protection against the moths' entrance. However, from time to time, a moth may enter a greenhouse and lay enough eggs to cause considerable damage. Many female moths may lay 1000 to 1500 eggs within a few nights' time.

The female moths enter a greenhouse most frequently through open doors. Most moths are active only at night and are attracted to lights. During the day, they remain at rest on the walls, ceilings, benches, or foliage of the host plants. Eggs are laid singly by some species, but in clusters by others. A moth life cycle generally takes about 1 month. Eggs hatch in about 3 to 7 days. The larval or caterpillar stage lasts 14 to 28 days and the pupal stage lasts 7 to 10 days. The only damaging stage (or feeding stage) is the larval stage.

Most moth eggs are so small when they are laid that they are seldom noticed. Consequently, the larvae, when born, are also very small and can only scar the surface of the leaves. Their mouthparts are not large enough to eat holes in the leaves. The larvae grow fast and within a few days become large enough to not only to draw attention to their size, but to their feeding as well. Often the first warning is holes in the leaves that seem to appear overnight. When larvae reach this stage, the damage occurs quickly. Most caterpillars will eat their body weight in foliage in less than 24 hours. They can damage a large area of foliage when they reach 1/2 inch or more in length.

Some caterpillar species are 1 inch long when full grown while other species may reach 4 inches. For instance, large tomato or tobacco hornworms, both of which are highly attracted to tomatoes, reach 3 to 4 inches in length the last week of their larval development. At this stage, they can eat 310 square inches of leaf tissue in 24 hours. If caterpillars are allowed to reach large sizes, a vine or a crop can be literally reduced to just stems overnight.

Caterpillar feeding is usually easy to detect since most of it takes place on the leaves. Holes made by recent feeding have fresh cut edges that are not healed or scabbed over. Caterpillars also leave fecal matter (droppings) that collect beneath feeding sites on the leaves, bags, or floor. Fresh droppings are a sure sign of caterpillar activity. Several caterpillars or worms will eat, or even prefer, fruit at certain times. Tomatoes are one of the most susceptible of the vegetables.

Although numerous caterpillar species may feed on tomatoes, cucumbers, and lettuce, the following are most likely to be encountered in the greenhouse: corn earworm (also known as the tomato fruitworm); cabbage looper; armyworms (beet, southern, and yellowstriped, and hornworms (tomato and tobacco). However, most caterpillar damage can be traced to female moths that have been attracted to or entered the greenhouse and become entrapped.

Corn Earworm (Tomato Fruitworm)

The corn earworm adult females are medium sized, light brown to golden brown, hairy moths. The wingspan is about 1 1/2 inches from tip to tip. Females lay eggs at night and prefer tomatoes that are blooming since the females feed only on bloom nectar. The females will lay 1000 to 1500 eggs during their lifetime. The eggs are about half the size of a pinhead. The small egg is hemispherical and is cream to yellow in color when first laid. The eggshell has tiny, fluted grooves running from top to bottom. Under magnification the egg resembles a tiny sea urchin. The eggs take on a reddish, purple, or brown band just before they hatch, which occurs in 3 to 7 days. The eggs are usually laid on the underside of leaves on the growing terminals or around blooms in the upper canopy of the plant. The corn earworm lays her eggs singly, not in clusters.

The eggs hatch into small, dark-headed larvae that are usually yellowish and about 1/2 inch long. The larvae soon darken as they grow. Typically, they are yellowish-green or light brown, with different shades of green or brown stripes running along the sides of their bodies. However, some earworms may be pink or yellow. Their skin is coarse and has many shiny, mole-like bumps, each with a bristle-like protruding hair.

The larvae live for about 14 to 18 days and reach approximately 1 3/4 inches in length before the pupal stage. The larval stages prefer to feed on fruiting structures or flower buds, particularly on tomatoes, but will also feed on leaves in a ragged fashion. Besides tomatoes, the earworm also feeds on cucumbers and lettuce as well as many other plants.

When feeding on the fruit, the larva may stay inside a single fruit, boring and feeding until it pupates. However, it also may bore into numerous fruit during its life cycle. Pupation takes place on the ground, soil, or trash after the larva drops from its feeding site. The pupal stage will take 7 to 10 days.

The major damage of the earworm is that its feeding habits ruin the fruit so that it cannot be marketed. This is particularly costly since much energy, time, and money have been put into a crop by the time this damage occurs.

Cabbage Looper

The adult cabbage looper is a medium-sized grayish-brown moth with about a 1 1/4 inch wingspan (tip to tip). The front wings have a small white blotch near the center that resembles a figure 8. The females are most active at night and lay from 50 to 200 eggs, one at a time, generally near the edges of leaves on both the upper and lower leaf surfaces.

Cabbage looper eggs are greenish-white when laid and are half the size of a pinhead. The eggs darken as they become older and in seven days, just before hatching, the eggs turn black. The larvae are about 1/8 of an inch long when they hatch. The larvae generally are light to medium green and have a thin white stripe (which can be faint) running along each side of their body. The larvae are characterized by their looping motion as they move. The larvae are also shaped somewhat like a baseball bat, being larger at the rear end and tapering to a smaller head end.

The loopers differ from most other caterpillars that are found in the greenhouse in the numbers of pairs of prolegs they have. Prolegs are fleshy, leg-like structures found on true caterpillars that are located under the posterior half of the body. There is also a single pair of prolegs at the very rear end. Prolegs differ from the small true legs (all three pairs) that are jointed and located just behind the head of a caterpillar. The cabbage looper has two pair of prolegs, plus one pair of rear end, or anal prolegs. The other caterpillar types found in the greenhouse will have four pair of abdominal prolegs, plus one pair of anal prolegs.

The looper larvae are heavy feeders that primarily feed on leaves. Each larva eats several leaves during its life. They can defoliate a plant quickly. Although it is rare, the loopers sometimes eat shallow holes in tomato fruit. They feed on many vegetables, including tomatoes and lettuce.

Armyworms

Several species of armyworms feed on tomatoes and lettuce and also may attack cucumbers. The armyworms frequently attack crops grown in open fields. Armyworms can become a problem under greenhouse conditions when fertile females enter the greenhouse and lay eggs. The armyworm moths seem to migrate and move in large groups and from time to time will be found inside structures, open garages, and other buildings. Once they enter structures, and cannot escape, they lay eggs on most available plants.

Armyworm species differ from each other in many ways, but there are certain habits and characteristics that they all have in common. The adult moths are generally dull gray to brown and have somewhat fuzzy bodies. The wingspan is about 1 1/4 to 1 1/2 inches and the wings may have wavy lines running across them or dotted, irregularly shaped darkened areas.

The armyworm moths are active at night and this is when they usually lay their eggs. Unlike loopers and earworms, the armyworm female lays eggs in clusters of 60 to 150 eggs. Armyworm females may lay from 300 to 1500 eggs each, depending on the species. The eggs are generally glued to the underside of the leaf and are covered with a coating of tiny hairs taken from the female's abdomen.

The egg clusters appear as a fuzzy mass ranging in size from 1/4 to 1/2 inch in diameter. The masses may be round but usually are irregularly shaped, tan or dirty cream ovals. The individual eggs cannot be seen unless the fuzzy hairs are rubbed off. Just before the eggs hatch in 3 to 6 days, they look like black spots (referred to as the "blackhead" stage) and can be easily seen.

The young larvae generally have dark, shiny heads and smooth, green bodies. As the larvae reach to 1/2 inches long, they begin to acquire the color and characteristics of their species. Most of the larvae are 1 1/2 inches when fully grown. The beet armyworm is slightly smaller and may only reach a length of 1 1/4 inches.

Upon hatching, the larvae frequently cluster on the plant on which they were hatched. A plant may have 100 or more worms on it. Generally, the larvae migrate and scatter to other plants within a few days. The larvae usually stay on the underside of the leaves for the first three days of their lives. Early damage appears as small pinholes in the leaf or areas where the leaf surface is consumed (scarified), but the damage does not penetrate completely through the leaf. As the larvae increase in size, they feed on leaves and buds, and damage appears as very ragged or completely consumed leaves. The larger larvae will, at times, feed or eat holes in fruit.

Because the larvae move from plant to plant they are called "armyworms." The larvae, like the adults, are generally more active at night, which is when much of the feeding occurs. When armyworms become plentiful, they can strip entire plants in a short period of time, leaving only stems, limbs, and stalks. The larvae generally feed from 14 to 21 days, depending on the temperature. When mature, the armyworms drop to the ground or soil and pupate.

The pupal stage lasts 10 to 30 days and gives rise to the emerging adult moth. The armyworms are active from spring through fall, with the highest degree of activity from June through September. Under Florida conditions, the average life cycle, from egg to adult, is about 25 to 35 days.

Growers should look for worms or caterpillars when scouting the plants and try to identify as closely as possible which species has invaded the greenhouse. Certain species, such as the beet armyworms, are more difficult to control than other armyworm species. All larvae look alike to some extent, particularly when they are under 1/2 inch in length. The armyworms, like the corn earworms, have five total pairs of prolegs, four abdominal pairs and one anal pair.

The following brief descriptions may serve to help separate and identify the different armyworm species.

Beet Armyworm

The beet armyworm larvae are generally pale to medium green with either a darker or lighter band (differing from the body color) running lengthwise down the sides of the body. The larvae have a single black spot approximately halfway down the sides of the body, just above the second pair of true legs. They reach 1 to 1 1/4 inches when mature. Larvae scarify foliage, leaving a net-like pattern of leaf tissue; occasionally they will eat holes in the fruit.

Southern Armyworm

Southern armyworm larvae are dark, usually gray, with a yellow line running lengthwise along the upper sides of the body. The yellow line is interrupted by a large, dark spot on the first abdominal segment, just behind the third pair of true legs. Large larvae have two rows of black triangles on the upper surface of the body inside the yellow stripes. The head is generally yellowish brown and the body has a velvety texture. Larvae may reach 2 inches long. They eat foliage and large holes in the fruit.

Yellow-Striped Armyworm

For all practical purposes, the yellow-striped armyworm is almost identical in appearance to the southern armyworm. Both species are velvety textured and have yellow stripes running the length of the body. The yellowstriped armyworm is about the same color as the southern armyworm, but does not have the large, dark spot on the side of the body behind the third pair of true legs. The yellowstriped armyworm feeds on foliage and fruit.

Control of Armyworms

The best control for armyworms under greenhouse conditions is to prevent the entry of the female moths. In most cases, the moths enter the greenhouse through open doors or vents. The moths are generally night flying insects that are attracted to light. Lights should be turned off around the greenhouse at night to help prevent armyworms from entering the greenhouse. If lights must be used at night, care should be taken to see that there are no openings where moths could enter the greenhouse.

Once the moths have entered the greenhouse, they usually rest during the day on the walls or ceilings. Growers can use mechanical or chemical methods to kill any moths found. One moth killed can prevent the occurrence of as many as 1500 worms, which are not so easy to control.

There are no specific thresholds for armyworms under greenhouse conditions. However, research under field conditions indicates that action should be taken when any eggs or one worm per 4 plants are found. Growers should carefully scout for worms. Larvae begin to eat tremendous volumes of foliage once they are 1/2 inch long. Worms are increasingly difficult to control as they increase in size and once they reach the late instars, insecticides may not be effective. Greenhouse growers cannot legally use a majority of the insecticides that farmers can use on the same crop under field conditions. Therefore, the objective is to control any worm species before they exceed 1/2 inch in length.

Bacillus thuringiensis (B.t.) formulations can be very effective against some worms such as loopers and hornworms. To be effective against the armyworm and corn earworm, they must be used on a regular basis when the worms are in the early stages of growth, that is, before they are 3/8 of an inch long.

Hornworms

Occasionally, hornworm moths enter greenhouses and become trapped. If this occurs, the female may lay green, pearl-shaped eggs that are about the size of number six or eight birdshot. Eggs are laid singly, usually on the upper leaf surface. The females are gray and have orange-yellow spots on their abdomen; the tobacco hornworm has six pairs of spots and the tomato hornworm has five pairs of spots.

The egg hatches in about seven days and a small, green caterpillar emerges equipped with a prominent horn located near the rear end of the body. The larvae continue to grow for approximately 28 days and are approximately 4 inches long at maturity. The hornworm body is green with a green head capsule. The tobacco hornworm has a red horn and seven straight, white, hash marks on its side. The tomato hornworm has a black horn and eight L- or V-shaped, white marks on its side. For all practical purposes, the two species behave similarly as they feed on tomatoes. The hornworms eat large amounts of foliage in short periods. One larva can defoliate a single plant if allowed to live its normal life cycle.

The worms are easily detected since they eat large leaf sections or entire leaves. The hornworms also deposit large, barrel-shaped fecal pellets, which are frequently found, on the leaves and on the area beneath the infested plant.

There are no specific economic thresholds for hornworms. However, in the case of smaller worms such as armyworms, with a lesser capacity to feed than the hornworm, control efforts should begin when there is one worm per six plants. Therefore, one hornworm per six plants would severely damage leaves, and control measures should be used to prevent further yield loss.

Hornworm Control

Growers must strive to prevent the entry of hornworm moths into the greenhouse by keeping doors, and other greenhouse openings closed or screened, particularly in the evening and night hours when the moths fly and are active. The moths are also attracted to light, and if not specifically needed, the lights should be turned off.

Should the moths enter the greenhouse, they will rest on the walls, ceilings, or other structures during the day. If found, the moths should be destroyed by mechanical, chemical, or other available methods before they can lay eggs.

If larvae are found, they should be handpicked if they are not too numerous. If chemical control is desired, *Bacillus thuringiensis* or most greenhouse-approved, broad-spectrum insecticides seem to be effective. Hornworms are easier to control with chemicals than earworms, armyworms, or loopers but growers should control the hornworms before they are 1/2 inch long.

Related Literature

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Hochmuth, R., and L. C. Leon 1995 Observations of Delphastus Pusillus in a greenhouse tomato crop. University of Florida. Coop. Ext. Report Suwannee Valley REC 95 to 5. 3 pp.

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More Information

For more information on greenhouse crop production, please visit our website at http://nfrec-sv.ifas.ufl.edu.

For the other chapters in the Greenhouse Vegetable Production Handbook, see the documents listed below:

Florida Greenhouse Vegetable Production Handbook, Vol 1

Introduction, HS 766

Financial Considerations, HS767

Pre-Construction Considerations, HS768

Crop Production, HS769

Considerations for Managing Greenhouse Pests, HS770

Harvest and Handling Considerations, HS771

Marketing Considerations, HS772

Summary, HS773

Florida Greenhouse Vegetable Production Handbook, Vol 2

General Considerations, HS774

Site Selection, HS775

Physical Greenhouse Design Considerations, HS776

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Preface, HS783

General Aspects of Plant Growth, HS784

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Irrigation of Greenhouse Vegetables, HS786

Fertilizer Management for Greenhouse Vegetables, HS787

Production of Greenhouse Tomatoes, HS788

Generalized Sequence of Operations for Tomato Culture, HS789

Greenhouse Cucumber Production, HS790

Alternative Greenhouse Crops, HS791

Operational Considerations for Harvest, HS792

Enterprise Budget and Cash Flow for Greenhouse Tomato Production, HS793

Vegetable Disease Recognition and Control, HS797

Vegetable Insect Identification and Control, HS798