HS798

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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 and mites 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 and miticides. IPM implies management of all crop pests, including insects, mites, diseases, nematodes, and weeds; however, only insects and mites will be considered here. 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 their life stages, 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 once or twice a week. As a first step, growers should observe the overall plant, looking for speckling or bronzing on leaves, holes and other damage caused by chewing insects, distorted growth, and fruit damage. 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 grower must become proficient at quickly examining these plant parts and recognizing the presence of pests and the damage they cause.

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Workers engaged in cultural practices should be trained to recognize insects and the damage they cause.

Both the upper and lower leaf surfaces must be thoroughly inspected. Many insects, as well as some diseases, begin 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, 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 insects, mites, and diseases 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. Tap the blossoms over a white pan or card to see these tiny insects. 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.

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 or where irrigation may be more or less than usual. 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 sample a reasonable number of plants to get a feel for the pest situation. A good number for small greenhouse operators (1/10 of an acre) would be at least 2 plants per 100 row ft.

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. One recommendation is to use one to three cards per 1000 sq ft. Traps should be inspected weekly and replaced regularly. A system of numbered traps can facilitate sampling and simplify record keeping. Yellow sticky tape can be used on a larger scale to reduce insect populations by trapping. Yellow sticky traps and tape are available from many online distributors.

Many of the arthropod pests that infest greenhouses are very small. Mites are 1/50–1/60 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), but a 16x–20x is preferred. With a hand lens, a grower can quickly identify many of the arthropod 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 a monocular (one barrel) or binocular (two barrel) type. They have approximately 10x–200x magnification. With a microscope, a grower can see small mites, such as broad mites, 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 which pests are present, proper chemical or biological controls can be selected and steps taken to exclude or limit further introductions. In Florida, Cooperative Extension Service offices in each county are able to help with pest identification (to find an office near you, visit http://solutionsforyourlife.ufl.edu/map/). Workshops may be offered on pest scouting and identification, and there are many publications and online resources available (see http://ipm.ifas.ufl.edu).

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 and should include the time and date of application, product name, EPA registration number, active ingredient, amount used, the target pest, and effectiveness. Some things that general records should include are daily minimum and maximum temperatures, measurements of plant growth and development, the pH of the growing medium, soluble salts, general root health, and other specific crop observations. Insect counts from monitored plants and sticky cards are also useful for identifying trends over time and for determining the effectiveness of control efforts. Over several seasons, it may be possible to see that certain problems occur at the same time each year. Details of releases of beneficial insects and mites 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 and mite pests into the greenhouse. The old saying, "An ounce of prevention is worth a pound of cure," certainly applies to greenhouse operations. The University of Florida has produced a series of short videos on the topic of greenhouse pest exclusion. These videos are available at http://vfd.ifas.ufl.edu. Additional information on insect pest exclusion can be found in the publication "Exclusion Methods for Managing Greenhouse Vegetable Pests" (http://edis.ifas.ufl.edu/IN730). 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 3 weeks.

The walk-in doorways in greenhouses provide an easy entrance for many pests. Growers need to evaluate various strategies to reduce the likelihood of pest entrance. In greenhouses with fan and pad-type ventilation, an air lock entrance room is essential. The added room is attached to the exterior of the greenhouse, enclosing the entry doorway. The double door system allows workers to enter the air lock room and close the outside door behind them prior to entering the greenhouse production area. Without the air lock room, the fans pull air in through unprotected doorways rather than screened openings. It is common to see pest infestations beginning in plants close to an unprotected doorway. Even in passively ventilated greenhouses, a secure entrance room is important in regulating easy entrance of pests to the production area. These rooms can also be used to maintain a footbath and hand-washing area, and also to provide for any other sanitation techniques for workers.

Modern technology in manufacturing has produced screening material so fine that insects can be excluded from the greenhouse. Insect screens with this fine mesh can be an important addition to an IPM program. Screens can be used effectively in both passively ventilated and fan and pad greenhouses. Any screens added to a ventilation opening will reduce airflow through that opening; therefore, it is important to follow the manufacturer's recommendations and increase the surface area covered by the screen to compensate for the reduction in airflow. The reduction in airflow can cause fan motors to burn out and reduce cooling. Recent studies conducted by the University of Florida with growers in the Live Oak area confirmed that silverleaf whiteflies can enter through unscreened roof vents even 20 ft above ground. Therefore, roof vent openings in passively ventilated greenhouses may need to be screened to exclude whiteflies and other flying insects.

Research in Israel and the United States has shown that covering greenhouses 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.

Highly reflective or metalized plastic mulches have been used in agriculture for many purposes, but the primary use has been to repel certain insects. Metalized mulches are effectively used in field production by covering the narrow raised beds in a full-bed polyethylene mulch production system. Research at the University of Florida's North Florida

Research and Education Center (NFREC) in Quincy showed a 30%–50% reduction in the incidence of the thrips-vectored virus, *Tomato spotted wilt virus*, in field tomato production. Researchers at the NFREC, Suwannee Valley tested the same approach around the outside of greenhouses, using 20-ft-wide strips of metalized mulch to exclude whiteflies. Preliminary results suggest that the metalized mulch was effective in reducing silverleaf whitefly entrance by 90% through the cool pad opening in a fan and pad system. It is important to have a continuous metalized mulch barrier that extends 20 ft along the side wall from the ventilation air intake end wall. Additional mulch along the sidewalls may also help repel the whiteflies away from the air intake area. The combination of screening and metalized mulch should be used together to most effectively restrict whitefly entry.

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:

- 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.

- In addition to removing all plant debris, growers should thoroughly clean or sterilize the greenhouse to make it as insect free as possible. A one-month crop free period can be helpful in reducing insect and mite problems.

- 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.

- Avoid planting outdoor crops near greenhouses, as they may provide host plants for insect pests and may also be a source of diseases. Weeds should not be allowed to grow around or within the greenhouse. A 10–30-ft vegetation-free zone around the greenhouse can be created with a heavy-duty geotextile weed barrier material typically used in the container nursery industry as a groundcover.

- A clean transplant program will aid in keeping pests out of the greenhouse. Plants coming from other greenhouses should be carefully inspected for insects, mites, 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 hitch rides into the greenhouse or from one greenhouse to another.

Biological Control

Biological control in the greenhouse environment means providing or releasing insect or mite predators, parasitoids (specialized parasites that ultimately kill their hosts), nematodes, or disease-causing organisms (fungi, bacteria, and viruses) that attack insect pests. Some biological controls cannot be used with most insecticides. Reducing or eliminating chemical pesticides leads to a safer working environment, can reduce production costs, 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 insecticides and miticides and requires a greater knowledge of pest biology and pest numbers. Many factors contribute to success or failure of biological control: type and quality of the natural enemy selected, release rates, timing, placement, temperature and humidity, and the previous use of insecticides and miticides.

Suppliers can provide technical advice on the optimum use of their products. Some have detailed Web sites. In general, releases must be made when or before the pest population is first detected. High pest populations will be difficult to control biologically. Some predators and parasitoids 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 parasitoid or predator will determine how often it has to be reintroduced. It is important to note that if all the pests are eliminated, the natural enemies will also be eliminated. Providing nectar sources (flowering plants) may prolong the life of parasitoid wasps. Yellow sticky cards may have to be temporarily removed to avoid trapping predators and parasitoids.

Banker Plant System

A banker plant system is an innovative way to provide natural enemies in a biological control program. A banker plant is a plant that is used as a reservoir of natural enemies. The banker plant is generally different than the crop plant being grown in the greenhouse. The banker plant serves as a host for an alternate nonpest insect. For instance, papaya is a host plant for the papaya whitefly. Papaya can be used as a banker plant for greenhouse vegetable crops because the papaya whitefly will not attack vegetable crops, but it will serve as a host for beneficial parasitic wasps such as *Encarsia transvena*. Once *E. transvena* emerges from the papaya whitefly, it will also attack vegetable pest species of whitefly found in the main greenhouse crop. The papaya banker plant system has been successfully used in Florida greenhouse vegetable crops. Other banker plant systems useful in Florida greenhouse vegetable crops include grain crops such as barley, wheat, rye, corn, or sorghum, which support aphid species such as bird-cherry oat aphid or corn leaf aphid. These aphids are not pests of commonly grown greenhouse vegetable crops, but serve as prey for various predators and parasitoids that attack aphid pests of vegetables, such as melon or green peach aphids.

Other banker plant systems are being evaluated for greenhouse vegetables. The banker plant system may be an economical method of providing a reproducing population of natural enemies. The system will also reduce reliance on insecticides and miticides, thus reducing insect and mite resistance to applied chemicals. On the other hand, if growers anticipate problems with insect-vectored viruses, based on past history, even the low pest populations present in banker plant systems may be unacceptable. If low pest populations present a high risk of virus transmission, then biological control measures may not be the best choice.

Insecticides and Miticides

Even when a good biological control program has been established, there may be times when a conventional insecticide or miticide is needed. Biorational insecticides, 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 lady beetles and lacewings. Soaps are toxic to young lady beetle larvae. Neem and Bt products are generally safe for use with natural enemies. Other advantages of biorational insecticides are shorter reentry intervals and safety for workers.

Conventional insecticides and miticides also have a place in IPM, if it is not feasible to use biological controls and if biorational insecticides do not offer sufficient control. These options are limited, however, to only a few registered pesticides. The development of resistance to insecticides is more likely if a product is used repeatedly. Therefore, pesticides with different modes of action should be used in a sequence that will help prevent resistance.

The following steps are suggested when using any pesticide:

Step 1: Choose the right insecticide or miticide.

Only after the grower has properly identified the pest can the best insecticide or miticide be selected. Insecticides and miticides 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 others may be effective against a different stage, or even against all developmental stages. Properly identifying the pest and understanding its biology and life cycle allow the grower to make wiser decisions when choosing an insecticide or miticide. 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 pesticide.

After choosing the pesticide, the grower 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 caterpillars may require the lowest recommended label rate, while large ones may require the highest.

Greenhouse growers frequently have smaller areas to spray than field growers and therefore need smaller amounts of pesticide to do the job. For example, a field tomato farmer may use 1 qt (32 oz) of a material per 100 gal of water per acre. However, in a greenhouse, only 1 gal of spray might be needed to cover the greenhouse block. This means one must measure out 0.32 oz or 9.3 mL (or cubic centimeters), which is less than 1 tablespoon. It is critical that this measurement be accurate; 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. Plastic syringes (minus the needles) are very useful for measuring thick liquids, such as suspension concentrate (SC) formulations. These are available in several sizes from suppliers of animal feed. 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 enable accurate measurements. Plastic is generally 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 (burning).

Proper measuring devices also play an important role in the overall safety and handling of pesticides. They aid in preventing spills of concentrated materials. Pesticide concentrates are usually handled when the sprayer is loaded and diluted 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 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:

- 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.
- 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.
- Reentry by workers into overdosed areas could be dangerous and lead to illnesses, medical costs, and liability to the grower.
- Production costs could increase without the benefit of added profits.
- 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, such as poor coverage or resistance to the insecticide in the target insect population.

Step 3: Apply pesticides at the right time.

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

- Growers should regularly and thoroughly inspect the crop so that they are aware of the presence of insects and mites as well as any increase in numbers.
- Growers should know the pest, its behavior, and its ability to damage the crop.

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

- Growers should know the biology of the pest so that insecticide or miticide 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 or miticide than older stages. Pesticides generally do not affect pupae (large larvae nearing this stage are also difficult to control).

It is generally best to apply pesticides in the late afternoon or evening hours when temperatures start to decrease. This also allows for maximum exposure before "airing" out the sprayed area for employees. Also, many insects are most active at night. The risk of phytotoxicity 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 achieved by spraying early in the morning hours. As a rule, insecticide or miticide applications should be made while temperatures are low. Pesticides should not be applied when plants are water stressed.

Step 4: Apply pesticides correctly.

Proper application, like 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 pesticides.

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

Growers should purchase the proper type of equipment to meet the needs of the operation and use 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 are popular and have been used for years in greenhouses. They can accommodate a wide range of pesticide types and offer flexibility in their 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 when using high-volume systems. However, most insecticides and miticides 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, 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 it uses 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 high or low volume, has its own advantages 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 be thoroughly aware of all rules, regulations, and applicable laws before purchasing spray equipment.

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

Another consideration when correctly applying insecticides and miticides is the proper maintenance of spray equipment. Many spray operations are hampered and their 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 meet 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. Equipment upkeep 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. The resulting corrosion 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 of by application to a labeled site. Disposal of pesticides is a growing concern, with liability becoming more of a problem. Therefore, growers need to plan carefully for the amount of pesticide 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. Rust particles, pieces of rubber lines, and other unwanted particles can quickly stop up a 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 contains 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 operational problems. 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 of the equipment.

Pesticides should be used as soon as they are mixed. Once mixed with water, the pesticide begins to change. The effective life of certain pesticides 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 pesticides. Generally speaking, the higher the pH, the faster the pesticide 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 Pesticides

When storing pesticides, growers should follow these rules:

- Purchase only as much pesticide as will be necessary for a single season, so as to avoid storing materials for longer periods. Consult the pesticide label or the manufacturer for specific information on the shelf life of a product.

- Pesticides must be stored in a safe, dry location. The best storage temperatures are generally room temperature (70–80°F). Temperatures over 90°F are not recommended. Some pesticides also undergo undesirable changes if storage temperature drops below freezing (32°F). Always look for and follow storage recommendations on the label.

- Applicators must follow local and state laws as to storage sheds, ventilation, safety equipment (eye wash, showers, sinks), drains, locks, and warning signs.

Safety

Pesticides can create serious problems when rules of common sense and safe use and handling are not followed. The pesticide label is considered a legal document. "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 and material data safety sheets (MSDS) can be found on the Internet. One general site is http://www.cdms.net/. Growers should keep a binder with information on all pesticides used in their operations. It should include at least the label and MSDS for each product.

Not understanding or not following the pesticide label can have serious consequences. The label contains statements concerning safe use, such as required personal protective equipment (PPE) (clothing, eye protection, and respirators), worker contact, poisoning symptoms, and proper storage and disposal of containers. The user must become familiar with all safety requirements and other aspects of the label before using the product.

Growers should be completely familiar with worker protection standards (WPS) and record-keeping requirements (see: http://edis.ifas.ufl.edu/topic_pesticide_safety).

Specific Greenhouse Pests

Many insects that will feed on a plant grown under field conditions will feed on that plant in a greenhouse. 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 insecticides and miticides registered, labeled and recommended for field conditions are not automatically legal for use in the greenhouse for the same crop and pest. As a rule, growers are restricted by law to only a small number of pesticides for greenhouse use.

Successfully managing insect and mite problems in the greenhouse can be more difficult than under open field conditions. Therefore, the grower must know specific tactics and methods that are legal and effective for managing greenhouse pests.

As stated earlier, one of the foremost factors in pest management is identifying the pest and understanding the biology, behavior, feeding habits, and other information on how it 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 determines if they can be controlled successfully, if the crop will be chronically infested for the entire season, or if the crop will be lost.

Aphids

http://entnem.ifas.ufl.edu/creatures/veg/aphid/green_peach_aphid.htm

http://entnem.ifas.ufl.edu/creatures/veg/aphid/melon_aphid.htm

Aphids, sometimes 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 upper abdominal surface. These tubes (cornicles) can be seen easily with a hand lens or dissecting microscope. Winged aphids develop when plants are heavily infested or deteriorating. The presence of a winged aphid on a sticky trap when plants are not yet infested signals the possible beginning of an infestation.

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:

- As the aphid populations increase, they suck nutritional fluids (sap) from the plant and create stress problems, such as stunting.
- The aphids inject enzymes through their needlelike mouthparts as they feed, causing physiological changes in some plants. These changes result in distorted plant growth, such as leaves that are twisted and abnormally thick with leaf edges cupping downward.
- 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.
- Aphids are also capable of vectoring (carrying and transmitting) certain viruses that cause plant diseases, which can spread quickly through a crop and result in severely stunted plants or plant death.

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 five to seven days and begin giving birth themselves. Aphids can live for 30–45 days and continue to produce offspring daily. Due to this biological process, aphids can have 30 or more generations per year in Florida, and populations can explode rapidly.

Aphid Control

In outdoor conditions, aphids frequently are kept under control by a multitude of beneficial insects, such as lady beetles, wasps, syrphid flies, and lacewings. 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, lacewing larvae, and lady beetles. A predacious midge, *Aphidoletes aphidimyza*, can also be effective. Beneficials should be introduced early, before aphid populations grow large. The banker plant system mentioned earlier (see Biological Control above) can be used to sustain a population of parasitoid wasps even when pest populations are low.

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. Unless a systemic insecticide is used, the aphids must be contacted directly by the spray. Imidacloprid, the only systemic insecticide that is labeled for use on greenhouse tomatoes and cucumbers, is known to have adverse effects on bumblebees used for pollination. Because aphids primarily feed underneath the leaves, they are protected unless extra efforts are made to deliver contact insecticides to this area. Any aphids that are not controlled by a given spray application will 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.

Whiteflies

http://entnem.ifas.ufl.edu/creatures/veg/leaf/silverleaf_whitefly.htm

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 "mothlike" insects on the undersides of leaves. Generally, 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. In the past, the greenhouse whitefly was the most commonly encountered species, but the silverleaf whitefly (also commonly known as sweetpotato whitefly) has become the dominant species in Florida. The silverleaf whitefly has been an especially prolific 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 bodies 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 and take them to their local Extension office.

The silverleaf whitefly female lays approximately 100 or more eggs at a rate of 6–12 eggs per day. The eggs are generally yellow, very small (1/132 of an inch), and are attached to the undersides of the leaves by a short stalk. Eggs may be placed unevenly or arranged in small, circular patterns. Eggs hatch in three to seven days, giving rise to tiny, pale green first nymphal instars (growth stages), 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 spot 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, transparent, and green to greenish yellow in color. The pupa is a nonfeeding 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. A 10x hand lens or dissecting microscope can be 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 6–12 days, and the pupal stage lasts for 6–12 days. Adult females lay eggs for 10–14 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 of the greenhouse whitefly is reported to be longer than that of the silverleaf whitefly, with the nymphal stages lasting 28–30 days. Adults are thought to live and feed for 30–40 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 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 renamed *Tomato chlorosis virus* (ToCV). Silverleaf whitefly also vectors *Tomato yellow leaf curl virus* (TYLCV) and *Tomato mottle virus*, which are both begomoviruses (whitefly-transmitted geminiviruses). Several whitefly-transmitted viruses that infect cucurbits are also now found in Florida. *Cucurbit leaf crumple virus* and *Cucurbit yellow stunting disorder virus* may cause problems in greenhouse cucumber and melon crops.

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 whitefly nymphs are necessary to cause this problem, which is believed to be caused by an enzyme or other chemical in whitefly saliva. This disorder makes the silverleaf whitefly particularly dangerous in a greenhouse.

Whiteflies can be detected using several methods, such as observation, shaking the plants, or using the yellow sticky traps mentioned earlier. 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 can be purchased from most greenhouse supply companies or online. 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 also 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:

- New crops should not be planted in or near greenhouses that currently have a whitefly problem.
- Cooperation among growers is helpful 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.
- Greenhouse owners who 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.
- Workers should not wear yellow clothing. Since whiteflies are attracted to yellow, they may hitchhike on clothing and be moved to other houses.
- Workers must control or destroy volunteer host plants, including weeds, both during production and in the off season.
- 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.
- Sanitation should be practiced at all times, and infested plants and parts should be destroyed as soon as the crop is harvested.
- Exclusion is very important. See the beginning of this publication for details and suggestions.

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 insecticides available than under greenhouse conditions. The following are reasons for this difficulty, particularly with regard to tomatoes:

- 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 undersides of the leaves.
- Whiteflies are covered with waxy materials that reduce the adherence of spray to their bodies.
- Whiteflies suck the juices from the plant; therefore, they do not eat or consume the insecticide like a chewing insect. However, systemic insecticides are consumed by whiteflies. Imidacloprid, a systemic insecticide which is labeled for use on greenhouse cucumbers and tomatoes, can cause problems if bumble bees are being used for pollination.
- Egg and pupal stages do not feed and are therefore protected from systemic insecticides.
- Only the adult and crawler stages (short time period only) move and come into contact with spray residues. Eggs, nymphs, and pupae do not move and thus avoid spray residues.
- The immature whiteflies must be hit directly with contact insecticides in order to kill them. This requires strategic and careful application of insecticides.
- Whiteflies appear to have become resistant to 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 make every effort to prevent and control the whitefly. For chemical control to be successful, growers must concentrate on all stages. Some insecticides 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 four-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 (http://www.anbp.org). Trials using parasitic wasps against the silverleaf whitefly in Florida greenhouse tomato crops, however, have not been nearly as successful. Trials conducted at Suwannee Valley Research and Education Center in 1994 and 1995 tested *Encarsia formosa* as a control program for silverleaf whitefly. Control could be achieved, but release rates of 28 wasps per square meter were required. This is six to seven 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* (formerly known as *Eretmocerus californicus*), is now readily available.

In addition to trials with *E. formosa*, 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, *D. pusillus* was unable to live in the tomato crop even though plenty of whiteflies were available as food. It is speculated that the hairs on tomato leaves and stems make it impossible for *D. pusillus* to become established in the tomato crop. The hairs, or trichomes, interfere with searching, feeding, and egg-laying by the beetle, making it more likely to leave the plant. In general, parasites and predators are less effective on tomatoes than they are on other greenhouse crops.

Spider Mites and Broad Mites

Spider Mites

http://entnem.ifas.ufl.edu/creatures/orn/twospotted_mite.htm

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 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, 1/8–1/4 the size of the adult, on the underside of the leaf, usually along the sides of the midrib or large veins. After about three days at 30°C, small, whitish larvae hatch from the eggs. These have three pairs of legs. The larval stage lasts one to two days at 30°C. The mite then becomes a protonymph (one to two days) and then a deutonymph (one to two days). In both nymphal stages, the mites have eight legs. The deutonymph matures into an eight-legged adult spider mite, with the entire life cycle lasting five to eight days at 30°C and about 17 days at 20°C. 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. Recent research indicates that the life cycle can be completed in as little as 3.5 days at 90°F.

The adult female can start laying eggs within 36 hours and will lay five to seven eggs per day. Spider mites can go through 30–50 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, styletlike 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 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. Because even the adult mites are generally too small to be seen without a hand lens or a microscope, the leaves often shrivel and die before the grower realizes spider mites are causing the problem. The eggs and feeding marks are even smaller and can be observed only with the use of magnification.

Once the number of spider mites has become excessive and they are forced to move to the upper surface of the leaves, they continue upward to the apical or terminal leaves, where they produce silken webs. An individual 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 guidelines for damage indexes for cucumbers and tomatoes. The number found per square inch of leaf determines the severity of a spider mite infestation. On cucumbers, slightly less than 12 mites per square inch will start causing crop losses. At this infestation level, 40% of the leaf area will be affected. Approximately 55–60 mites per square inch can result in 40% yield loss when this number is reached after the plants are five weeks old or older. On tomatoes, the threshold is similar, with 12 mites per square inch resulting in approximately 30% of the leaf photosynthetic area being 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 61°F and 70°F. At warmer temperatures, the mite populations would be expected to be even greater for a given time period.

Broad Mites

http://entnemdept.ufl.edu/creatures/orn/broad_mite.htm

Broad mites are even smaller than spider mites and are a serious pest of peppers and eggplant in the greenhouse. They sometimes also affect greenhouse tomatoes. Their feeding causes malformation of young leaves and flower buds. This mite has four stages: egg, larva, nymph, and adult. A female can produce up to 76 eggs during her lifetime. After feeding for a few days, larvae enter a quiescent nymphal stage. Males will carry quiescent females to new leaves and mate with them as soon as the females emerge as adults. Broad mites have been known to hitchhike on the legs of whiteflies and reach new plants this way.

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 colonize ornamentals and wild hosts that are often found around greenhouses. The mites easily climb 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, barns, 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. Sprinkler 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 expertise concerning the risk of increasing certain plant diseases.

Once mites are found, miticides that do not affect eggs need to be applied three times at five-day intervals (or as described on the label for the crop). The reason for this tight spray schedule is the short life cycle (egg to adult) of five to seven days. Within a five-day period, growers must try to kill all adults and immature stages that would otherwise become egg-laying adults. Failure to repeat application in five days will allow today's eggs to reach adulthood shortly after five days have passed and the life cycle will remain unbroken. Take care to direct sprays to the undersides 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 may be impossible to gain control for the entire season. Predacious mites can be purchased and released to control spider and broad mites if the infestation is light, and these predators can prevent a more serious problem if they are introduced into the crop early. Suppliers can recommend which species to use, depending on environmental conditions and the species of mite present in the greenhouse. *Orius* spp., or minute pirate bugs, also feed on mites.

Leafminers

http://entnem.ifas.ufl.edu/creatures/veg/leaf/a_serpentine_leafminer.htm

American serpentine leafminer and vegetable leafminer are tiny flies (less than 2 mm) that attack crops outdoors, but will also infest greenhouses. Both flies, which are black with yellow markings, attack a wide variety of plants, including vegetables commonly grown in greenhouses (i. e., cucumber, melons, lettuce, peppers, and tomatoes). The female fly punctures the leaf with her ovipositor, laying eggs in the leaf, but also feeding from the puncture sites. The most damaging stage is the larva or maggot, which feeds inside the leaf. As the maggot feeds and grows, it moves through the leaf, creating an ever larger mine in a highly visible, irregular path (hence the name serpentine). When the maggot is mature, it cuts through the leaf surface to pupate outside the leaf.

Pupae, when first formed, are light yellow and 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 warm conditions, the life cycle, from egg to adult, takes as little as 16 days. Adult females can start laying eggs after one to five 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. These characteristics 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.

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 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. Transplants often 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, and eggs are also inside the leaf. A few insecticides will knock down the adult flies, although they become resistant to insecticides very quickly. In greenhouse tomato production, lower leaves are often removed to help control diseases, and because leafminer flies prefer to lay their eggs in mature leaves, this practice will help control them also. Removing the leaves before the larvae leave the mines and pupate will reduce the population. Biological control with parasitoid wasps can be very effective if insecticide use in the greenhouse is limited. These wasps (*Dacnusa sibiricus* and *Diglyphus isaea*) are commercially available.

Tomato Pinworm

http://entnem.ifas.ufl.edu/creatures/veg/tomato/tomato_pinworm.htm

Tomato pinworm larvae mine leaves and tunnel into the fruit of the tomato plant and sometimes eggplant. Populations can 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 of an inch. The threadlike antennae are about 2/3 the length of the body. The moth can be identified under a dissecting microscope by the antennae, 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 marked with gray and yellow flecks.

The moth's legs are gray, yellow, and black with small spines protruding from the surface. Frequently, adult moths 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.

Tomato pinworm moths usually lay eggs singly (occasionally in clusters of two or three) on the surfaces of 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 silklike 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).

Pinworm larvae go through several instars (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 first and second instars being yellowish gray. These stages create the blotch mines. The third and fourth instars become gray to grayish green with dark purple spots spaced along the back and sides of their bodies.

Feeding behavior changes as the caterpillar grows larger. The older caterpillars move out of the leaf mines and feed on newly developing unrolled or unfolded leaves, on foliage after tying the leaves together with silk, or by boring into the stem or the fruit. Larvae frequently enter the fruit in the region below the calyx, often 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 its 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 of an inch deep.

The mature, fully grown larvae (caterpillars) are approximately 1/4 of an 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, forming the cocoon. The pupa forms inside the cocoon and is about 1/4 of an inch long. The complete life cycle is about 30 days in warm weather.

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

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.

A pheromone is available that can be used with a sticky trap for early detection of tomato pinworm. This same pheromone is available in slow-release dispensers or as a microencapsulated pheromone spray for mating disruption. The male moth uses the pheromone to locate the female. With the application of the pheromone to the crop, the male can no longer follow a plume to a female. Mating, then, cannot take place and no fertile eggs are produced.

Insecticides, such as a product containing *Bacillus thuringiensis*, 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 inside the leaves 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.

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 20 years their activity has caused great concern to growers of both greenhouse and field-grown crops, including tomatoes and peppers. The western flower thrips has caused concern because it vectors *Tomato spotted wilt virus* (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 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 a total of 25–75 extremely small, bean-shaped, delicate eggs in the leaf tissue. She lays the eggs individually over a span of two to seven 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 1/20–1/25 of an inch in length. The larvae are much more sluggish than the adults. They feed in colonies over a period of 10–14 days. Feeding sites are usually between two leaf veins. Larvae are generally cream colored when first hatched and turn yellow as they develop.

The thrips pass through a prepupal stage that lasts only about one day. They then transform into the pupal stage, which lasts four to five 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 or onto trash to go through this stage of development. The entire life cycle depends on temperature and takes 20–25 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 others 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 appear 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 paperlike. 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 most likely causes this damage. Western flower thrips transmit *Tomato spotted wilt virus*. They also cause cucumbers to become 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 undersides of the leaves. The leaves can be distorted and twisted. One can view the colonies by opening the curled, damaged leaves. 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 appear, 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. Most commonly, winged adults fly in from other host plants or crops. Thrips also may enter on boxes and equipment from packinghouses, fields, or other areas outside the greenhouse.

Thrips Control

Growers should try to prevent thrips from flying or moving into greenhouses. Small mesh screens, door protection, fan shrouds, and entry holding rooms (air lock porch) may slow down or eliminate entry. The reflective mulch mentioned previously under the heading "Exclusion" will also help exclude thrips as well as aphids and whiteflies. Workers should thoroughly wash equipment using sweepers or compressed air guns to help prevent 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. It may also increase plant fungal diseases, however. 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 insecticides for thrips. Thrips have become resistant to many of the available insecticides. A predacious mite, *Amblyseius cucumeris*, can be very effective but must be released over a period of several weeks to control thrips. *Amblyseius swirskii* is even more effective than *A. cucumeris.* Both predators attack thrips larvae but not adults. *A. swirskii* will also help control whiteflies and broad mites, but not twospotted mites. Commonly, minute pirate bugs (*Orius* spp.) are used to control adult thrips when the crop begins to flower, after releasing mites earlier in the crop cycle. The minute pirate bugs are much more expensive to buy but will also prey on certain stages of other pests, such as the eggs of whiteflies. Biological controls cannot be used with most insecticides.

Other Insect Pests

Aphids, whiteflies, mites, leafminers, 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. If caterpillars are a common problem, this is a strong indication that there are easy entry areas for the adult moths. These areas should be located and repaired. Moths can easily be excluded from greenhouse crops. However, from time to time, a moth may enter a greenhouse and lay enough eggs to cause considerable damage. Many female moths can lay 1000–1500 eggs within a few nights' time.

Female moths enter greenhouses most frequently through open doors. Most moths are active only at night and are attracted to lights; therefore, lights should not be used in or around the greenhouse at night, if possible. During the day, moths remain at rest on walls, ceilings, benches, or the foliage of the host plants. Eggs are laid singly by some species but in clusters by others. A moth life cycle generally takes about one month. Eggs hatch in about three to seven days. The larval or caterpillar stage lasts 14–28 days and the pupal stage lasts 7–10 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 they hatch, are also very small and can only scar the surface of the leaves, although some can tunnel and make mines when they are small. 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 draw attention. 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 of an inch or more in length.

Some caterpillar species are under an inch long when in their last growth stage as larvae, while other species may reach 4 in. For instance, large tomato or tobacco hornworms, both of which are highly attracted to tomatoes, reach 3–4 in. in length the last week of their larval development. At this stage, they can eat 310 sq. in. of leaf tissue in 24 hours, and they can also damage the fruit. If caterpillars are allowed to reach large sizes, a vine or a crop can be literally reduced to stems overnight.

Caterpillar feeding is usually easy to detect because 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 collects beneath feeding sites on the leaves or floor. Fresh droppings are a sure sign of caterpillar activity. Several caterpillars or worms will eat, or even prefer, fruit at certain times, with tomatoes being the most susceptible.

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).

Corn Earworm (Tomato Fruitworm)

http://entnem.ifas.ufl.edu/creatures/veg/corn_earworm.htm

Adult female corn earworms are medium-sized, light brown to golden brown, hairy moths. The wingspan is about 1 1/2 in. from tip to tip. Females lay eggs at night and prefer tomatoes that are blooming since they feed only on bloom nectar. A female can lay 1000–1500 eggs during her lifetime. The eggs are about 2/10 of an inch in diameter. 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 egg takes on a reddish, purple, or brown band just before it hatches, which occurs in three to seven days. The eggs are usually laid on the undersides of leaves on the growing terminals or around blooms in the upper canopy of the plant. Corn earworms lay eggs singly, not in clusters.

The eggs hatch into small, dark-headed larvae that are usually yellowish and about 1/2 of an 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, molelike bumps, each with a bristlelike protruding hair.

The larval stage lasts 14–18 days, and the larvae reach approximately 1 3/4 in. 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 fruits during its life cycle. Pupation takes place on the ground, soil, or trash after the larva drops from its feeding site. The pupal stage takes 7–10 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

http://entnem.ifas.ufl.edu/creatures/veg/leaf/cabbage_looper.htm

The adult cabbage looper is a medium-sized grayish brown moth with about a 1 1/4 in. wingspan (tip to tip). The front wings have a small white blotch near the center that resembles a "figure 8." The females are active at night and lay 50–200 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 about 2/10 of an inch wide. The eggs darken as they age, and in seven days, just before hatching, they 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 bodies. The larvae move by arching their backs and then stretching out the front of their bodies to a new position. Then they bring their rear prolegs forward, creating another "loop." The larvae are also shaped somewhat like a baseball bat, being larger at the rear and tapering to a smaller head. 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.

The loopers differ from most other caterpillars that are found in the greenhouse based on the number of pairs of prolegs they have. Prolegs are fleshy, leglike 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 main pairs of prolegs, plus one pair of rear end, or anal, prolegs. The other caterpillar types found in the greenhouse have four pairs of abdominal prolegs, plus one pair of anal prolegs.

Armyworms

Several species of armyworms feed on tomatoes and lettuce and also may attack cucumbers. Armyworms frequently infest crops grown in open fields. Armyworms can become a problem under greenhouse conditions when fertile females enter and lay eggs. Again, the presence of armyworm larvae means that there are openings in the greenhouse that are large enough for moths to enter.

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 1 1/4–1 1/2 in., and the wings may have wavy lines running across them or dotted, irregularly shaped darkened areas.

Armyworm moths are active at night, and this is when they lay their eggs. Unlike loopers and earworms, the armyworm female lays eggs in clusters of 60–150 eggs. Armyworm females can lay 300–1500 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 of an 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 three to six 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 half an inch in length, they begin to acquire the color and characteristics of their species. Most of the larvae are 1 1/2 in. long when fully grown. The beet armyworm is slightly smaller and may only reach a length of 1 1/4 in.

Larvae frequently cluster on the plant on which they were hatched. A plant may have 100 or more caterpillars on it. Generally, the larvae migrate and scatter to other plants within a few days. The larvae usually stay on the undersides 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, eat holes in fruit.

Because the larvae move from plant to plant (sometimes in groups), 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. Mature armyworms drop to the ground or soil and pupate.

The pupal stage lasts 10–30 days and gives rise to the emerging adult moth. 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 25–35 days.

Growers should look for 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 armyworm, are more difficult to control than others. All larvae look alike to some extent, particularly when they are under 1/2 of an inch in length. Armyworm larvae, like corn earworm, have five total pairs of prolegs—four abdominal pairs and one anal pair.

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

Beet Armyworm

http://entnem.ifas.ufl.edu/creatures/veg/leaf/beet_armyworm.htm

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 1–1 1/4 in. in length when mature. Larvae scarify foliage, leaving a netlike pattern of leaf tissue; occasionally they will eat holes in the fruit.

Southern Armyworm

http://entnem.ifas.ufl.edu/creatures/veg/leaf/southern_armyworm.htm

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 in. long. They eat foliage and large holes in the fruit.

Yellow-Striped Armyworm

http://entnem.ifas.ufl.edu/creatures/veg/leaf/yellowstriped_armyworm.htm

For all practical purposes, the yellowstriped 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 entry of female moths. In most cases, the moths enter the greenhouse through open doors or vents. The moths are night-flying insects that are attracted to light. Lights should be turned off around the greenhouse at night to help prevent armyworms from entering. If lights must be used at night, there should be 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 and can be killed using mechanical or chemical methods. One moth killed can prevent the occurrence of as many as 1500 worms, which are not as 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 larva per four plants is found. Growers should carefully scout for larvae. Larvae begin to eat tremendous volumes of foliage once they are 1/2 of an inch long. Larvae 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 armyworm before it exceeds 1/2 of an inch in length.

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

Hornworms

http://entnem.ifas.ufl.edu/creatures/field/hornworm.htm

Occasionally, hornworm moths enter greenhouses and become trapped. If this occurs, the female may lay green, pearl-shaped eggs that are about 1/16 of an inch in diameter. Eggs are laid singly, usually on the upper leaf surface. Females are gray and have orange-yellow spots on their abdomens; the tobacco hornworm has six pairs of spots and the tomato hornworm has five pairs.

The egg hatches in about seven days and a small, green caterpillar emerges, equipped with a prominent horn located near the rear of the body. New larvae continue to grow for approximately 28 days and are approximately 4 in. 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. Hornworms eat large amounts of foliage in short periods. One larva can defoliate an entire plant if allowed to live its normal life cycle.

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

There are no specific economic thresholds for hornworms. However, in the case of smaller larvae, such as armyworms, which have a lesser capacity to feed than hornworms, 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 are active. The moths are also attracted to light; 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 of an inch long.

Related Literature

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More Information

For more information on greenhouse crop production, please visit our website at http://smallfarms.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

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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