CHAPTER 4

PLANT PROTECTION

INTRODUCTION

*Plants need to be protected against several things:

Animals… of all sorts, including

Birds that steal fruit from trees, shrubs, vines, etc.
Herbivores that browse your favorite fruits and flowers
Harvester ants that denude your shrubs of leaves to feed to their fungus
Errant children who want your tomatoes, peppers, etc.

NOTE: Most of these problems can be solved by erecting some form of physical barrier between the perpetrator and your prized plants. Barriers might include a fence or wall, bird netting, "tangle foot" or even a locked greenhouse.

NOTE: The above animals do not usually pose a significant problem in CEA and will therefore not be considered further here.

Insect and mite pests: Whiteflies, aphids, thrips, spider mites and other pests do pose a significant threat, particularly to crops growing in greenhouses.

Insects and mites can cause different types of damage:

Direct physical damage: chewing, sucking, etc.
Injection of toxins into the plant during feeding that effect growth or quality of the plant and/or fruit.
Transmission of bacterial, fungal or viral diseases.

Disease-causing organisms: In order for a pathogen to be considered "disease causing" it must meet 4 criteria, **"Koch's Rules"** (from Plant Pathology by Agrios, 1988):

1. The pathogen must be found associated with the disease in all the diseased plants examined.
2. The pathogen must be isolated and grown in pure culture on nutrient media, and its characteristics described (non-obligate parasites), or on a susceptible host plant (obligate parasites), and its appearance and effects recorded.
3. The pathogen from pure culture must be inoculated on healthy plants of the same species or variety on which the disease appears, and it must produce the same disease on the inoculated plants.
4. The pathogen must be isolated in pure culture again, and its characteristics must be exactly like those observed in step 2.

A. Disease-causing organisms that are major problems in CEA/hydroponics:

Fungi: Kingdom Mycetae

They usually produce hyphae on or within the plant.
Several types of fungi can infect every part of the plant (stems, leaves, fruit and roots) with "zoosporic" root fungi (that have a motile swimming spore stage) being a significant problem in recirculating hydroponic systems.
Fungi can cause rots, spots, wilts, blights, molds and mildews.

Prokaryotes (bacteria): Kingdom Prokaryote

Single celled organisms that (in tomatoes) usually infect the upper portions of the plant resulting in necrotic (dead) spots on various portions of the stem, leaves and fruit, as well as causing whole plant wilts.
NOTE: Another type of prokaryote, mycoplasmas, have not been seen in CEA/hydroponics.

Viruses: Kingdom Vira

Viruses are particles of infectious single or double stranded DNA or RNA surrounded by a protein coat.
NOTE: Viruses require a "**vector"** to be transmitted to a plant. Insects are common vectors, but viruses can also be transmitted mechanically (hands, pruning shears, etc.).
NOTE: Viroids (infectious, circular, single stranded RNA that lacks a protein coat) have not seen in CEA/hydroponics.

B. Disease-causing organisms that are not significant problems in CEA/hydroponics (These will not be considered further here.):

Parasitic higher plants: These plants grow into the host plant and obtain water and nutrients from the host. They include dodder, witchweed, mistletoe and broomrape. Greenhouse hydroponics excludes parasitic plants.

Nematodes: Microscopic animals that are worm-like in appearance but different, taxonomically, from true worms. They are free-living in fresh or salt water or in the soil and feed on microscopic plants and animals. In greenhouse hydroponics, where soil is not used, avenues for nematode infection would be from a contaminated water supply or from soil brought in on shoes, equipment, etc.

INSECT AND MITE PESTS

*As noted above, insects and mites can cause physical damage to plants, or transmit toxins, bacteria, fungi or viruses from plant to plant.

*CEA can help exclude many insects and mites from the greenhouse environment. The closed nature of the greenhouse in conjunction with **insect screening** on vents and air intakes can create an effective barrier.
However, the greenhouse environment coupled with the typical monoculture that is grown there can create a perfect breeding ground for insects and mites that do manage to get in and population explosions can occur quickly.

*Traditional insecticides CANNOT BE USED since most hydroponic greenhouse operations (especially tomatoes and peppers) use bees for pollination and insecticides would also kill the bees. Therefore, control measures listed here include predatory or parasitic insects or mites, infectious fungi and bacteria or soap solutions and dusting sulfur that can be spot sprayed onto pests.

*Many insects and mites harm plants. However, several groups are of major concern in CEA/hydroponics. If not monitored closely and controlled immediately, populations of pests can explode quickly and devastate a crop.

1. **Aphids (several genera):**
   *Appearance: 6 legs/insect, round body, several colors (white, green, tan, black).
   *Life cycle: Complicated: reproduce asexually in summer, sexually in winter.
      Young born complete (miniature adults) and molt 4 times.
      White "cast skins" indicate the presence of molting young.
      Can be wingless or winged if populations high or when changing hosts.
      Mainly produce females (except in winter for sexual reproduction).
      High growth rate: 40-100 larvae/aphid (3-10/day over a few weeks).
   *Damage:
      Young and adults suck plant sap (high in sugar); plant growth is reduced, and leaves curl upward.
      Excess sugar is excreted as honeydew that drops onto lower leaves; sooty molds colonize the honeydew and reduce photosynthesis.
      Toxic substances can be injected.
      Pathogens (esp. viruses) can be transmitted (mainly by winged adults).
   *Control/Natural enemies:
      Gall-midge (*Aphidoletes aphidimyza*): same family as flies, mosquitoes. Gall-midge larvae inject poison that paralyzes and liquefies the aphid's insides which can then be drained.
      Parasitic wasps (Ex. *Aphidius matricariae*): The wasp lays an egg on the aphid which then swells and hardens ("mummy"). After growth, the adult wasp leaves the mummy through a circular hole.
      Verticillium lecanii: A fungus that parasitizes and ultimately kills aphids.
      Ladybird Beetles or lady bugs (*Hippodamia convergens*) and Lacewings (*Chrysoperla carnea*) also provide control of aphids.

2. **Red spider mites (*Tetranychus urticae* and *T. cinnabarinus*):**

*Appearance: 8 legs (spider family); ovoid bodies; variable color (green, yellow, orange and black but reddish brown when feeding on tomatoes).

*Life cycle: 5 stages: egg, larva, first nymphal (6 legs), second nymphal, adult.
Time in each stage depends on temperature (~30C/86F is optimal).
The population = 75% females, 25% males.

*Damage:
Larvae, nymphs and adults pierce plant cells and suck out the contents usually from the under side of leaves.
Chlorophyll is destroyed leaving yellow patches and photosynthesis decreases. These patches are a major problem on ornamentals.
Nymphs and adults produce webbing which are swarming with mites and give the leaf a reddish hue.

*Control/Natural enemies:
Dusting sulfur is an effect miticide. DO NOT dust beneficial mites or bees
The predatory mite (*Phytoseiulus persimillis*): Belongs to the same order as the red spider mite – Acarina. Nymphs and adults eat spider mites. Feeding depends on populations, temperature and humidity.

3. **Thrips (*Thrips tabaci*, *T. fuscipennis* and *Frankliniella occidentalis*):**

*Appearance: 6 legs (smallest of the winged insects); long and narrow; tan.

*Life cycle: 6 stages:
Egg - laid inside the leaf surface, flower petals or soft stems – causes small warts on sweet pepper leaves.
2 larval stages – these are very active and feed on all aerial parts of the plant. After these stages they drop to the ground and pupate.
2 pupal stages – these stages do not feed. Wing stumps begin to form.
Adult – has two pairs of wings.

*Damage:
Larvae pierce and suck out cell contents; cells die and turn silvery gray. Loss of chlorophyll; decreased photosynthesis; brittle leaves.
Black spots appear – these are the excrement of the thrips.
Also damage to fruit (tomatoes, cucumbers, peppers) and flowers.
Tomato Spotted Wilt Virus: is acquired by the larvae during feeding on infected plants but TSWV is transmitted exclusively by the adults.

*Control/Natural enemies:
Predatory mites (*Amblyseius barkeri* and *A.cucumeris*) eat thrips. They are shipped in "sachets" with "grain mites" (plant/fungus feeders and food for the beneficials to eat during shipping). Hang sachets in the crop for a max. of 2 weeks and then removed to avoid grain mite infestation on the plants. (Grain mites: see *Eriophyid* mites below)
Predatory bugs of the genus *Orius* with flattened bodies and protruding mouth parts for sucking the juices from the thrips body.
Verticillium lecanii: a fungus that parasitizes and ultimately kills thrips. This fungus does not harm other natural enemies of the thrips.

4. Whitefly

Trialeurodes vaporariorum (Greenhouse whitefly)
Bemisia tabaci (Genn.) (Sweet Potato whitefly)

*Appearance: (Insect) Both are white in color. *Trialeurodes* holds its wings out giving it more of a triangular shape, whereas *Bemisia* appears more linear.

*Life cycle: Essentially 7 stages:

Egg: on a stalk on the leaf underside, sometimes with several in a circle.

4 larval stages: initially with legs, but lose their legs after they pierce the leaf tissue and begin to feed.

Pupal (or false pupa) stage: sedentary stage; adult red eye color appears.

Adult: emerges from the pupa. This stage also feeds.

*Damage:

Larvae and adults pierce and suck juices from plant cells causing reduced photosynthesis and growth, leaf drop and reduced harvest.

Larvae and adults excrete honeydew onto leaves and fruit. Molds colonize the honeydew reducing photosynthesis and transpiration on leaves and leaving sticky, "dirty" deposits on fruit (unmarketable).

Both whiteflies have been shown to transmit viruses (see Viruses below).

*Control/Natural enemies:

Parasitic wasps: An egg is laid in the whitefly larvae (3^{rd} or young 4^{th} stages preferred). The egg hatches and the wasp larvae devours the whitefly larvae, then uses the host's shell to develop to adult which emerges through a small round hole in the host's shell.

The wasp *Encarsia formosa* prefers the whitefly *Trialeurodes*. Upon entry the wasp larvae turns the w.f. pupa black.

The wasp *Eretmocerus eremicus* prefers the whitefly *Bemisia*. Upon entry the wasp larvae turns the w.f. pupa golden.

Verticillium lecanii: A fungus that parasitizes and ultimately kills whitefly.

5. Butterflies and Moths (Order *Lepidoptera* , 5 species in the family *Noctuidae* and one in the family *Tortricidae* are important in greenhouse culture.)

*Appearance: 6 legs (winged insects); varying sizes with 2 pairs of wings.

*Life cycle: 4 stages:

Egg – laid on leaves or even glass or greenhouse structures.

Larva – a caterpillar: well developed head with strong jaws; 3 pairs of real legs on the front, 5 pairs of false legs on the rear. Molt 3-9 times.

Pupa – a resting stage during which the larva is transformed.

Adult – winged butterfly or moth.

*Damage:

The larval stage or caterpillar causes immense damage. They feed on the undersides of leaves though larger ones will eat holes through the leaves. Certain types will bore into the stems, flowers, fruits and growing points. Their excrement can contaminate the crop.

*Control/Natural enemies:

Bacillus thuringiensis var. *kurstaki*: this bacterium kills larvae when eaten.

6. **Eriophyid mites (*Eriophyes sp.)* Also gall, rust, russet, bud and blister mites.**
   Appearance: (Spider family) Invisible to the unaided eye; 4 legs; worm, spindle or tear drop shaped; usually clear bodies with 2 parts – a mouth and a body.
   Life cycle: Egg; larva; nymph; adult. Unlike other mites, they have only 4 legs.
   Damage: Each species has a narrow range of host plants.
   Tomato stems and leaf petioles take on a reddish (russet) appearance.
   Leaflets will show chlorosis then necrosis from the petiole base outward.
   May be capable of transmitting viruses during feeding and moving fungi or other plant diseases during their movement from plant to plant.
   Control/Natural enemies:
   There are no known beneficial enemies of this group of mites.
   Dusting sulfur is effective but it must be applied evenly not only on the reddish areas (where mites have been), but above/below where mites are now feeding but are invisible to the unaided eye.

***Some insects may not cause significant direct harm to plants but may, as those listed above, act as vectors for devastating diseases.**

1. **Shore flies:**
   *Appearance: Look like miniature houseflies.
   *Life cycle:
   Eggs are laid in moist, algae infested areas.
   Larvae burrow down and feed on organic matter including plant roots.
   Pupal stage is in the root zone.
   Adults are black, usually only fly when disturbed and can be found on tops of Rockwool blocks or other moist places where algae grows.
   *Damage: Shore flies have been shown to transmit pathogenic fungi including *Pythium* and *Phytophthora*. They eat the fungal spores, that remain intact in the gut, fly to an uninfected plant and deposit the spores. The new plant can then become infected. Shore flies can also carry viruses.
   *Control:
   The bacteria *Bacillus thuringiensis* (Gnatrol) attacks the larval stage.
   A soap solution (Safer Soap) can be sprayed onto the adults, plugging their breathing tubes along their sides and suffocating them.
   Preventative: Silica sand can be put on the surface of the Rockwool blocks which will inhibit algae growth and subsequent fly habitat.

2. **Fungus gnats (or Sciarid flies):**
   *Appearance: Look like miniature mosquitoes.
   *Life cycle:
   Eggs are laid in moist, algae infested areas.
   Larvae are legless maggots with black heads that feed on organic matter.
   Pupal stage is in the root zone.
   Adults are grayish black with long antennae. They are very "nervous" fliers and are found near moist areas where algae grows (as above).

*Damage:

Fungus gnats, like Shore flies, can transmit fungal and viral pathogens.

*Control:

The bacteria *Bacillus thuringiensis* (Gnatrol) attacks the larval stage.

A soap solution (Safer Soap) can be sprayed onto the adults, plugging their breathing tubes along their sides and suffocating them.

Preventative: Silica sand can be put on the surface of the Rockwool blocks which will inhibit algae growth and subsequent fly habitat.

Parasitic nematodes (*Steinernema feltiae, S. carpocapsae*): The 3rd larval stage is infectious. Optimum conditions for the nematodes include a temperature of 15C/59F (a little cool for tomatoes, peppers and cucumbers) as well as high humidity.

DISEASES

*Many organisms (bacteria, fungi and viruses) cause disease in plants.

*Because of the closed nature of the greenhouse and the fact that soil (source of many diseases) is not used, many diseases are not seen in greenhouse hydroponics.

*The diseases that are seen can become catastrophic if not recognized and dealt with. Knowledge of plant diseases typical to greenhouses and hydroponics is essential.

***Selected diseases of tomato** also found in greenhouse hydroponics:

1. **Fungi:**

*The fungi listed here consist of a plant-like vegetative body (**mycelium**) made up of individual filaments (**hyphae**), each surrounded by a cell wall.

*They can be divided into two groups depending on whether or not they produce a zoospore (a motile, flagellate spore that lacks a cell wall):

Non-zoosporic fungi:

a) ***Botrytis cinerea*** **(botrytis or gray mold):**

*Has a wide host range and is a good saprophyte (lives on dead matter).

*Spores can be disseminated by air, water or by infested plant or greenhouse materials (clippers, gloves, etc.).

*Can infect all above-ground parts of the plant, usually through wounds.

*Gray fungal masses will form on the stem (girdling it), the leaves (forming a "V" shape), the calyx end of the fruit, or, if it spreads to the fruit but is then exposed to sun/high temperatures, "ghost spots" (white to pale yellow or green) will remain.

*Optimum conditions: cool, humid and overcast. Also, too close of plant spacing and poor ventilation can promote infection.

*CONTROL:

Adequate ventilation of the greenhouse to reduce humidity.

Increased ventilation around stems by pruning lower leaves.

Fungicides may be applied to pruning wounds or used in severe cases. (Ex: Mancozeb: bis-di-thio-carbamate + Mn & Zn)

b) *Fusarium* species (Fusarium Wilt, Fusarium Crown and Root Rot):

*Caused by several species and "pathovars" of the fungus.

*Spread by spores in the air, water, infected transplants, workers or infested greenhouse materials or equipment.

*Infection takes place through feeder roots and wounds caused by secondary root formation.

*Optimum conditions: moist, moderate temp. (20C/68F) in the root zone.

*General symptoms: leaf yellowing, vascular discoloration, wilting and plant death. In high humidity, the white mycelium may be visible.

*CONTROL:

Use resistant varieties.

c) *Verticillium dahliae* (Verticillium Wilt):

*Has a wide host range and can survive in soil for several years.

*Infection takes place through root wounds caused by secondary root formation (or cultivation or nematode feeding in soil culture).

*Optimum conditions: cooler temperatures (21-25C or 70-77F).

*General symptoms include plant stunting, a light tan discoloration in the vascular tissue, yellowing then browning in a "V" pattern on the leaflets with wilting, yellowing and finally dying of older leaves.

*CONTROL:

Use resistant varieties.

Zoosporic Fungi:

a) *Phytophthora* species:

*Different species of the fungus attack different hosts.

*Infection can be at the roots or on the leaves/stems/fruit depending on species. Note that the leaf/stem/fruit infections (Ex., Late Blight) is not usually seen in CEA/hydroponics.

*Optimum conditions: Most species prefer cooler (15-30C or 59-86F), humid conditions.

*General symptoms of root rots include stunting of the plants and/or a collapse of the entire plant. Plants can also become weakened and susceptible to attack by other pathogens. Attack on seedlings is known as "damping off" and causes death.

*The disease is spread by motile zoospores that swim through the nutrient solution. This is especially dangerous in recirculating systems.

*CONTROL: Sanitation is very important. Mats with disinfectant can be positioned at entry ways to remove soil from shoes. Tools, hands, gloves, etc. must also be cleaned between uses. Leaf, sucker and other prunings should be removed from the greenhouse. Since the motile zoospores do not have a cell wall, their naked membranes are easily dissolved by soaps or surfactants. These can be placed in the nutrient solution (use low concentrations only, 5-20 ppm, as higher concentrations will cause phytotoxicity).

b) *Pythium* species:

*Usually non-host-specific, though some have host specificity.

*Infection is most often at the roots or crowns but can also be on the fruit.

*Optimum conditions: Most species prefer warmth (20-40C or 68-104F)

*General symptoms on roots include stunting or plant collapse; plants using the same water source will die simultaneously due to rapid spread by zoospores. "Damping off" = attack/death of seedlings.

*The disease is spread by motile zoospores that swim through the nutrient solution. This is especially dangerous in recirculating systems.

*CONTROL: Sanitation is very important, including disinfectant mats, tool/hand/glove cleaning, and pruning removal. Surfactants in the nutrient solution have given 100% control over spread of disease.

2. Prokaryotes/Bacteria:

*Bacteria are single-celled microorganisms with a cell membrane and cell wall surrounding the cytoplasm that contains "naked DNA" (no nucleus). They often have one or more flagella (whip-like appendages that propel them through the water).

a) Bacterial Canker (*Clavibacter michiganensis subs. Michiganensis*)

*Has been shown to infect tomato in greenhouse hydroponics.

*Gram positive, non-sporing, non-motile, obligate aerobic rod. Survives up to 5 years in soil, on infected plant material, on weeds, volunteer tomato plants and seeds. Infection occurs via wounds but also through the roots or leaf stomata.

*Optimum conditions: moderate temperatures (18-24C or 65-75F) and greater than 80% relative humidity. Other conditions that promote the disease include optimum root zone moisture for plant growth, low light and high nutrient concentrations (especially nitrogen).

*General symptoms: Downward turning and wilting of lower leaves which remain attached to the stem. Streaking along leaf midribs, petioles and/or stems can break open forming cankers. Can show vascular discoloration with the pith becoming mealy or hollow. Diagnosis: place fresh cut stem in water – yellow stream of bacteria will exude from the end (bacterial streaming). Fruit will show small white lesions that develop into brown, scabby lesions surrounded by a "halo" (bird's eye).

*Spread by splashing water and contaminated equipment and/or tools.

*CONTROL: Use disease-free seed and/or transplants. Sterilize tools and equipment. In soil systems: rotate to a non-host crop for at least 3 years (not practical in greenhouse hydroponics!).

b) Bacterial Wilt (*Burkholderia solanacearum* or *Pseudomonas solanacearum*)

*Can infect over 200 species of plants, including tomato.

*Gram negative, aerobic, motile rod.

Survives in the soil where it attacks the roots through natural wounds caused by secondary root formation, or wounds caused by transplanting, cultivation or nematode feeding.

It can also be transmitted via chewing insects.

*Optimum conditions: Warm temperatures (29-35C or 84-95F) and high root zone moisture favor development.

*General symptoms: Drooping of the lower leaves followed by wilting of the entire plant (no leaf yellowing). A longitudinal section of the stem shows yellow to light brown vascular discoloration (later turning dark and/or hollow).

Diagnosis: place fresh cut stem in water – milky stream of bacteria will exude from the cut end (bacterial streaming).

*The disease is spread in irrigation water, from soil on shoes, equipment, etc., and from diseased transplants.

*CONTROL: Use disease-free transplants and/or tolerant varieties.

In soil systems: soil fumigation, weed control, crop rotation and grafting to resistant root stocks can minimize losses.

3. Viruses:

*Definition:

"Nucleoprotein" (single or double stranded RNA or DNA surrounded by a protein coat).

Very small. Need an electron microscope.

Multiplies only in living cells.

Has the ability to cause disease.

*Many viruses infect tomatoes, however, only a few have been seen in greenhouse hydroponics.

a) Tomato Mosaic Virus (or Tobacco Mosaic Virus): ToMV or TMV

*These two viruses are nearly identical and can both infect tomato.

*Single-stranded RNA, rod shaped.

Can survive on plant debris, tools or worker's hands…

NOTE: If you smoke, wash hands before entering greenhouse!

Chewing insects can transmit the virus, but rarely.

*General symptoms: Leaves show light green to yellow or dark green mottling, necrosis and upward leaf rolling. Stems will show streaking depending on strain. The entire plant can be stunted. With cool temperatures leaves may appear "fernlike". Fruit can show uneven ripening or a browning of the fruit wall. If resistant varieties are used necrotic streaks or spots on the stem, petioles, leaves and fruit may develop.

*CONTROL: Use TMV resistant varieties. Steam sterilize all equipment and tools before use.
NOTE…NOTE: All workers should wash their hands with soap and water… ESPECIALLY SMOKERS… before entering the greenhouse or handling plants, tools, equipment, etc.

b) Family = Geminiviruses, Genus = Begomovirus

*At least 15 different viruses infect many plant species, including tomato.
*Small, paired, isometric virus, each virus pair containing one circular single-stranded DNA.
*These viruses are specifically transmitted by whiteflies. Examples:
Tomato Mottle Virus transmitted by *Bemisia tabaci*
Tomato Yellow Leaf Curl Virus transmitted by *Bemisia tabaci*
Tomato Infectious Chlorosis Virus by *Trialeurodes vaporariorum*
*General symptoms: Most geminiviruses cause leaf mottling and/or chlorosis (yellowing) in various patterns as well as leaf curl. With chlorosis comes reduced photosynthesis and growth resulting in stunting of plants and reduced yields.
*CONTROL: Since these viruses are specifically transmitted by whiteflies, control of the whitefly population in the greenhouse is the best control measure.
Use insect screening specific for whitefly.
Use biological control (parasitic wasps – see insects above).
Use whitefly free transplants.
Remove old crop and allow greenhouse to heat up (sterilize).

c) Tomato Spotted Wilt Virus (Tospovirus or TSWV)

*Has a large host range including tomato, tobacco, dahlia and pineapple.
*Fairly large uniquely spherical particles surrounded by a membrane, containing a single strand of RNA.
*Spread by thrips (onion and western flower). Initially acquired by the larval stage, but only transmitted by the adult thrips
*General symptoms: In tomatoes older leaves show orange-yellow flecks which develop into dark circular spots giving a bronzing appearance. Leaves may show irregular or one-sided growth. Stem and petioles may show dark, shiny streaks. Plants become stunted with yellowing, drooping foliage (appears wilted). Fruit can have green, yellow and red bumpy concentric rings.
*CONTROL: Use resistant varieties, and virus-free transplants.
Control thrips using insect screening and, when necessary, predatory insects or parasitic fungi as noted above).
Also, remove nearby virus host weeds.

***Selected diseases of other crops** grown in greenhouse hydroponics:

1. Fungus: *Didymella* or *Mycosphaerella* (Gummy Stem Blight):

*A non-zoosporic fungus that can be host-specific or attack different hosts depending on the fungal species. The greenhouse cucumber is particularly susceptible (another species of the fungus attacks tomatoes but is more common in Europe, the Middle East and North Africa).

*Infection usually occurs on the stem at or above the soil line.

*Optimum conditions: Prefers high moisture and humidity. Optimum temperatures range from 20-25C/68-77F

*General symptoms include initial tan spots then necrotic (dead) spots on the leaves, stem lesions and fruit rot, usually at the flower end. Black "dots" that appear from these spots, lesions and rots are spores oozing out.

*The fungus is spread by aerial spores, by workers who handle infected plants or plant material, by splashing or dripping water, through infected transplants or via infested greenhouse materials or tools.

*CONTROL:

Use clean transplants.

Reduce greenhouse humidity by not using mist cooling.

Remove infected plants and plant material. Workers should wash hands with soap and water after handling infected material.

Can use fungicides (but not usually used in greenhouse hydroponics).

2. Fungus: *Olpidium brassicae*:

*A zoosporic fungus that has been shown to infect roots of hydroponic lettuce. Main problem: this fungus is a carrier for **Lettuce Big Vein Virus** and several other viruses, as well.

*Optimum conditions for the fungus: Moisture; temperatures less than 16C/61F.

*General symptoms: The fungus does not produce any real symptoms, whereas Lettuce Big Vein Virus causes swollen leaf veins and bitter tasting leaves.

*The fungus is spread by motile zoospores as well as on infected plant parts or on contaminated plants and soil.

* CONTROL: Remove all contaminated plant material.

Surfactants can be used to halt the spread of fungal zoospores.

Some fungicides are effective but are prohibitively expensive and are not usually used in hydroponics.

3. Fungus: Powdery Mildews:

*Non-zoosporic fungi where species in 3 different genera cause infections on specific hosts including peppers, cucumbers, lettuce and tomatoes.

NOTE: The fungus on tomatoes moves fairly slowly and can be effectively controlled by removal of the contaminated leaves.

*Optimum conditions: Prefers warm and dry conditions, which makes it a significant problem in the desert southwest USA. Needs some moisture for spore germination, so it does well in humid greenhouse conditions.

*General symptoms: The fungus usually attacks the leaves forming yellow lesions or white powdery areas. Severe infections cause reduced photosynthesis and growth and sometimes leaf drop.
*These fungi are obligate parasites (can not be cultured) that are spread by aerial spores and by workers.
*CONTROL: Use resistant varieties (particularly peppers and cucumbers). Fungicides can be used but resistance tends to develop easily. Dusting with sulfur has provided excellent control of powdery mildews. At present various biofungicides are being tested for efficacy.

BIOLOGICAL CONTROL AND INTEGRATED PEST MANAGEMENT

Biological Control: The use of one organism (beneficial) to control another (pest).
*Often used to refer to beneficial insects such as wasps, bugs or mites that are used to control such pests as white flies, thrips or aphids (see above).
*This term can also apply to parasitic bacteria, fungi and nematodes (see above).
*Note that there are at least 72 species of predators/parasites for 60 pest species.

***History**: By the late 1930's biological control (i.e., use of the parasitic wasp *Encarsia Formosa*, originally discovered in a greenhouse in England in 1926, to control the white fly) was common in commercial greenhouses in England and Australia.
In the 1940's, with the introduction of the insecticide DDT, the use of biological control ceased. Other chemical pesticides were also developed.
In the later part of the 20th Century many growers, especially greenhouse hydroponic growers, began returning to biological control due to
- the development of pesticide resistant pest populations
- the high cost of pesticides
- the difficulty in observing "harvest restrictions", the delay time between application of pesticide and harvest
- the reduction in yields due to phytotoxicity of the pesticides
- the fact that DDT and other chemical pesticides were persistent in the environment and affected other species than those intended (i.e., DDT which caused thinning and brittleness of the eggs of the California Condor, death of the chicks, and decreased populations almost to the point of extinction)
- the increased concern with exposure of greenhouse workers to pesticides and, for the consumer, of exposure to pesticide residues on the produce
- the use of bumble bees in the greenhouse to pollinate the crop, especially tomatoes and peppers (see Chapter 6). Pesticides would not only kill the pest but the bees as well!
- the fact that vegetables produced "pesticide free" command a higher price at the market!

***Biological control is an extremely "knowledge intensive" technique**.

Example: If white flies are discovered on tomatoes, the grower could spray… and that would be that.

However, if biological control is used, the grower must first identify the type of white fly (*Trialeurodes* verses *Bemisia*) then order the appropriate beneficial wasp, then place the wasps in the proper locations in the crop…

***Introduce the beneficial(s) BEFORE the pest organism is present.**

If the grower waits until the pest is noticed, populations are already rising and the lag time between noticing-ordering-introduction may be up to 2 weeks – plenty of time for a pest to get out of control! This is commonly done with white fly parasitic wasps.

***There are natural "swings" in both the beneficial and pest populations.**

As the pest population rises there will be more food/hosts for the beneficial (predator/parasite) population which will begin rising.

As the beneficial population rises and eats/parasitizes the pests, the pest population will decrease resulting in less food/hosts for the beneficials.

As the beneficial population decreases the pest population rises again, etc.

***There are 3 ways to introduce "beneficials" to a crop:**

1. **Conservation:** Attraction and preservation of naturally occurring beneficial organisms in the crop (best for field crops).
2. **Inoculation:** Periodic releases of small numbers of "beneficials" starting early in the season. Used in greenhouse hydroponics.
3. **Inundation:** Mass introductions of "beneficials" aimed at eliminating pests immediately, especially when pest populations are high.

Integrated Pest Management (IPM): The prevention and control of pests and diseases using all existing crop protection techniques and strategies.

***Techniques and strategies that prevent pests and diseases:**

1. **Hygienic measures:**
   - *Start with clean seed and/or transplants.
   - *Remove old plant material (source of disease inoculum and refuge for insects) from greenhouse and dispose of.
   - *Solarization: increase the temperature set point in the greenhouse after the last crop is removed. This can kill harmful organisms on gravel, walls, tubing, etc.
   - *Remove weeds inside and outside the greenhouse (these can be hosts for insects and diseases for present and future crops).
   - *Prevent transmission of pests/disease by humans/machines/tools. ("Hygiene coats" for guests; disinfect shoes/hands/tools.) Note: Skimmed milk can encapsulate viruses on tools!
   - *Prevent transmission of pests/diseases in the irrigation water by filtering, UV radiation or ozone treatment.

2. **Mechanical measures:**
    *Use insect netting (several sizes specific to different insects) over air intakes or vents to prevent entry.
    *Use a plastic or woven floor covering to isolate the plants from insect pests and diseases in the soil below.

3. **Cultural practices:**
    *Optimize plant growth: a healthy plant is a more resistant plant.
    *Avoid plant damage (creates easy entry for disease).
    *Plant workers should move from clean to infested areas.
    *Although greenhouse hydroponic crops are planted at higher densities than field crops (see Chapter 3, General Cultural Practices), too high of planting densities can result in thin, weak plants that are more susceptible to pests/diseases.
    *Maintain a regular harvest schedule – plants allowed to get over or under-loaded with fruit may become weakened.
    *Can use "crop rotation" – alternating host and non-host crops. This is not usually done in greenhouse hydroponics.

4. **Genetic/transgenic/other control:**
    *Use "resistant" or "tolerant" varieties. If growing "susceptible" varieties, grow during times of low infestations.
    *Note: There may be a trade-off between growing resistant or tolerant species/varieties and maintaining maximum yields.
    *Can use plant material from tissue culture – disease free.

***Techniques and strategies that control, reduce or eliminate pests and diseases that have already become established:**

1. **Mechanical measures:**
    *Check the crop regularly for the presence of pests and diseases.
    *Capture insects (best for winged/flying insects)
        Sticky traps: plastic or other non-porous surface covered with a sticky substance and of a certain color (white flies prefer yellow, thrips prefer blue, etc.).
        Trap plants or pheromone traps (both attract insects and can then be removed from the greenhouse).
    *High temperature treatment
        Not appropriate for mature tomatoes, peppers, etc.
        Hot water or air on seeds/bulbs/tubers/cuttings can remove mites, nematodes, bacteria and some viruses.

2. **Biological control:** (See above for definition) Pay attention to:
   *The directions for use (application, time of day, location in crop).
   *The directions for storage (temperature and "use-by" date).
   *The quality of material (supplier guarantees quality and quantity).
   *The "biology of the beneficials".
   *The reduction of beneficial insects by the removal of lower leaves or other prunings where they might be developing.
      Useful practice: pile prunings at one end of the house for a day or two to let beneficials migrate back into crop.
      Opposite practice: if pest population has soared, prunings can be removed immediately to cut pest numbers.
   *The possible use of "banker plants" – plants that attract pests and can also be hosts for beneficials.

3. **Natural control:** The control of pests and diseases by spontaneously occurring natural enemies. Ex: Stimulate colonization of beneficials by creating optimal conditions for them.
   Not usually done in greenhouse hydroponics. (Too "iffy"!)

4. **Chemical control:** Only used as a "last ditch" corrective measure.
   *Start with "natural pesticides":
      Soaps/surfactants: they plug insect breathing tubes
      Neem oil: Neem tree/India: interrupts insect metamorphosis
      Sulfur: effective mitacide but also kills insects and bees
   *Use selective pesticides (do not kill or harm beneficials or plants).
   *Use selective application techniques.
   *Use pesticides with short persistence times.
   *Check the compatibility of all pesticides with beneficials (i.e., Koppert Side Effect List – see Ref. 3 below).

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11. **Tomato Diseases.** 1997. Ed. By B.Gabor, W. Wiebe. Seminis Vegetable Seeds, Inc. 1905 Lirio Avenue, Saticoy, CA 93004
12. **Web Pages:**

Canadian Greenhouse Vegetable Research Network:
http://res.agr.ca/harrow/cgvrn/

DIR, "Database of IPM Resources":
http://ipmwww.ncsu.edu/cicp/knowledge.html

National IPM Network
http://www.reeusda.gov/agsys/nipmn/index/htm

Greenhouse Pest Management
http://www.wvu.edu/~agexten/ipm/common/insect/greenhs/index.html

Solutions To Pest Problems
http://www.edu/~agexten/ipm/index.htm
http://www.edu/~agexten/ipm/common/insect.htm
http://whiteflies.ifas.ufl.edu/
http://www.ifas.ufl.edu/~pest/
http://www.hygienicus.org