CHAPTER 4

PLANT PROTECTION

INTRODUCTION

*****Plants need to be protected against:

<u>Animals</u>… 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 a locked greenhouse.

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

<u>Other organisms</u> that are not usually a significant problem 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 usually excludes parasitic plants.

Nematodes: These are 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, nematode infection could come from a contaminated water supply or from soil brought in on shoes, equipment, etc.

<u>Insect and mite pests:</u> 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.

<u>Disease causing organisms:</u> Fungi, chromista, bacteria and viruses/viroids can all pose a significant threat to crops growing in greenhouses and hydroponics. They can affect every part of the plant (roots, stems, leaves and fruit) and can cause problems including rots, spots, wilts, chlorosis, necrosis and plant death.

*Control of pests – Using chemical or other pesticides:

For field agriculture, pest populations and damage are monitored and when they reach an "economic threshold", pesticides are applied to control/eliminate the problem.

For greenhouse hydroponics, **traditional pesticides are not normally used…** WHY?

- Bees are used for pollination and insecticides would also kill the bees.
- Pesticide application could pose health problems for workers due to exposure as well as interrupt working schedules (due to long re-entry periods).
- The closed nature of the greenhouse promotes pesticide-resistant populations.
- "Pesticide Free" commands a higher price in the market and is preferred.

Therefore, control measures for CEA include exclusion, trapping, predator/parasitic insects/mites, infectious fungi and bacteria, soap solutions, sulfur, neem or other oils, potassium salts, etc., that can be spot sprayed. Some, like the soaps and oils, work by clogging the breathing holes (spiracles) on the sides of the pest's bodies.

INSECT AND MITE PESTS

*Insects and mites can cause physical damage, or transmit toxins or diseases.

*CEA can help exclude many insects and mites from the greenhouse environment.

The closed nature of the greenhouse in conjunction with **insect screening** or **sticky traps** at vents and air intakes can create effective barriers.

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.

If not identified and controlled quickly, they can devastate your crop.

*Early detection of insect and mite pests is critical. Often you will see "signs" of an infestation before you see the insect or mite. Signs include, but are not limited to, cast skins, frass (insect droppings), webbing, holes in leaves stems or fruit, and silvery or yellow spots. NOTE: A hand-lens is recommended.

INSECTS:

Whitefly ***Trialeurodes vaporariorum*** (greenhouse whitefly)
Bemisia tabaci (also sweet potato, tobacco, cotton & silverleaf wf)

***Appearance:** Both are white in color. *Trialeurodes* holds its wings flat giving it a triangular shape. *Bemisia* wings are held like a tent over the back.

***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 the legs after they pierce the leaf tissue and begin to feed.

Pupal (false pupa) stage: sedentary, flat to leaf; adult red eyes appear.

Adult: emerges from the pupa through a jagged tear. This stage 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. Sooty molds colonize the honeydew reducing photosynthesis & transpiration and marketability of fruit.
Adults can inject a toxin that interferes with ethylene & fruit ripening.
Both whiteflies have been shown to transmit viruses (see Viruses below).

*Control/Natural enemies:

Parasitic wasps: An egg is laid on the whitefly 3rd or 4th stage larvae. The egg hatches and the wasp larvae devours the whitefly larvae, then uses the host's shell to develop to adult, emerging through a round hole.

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.

Lecanicillium lecanii: Fungus that parasitizes & ultimately kills whitefly.

Aphid (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 alive (no egg stage); molt 4 times. "Cornicles" are diagnostic.
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 with 3-10/day over a few weeks.

*Damage:
Young & adults suck plant sap; reduced plant growth; leaves curl up.
Excess sugar (from sap) is excreted as honeydew that drops onto lower leaves; sooty molds colonize the honeydew & cut photosynthesis.
Toxic substances can be injected.
Pathogens (esp. viruses) can be transmitted (mainly by winged adults).

*Control/Natural enemies:
Gall-midge (*Aphidoletes aphidimyza*): It injects a poison which paralyzes and liquefies the aphid's insides which are then drained.
Parasitic wasps (Ex. *Aphidius matricariae*): Lays an egg on the aphid which then swells and hardens ("mummy"). After growth, the adult wasp leaves the mummy through a circular hole.
Lecanicillium lecanii: A fungus that parasitizes & ultimately kills aphids.
Ladybird Beetles or lady bugs (*Hippodamia convergens*) and Lacewings (*Chrysoperla carnea*) also provide control of aphids by eating.

Leafminer (*Liriomyza bryoniae* and 2 other *Liriomyza* species):

*Appearance: adult has 6 legs, is winged and is yellow with black markings.

*Life cycle: 6 stages:
Egg – oviposited into the leaf where the larva hatches.
3 larval stages – feed within the leaf and create the diagnostic "mines".
Pupal stage – exits the leaf and drops to the ground; pupates in soil or rarely between layers of plastic in the greenhouse.
Adult – emerges and mates immediately; can live 3-4 weeks.

*Damage:

Larval stages feed within the leave tissue causing "mines" (diagnostic).

Adult females pierce leaf cells with their barbed ovipositors and create holes called feeding spots. Females and males drink the cell sap.

*Control/Natural enemies:

Parasitic wasps (*Dacnusa sibirica, Diglyphus isaea, Opius pallipes)* are shipped as adults in shaker bottles; use individual species or mixes.

Oftentimes, infestations are low or parasitic wasps come into the greenhouse along with the leafminers and no action is necessary.

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

*Appearance: 6 legs (smallest of the winged insects); long, narrow; orange to 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 – very active and feed on all aerial parts of the plant. After these stages they drop to the ground and pupate.

Note: greenhouse floor cover keeps larva from entering the ground.

2 pupal stages – requires soil; these stages do not feed; wing stumps form.

Adult – has two pairs of wings and are active feeders.

*Damage:

Larval & adult rasping mouth parts cut into cells and suck out contents; cells die and area turns silvery gray. Plant experiences a loss of chlorophyll, decreased photosynthesis and brittle leaves.

Black spots (thrips excrement or frass) appear in the silvery dead areas.

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. Shipped in sachets with grain mites (food for beneficials during shipping). Hang sachets in crop for a maximum of 2 weeks, then removed to avoid grain mite infestation.

Predatory bugs of the genus *Orius*; suck juices from the thrips' body.

Lecanicillium lecanii: a fungus that parasitizes & ultimately kills thrips. This fungus does not harm other natural enemies of the thrips.

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. Molts 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 leaves. Certain types will bore into the stems, flowers, fruits and growing points. Their excrement (frass) can contaminate the crop.

Tomato fruit worm: lays individual eggs near terminal; burrows into fruit; prior to fruit formation, will burrow into stems.

Army worm: lays egg masses; causes "window paning"; eats the outside of fruit only (does not burrow in).

"Looper": ("inch worm") feeds on leaves; rarely on fruit.

Tomato pin worm: creates webbing to hold leaves together; scrapes leaves and mines into fruit (damage undetectable from the outside).

*Control/Natural enemies:

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

Tomato Bug also Tomato Suck Bug (*Cyrtopeltis modesta*):

*Appearance: 6 legs; large, 7-8 mm (1/4") long; winged; light green body.

*Life cycle:

Egg - laid inside the stem near the top of the plant or in the leaf stem.

4-5 Nymph stages – like adult but smaller; lacks wings; active feeder.

Adult – slender; relatively large; moves rapidly; active feeder.

*Damage:

Nymph & adult have piercing/sucking mouth parts which they insert into the stem to feed. They typically feed in rings around the stems (girdling) producing thickened corky areas that are weak and brittle and can fall off easily. Can lose flowers, fruit or the head if feeding is in these areas.

*Control/Natural enemies:

No known beneficials. However, you can squash them with your fingers!

Sprays that control lygus or stink bugs might be affective.

Tomato Psyllids (*Bactericera cockerelli*)

*Appearance: 6 legs; ~3mm; resembles a cicada; white or yellowish markings on thorax; clear wings; lines on abdomen.

*Life cycle: 7 stages:

Egg – laid on stalks on underside of margins of leaf

5 Instars

Adult – emerge 3-5 weeks after egg is laid.

*Damage:

Wide host range but prefers Solenaceous plants with a preference for yellow pear tomatoes. Injects a toxin while feeding that kills transplants. Causes stunting, chlorosis & curling of leaves and reduction in marketable fruit. Concentrates plant sap into sugar crystals = psyllid sugar.

*Control/Natural enemies:

No beneficials are promising for control.

The drench/systemic Imidicloprid (Admire) works well.

***Insects that may not cause direct harm to plants but may act as disease vectors.**

<u>Shore flies (*Scatella spp.)*:</u>

*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, which remain intact in the gut, fly to an uninfected plant and deposit the spores in their frass causing infection. 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: Anything that will reduce or prevent algae growth will reduce the habitat for the shore flies. This includes covering the tops of grow blocks with sterile silica sand or other sterile cover that does not react with or add toxins to the nutrient solution or the growing material.

<u>Fungus gnats or Sciarid flies (*Bradysia spp.)*:</u>

*Appearance: Look like miniature mosquitoes – very “nervous” fliers.

*Life cycle:

Eggs - laid in moist, algae infested areas.

Larvae - legless maggot with black head that feeds on organic matter.

Pupal stage - in the root zone.

Adults - grayish black with long antennae; found near moist areas/algae.

*Damage:

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

*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 or other material can be put on the surface of the grow blocks to inhibit algae growth and subsequent fly habitat, as for the shore fly above.

Parasitic nematodes (*Steinernema feltiae, S. carpocapsae*): The 3rd larval stage is infectious. Optimum conditions for the nematodes include a temp of 15C/59F (a little cool for tomatoes) and high humidity (also not good for tomatoes – reduces transpiration and promotes various fungal infections such as *Botrytis*).

MITES:

Red spider mite (*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 or "stippling" and Photosynthesis is subsequently reduced. These yellow patches are a major problem on ornamentals.

Nymphs and adults produce webbing on the leaf surface and between the leaf blade and petiole. The webbing is the mite's home and will be swarming with mites and covered with frass and other particulates sometimes giving the leaf a reddish hue.

*Control/Natural enemies:

Dusting or liquid sulfur is an effective mitacide… However, beware: Sulfur also kills beneficial mites, insects or bees.

Predatory mites: There are several species that eat spider mites and their eggs but can also survive on flower pollen when mites are not present. One predator that only eats mites, *Phytoseiulus persimillis*, belongs to the same order as the red spider mite – Acarina. Nymphs and adults eat spider mites and their eggs. Feeding depends on populations, temperature and humidity.

Tomato russet mite (*Aculops lycopersici*) Also gall, rust, bud & 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.

Mites may transmit viruses or diseases during feeding or movement.

Feeding can cause scarring or "alligatoring" damage to tomato fruit skin.

To ID the mites, gently wrap then unwrap a 2-3" piece of black electrical tape around the stem just above the reddish area & check the tape using 20X or higher loupe or a dissecting microscope.

*Control/Natural enemies:

There are no known beneficial enemies of this mite – they are too small. Dusting or liquid sulfur or, better yet, oil & water (ex. 87ml vegetable or neem oil + 3 gal water) are effective but must be applied evenly not only on the reddish areas (where mites have been), but below and especially above the reddish area where most of the mite colony are now feeding (but are invisible to the unaided eye).

DISEASES
*****Many organisms (bacteria, fungi, chromista (many use to be considered fungi), viruses / viroids) can cause disease in plants.

*Because of the closed nature of the greenhouse and the fact that soil (source of many disease causing organisms) 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 early and immediately.

NOTE: In some areas of the world, greenhouses are used without hydroponics and plants are still grown in soil. In these situations, diseases can become significant problems. The soil will have to be treated between crops with either steam or various sterilizing agents (many detrimental to the environment).

***What is a "disease-causing organism": "Koch's Rules"** (from Plant Pathology by Agrios, 1988): For a pathogen to be considered "disease causing" it must meet 4 criteria:

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 (if a non-obligate parasites), and its characteristics described, or on a susceptible host plant (if a obligate parasites), and its appearance and effects recorded.

3. The pathogen from pure culture (or susceptible host) must then 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 (as in step 1).

4. The pathogen must be isolated in pure culture (or susceptible host) again, and its characteristics must be exactly like those observed in step 2.

*****The incidence or severity of a disease will depend on the presence of
- A susceptible host (choose tolerant or <u>resistant</u> varieties when available)
- A conducive environment (if the environment is even slightly altered, you might be able to exclude the pathogen)
- The virulent pathogen (try to exclude these from the greenhouse and/or systems)
- A "vector" (required in some diseases but not all; try to exclude vectors)

**If you interrupt or modify any one of these factors, you can control or eliminate the disease!

*****Host plants can be categorized as:
- Susceptible = plant will most likely contract the disease if exposed to it.
- Tolerant = plant can sustain the effects of disease without dying or sustaining serious injury or crop loss.
- Resistant = plant can exclude or overcome the effects of the disease.
- Immune = the plant can not be effected by the disease.

DISEASE-CAUSING ORGANISMS that are major problems in CEA/hydroponics:

FUNGI: Kingdom Mycota (or Eumycota)

The fungi are spore-bearing Eukaryotes (have a membrane-bound nucleus), without chlorophyll and the ability to absorb their food. They consist of a vegetative body (**thallus**) made up of individual filaments (**hyphae**), each surrounded by a cell wall which is composed of **chitin**. Several hyphae together are a **mycelium.** The cells are "**haploid**", contain 1 genetic copy. The spores usually have no flagella (whip-like appendages) or rarely 1.

The hyphae are produced on or within the plant and can infect every part of the plant (stems, leaves, fruit and roots).

Fungi can cause rots, spots, wilts, blights, molds, mildews and plant death.

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, clothing, hands, 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 on the fruit with sun/high temps, "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 higher humidity and infection.

*****CONTROL:

Adequate ventilation of the greenhouse to reduce humidity.
Increased air movement around stems by pruning lower leaves.
Fungicides: can apply to pruning wounds or use in severe cases.

Powdery Mildews:

***S**pecies in 3 genera (Oidium, Erysiphe & Leveillula or Oidiopsis) can cause infections on peppers, cucumbers, lettuce and tomatoes.

*These fungi are host-specific and obligate parasites (cannot be cultured) that are spread by aerial spores and by workers.

*****Optimum conditions: Many p.m. prefer warm dry conditions, which makes them a significant problem in the desert southwest USA. Needs moisture for spore germination, so p.m. does well in humid greenhouse conditions.

*General symptoms: Usually attacks the leaves forming yellow lesions or white powdery areas. Severe infections cause leaf drop and reduced photosynthesis, growth and yield.

*CONTROL: Use resistant varieties (particularly for peppers & cucumbers).
Fungicides can be used but resistance tends to develop easily.
Dust/liquid/vapor sulfur controls pm but also kills bees/beneficials.
Vegetable and/or neem oil + baking soda in water provide control; apply often. Do not use oil if temps above 32C (90F) or within 2 weeks of sulfur spray. Free water kills most spores. Milk sprays are effective.
Remove contaminated leaves to help reduce spore populations.

***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.

***Didymella* or *Mycosphaerella* (Gummy Stem Blight):**

*****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 temperature range is from 20 - 25C or 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 venting or by not using mist/fog cooling.

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

Certain fungicides (not usually used in greenhouse hydroponics).

***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, in soil culture, via cultivation or nematode feeding).

*Optimum conditions: Prefers moderate temperatures from 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.

CHROMISTA ("colored"; fungi-like): Kingdom Chromista

The Chromista are a very diverse group, the members of which were previously in the Plant, Animal or Fungi Kingdoms. They include aquatic members such as diatoms, golden algae and kelp, as well as terrestrial agronomic pathogens such as Phytophthora, Pythium & Downy Mildew.

Chromista are spore-bearing Eukaryotes, some are colorless but most have pigments as well as chlorophyll C though many can absorb nutrition from live or decaying matter.

Their bodies are made of **filaments** surrounded by a cell wall made up of **cellulosic compounds and glycan** (not chitin as in Fungi). Their cells are "**diploid**", contain 2 genetic copies.

They have **1-2 flagella** (whip-like appendages) that allow them to move through water (dangerous in recirculating hydroponic systems).

Pathogens of this group usually infect roots causing stunting, wilts and death.

***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: the leaf/stem/fruit infections (Ex., Late Blight, causing the 1840's potato famine in Ireland) are not usually seen in CEA/hydroponics.

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

*General symptoms include brown roots, stunting of plants and/or wilt/collapse of the entire plant. Plants can become weakened and susceptible to attack by other pathogens. Attack on seedlings ("damping off") causes death.

*This disease is spread by motile zoospores that swim through the nutrient solution. This is especially dangerous in recirculating systems. The spores can also be spread by shore fly & fungus gnat feeding.

*CONTROL: Sanitation: Mats with disinfectant can be positioned at entry ways to remove soil/spores 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 which can be placed in the nutrient solution; use only low concentrations, 5-20 ppm, as higher conc. can cause phytotoxicity. If the disease is present, eliminate fungus gnats & shore flies and fungicides are also available.

***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 include brown roots, stunting or plant wilt/collapse; plants using the same water source will die simultaneously due to rapid spread by zoospores. Attack on seedlings ("damping off") causes death.

*The disease, like Phytophthora above, is spread by motile zoospores that swim through the nutrient solution and by shore fly & fungus gnat feeding.

*CONTROL: See "*Phytophthora*" above.

***Olpidium brassicae*:**

*Has been shown to infect roots of hydroponic lettuce.

*Problem: this fungus is a carrier for **Lettuce Big Vein (LBV) Virus** and several other viruses, as well.

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

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

*General symptoms: The fungus does not produce any symptoms, but LBV Virus causes swollen leaf veins and bitter tasting leaves in lettuce.

*CONTROL:

Remove all contaminated plant material.

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

Fungicides: effective but expensive; not usually used in hydroponics.

Downy Mildew - *Peronospora sp.*

*Obligate parasite on crucifers (cabbages), grapes, tobacco, bell peppers, hops, cucurbits, basil and Impatiens (flower). Not important on tomatoes.

*Infection is usually in the leaves, twigs and fruit but also roots. Can also be carried in the seed.

*Has motile zoospores.

*Optimum conditions: Needs free water on the tissues; high relative humidity during cool to warm, but not hot, times.

*General symptoms: Distortion of infected stems and leaves; yellow spots that turn into brown sunken areas of stems, leaves and fruit due to cellular destruction. Necrotic lesions have irregular outlines, enlarge, coalesce and can ultimately cause defoliation. Fruit of grapes turn leathery & wrinkled.

*CONTROL: Use resistant varieties; various fungicides have been used.

BACTERIA: Kingdom Prokaryote

*****Bacteria are single-celled microorganisms with a cell membrane and cell wall surrounding the cytoplasm that contains “naked DNA” (no nucleus).

*Often have one or more flagella (whip-like; propels them through the water).

*In tomatoes, usually infect the upper portions of the plant resulting in necrotic (dead) spots on stems, leaves and fruit; also cause whole plant wilts.

*NOTE: Mycoplasmas (another prokaryote) have not been seen in hydroponics.

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, weeds, volunteer tomato plants or seeds. Infection occurs via wounds or through the roots or leaf stomata.

*Optimum conditions: Prefer 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. Fruits show small white lesions that develop into brown, scabby lesions surrounded by a halo (bird's eye). Diagnosis: place fresh cut stem in water – yellow streams of bacteria will exude into the water from the cut end (bacterial streaming).

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

*CONTROL: Use disease-free seeds 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!).

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

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

*Gram negative, aerobic, motile rod. Survives in soil where it attacks 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: Lower leaf droop followed by wilt of the entire plant (leaves stay green). 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 into the water from the cut end (bacterial streaming).

*Spread by irrigation water, diseased transplants or soil on shoes & equipment.

*CONTROL: Use disease-free transplants or tolerant varieties. In soil systems: fumigation, weed control, crop rotation and grafting to resistant root stocks can minimize losses.

VIRUSES: Kingdom Vira

*Viruses are particles of infectious single or double stranded DNA or RNA surrounded by a protein coat = "Nucleoprotein".

*Very small; need an electron microscope to see.

*Multiply only in living cells and have the ability to cause disease.

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

*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.).

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. Chewing insects can rarely transmit the virus.

*****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.

Everyone, but especially SMOKERS, should wash hands before entering the greenhouse or handling plants, tools, equipment, etc.

<u>Family = Geminiviruses, Genus = Begomovirus</u>

*****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 Infectious Chlorosis Virus by *Trialeurodes vaporariorum*

Tomato Mottle Virus transmitted by *Bemisia tabaci*

Tomato Yellow Leaf Curl Virus transmitted by *Bemisia tabaci* (below)

*General symptoms: Most geminiviruses cause leaf mottling and/or chlorosis (yellowing) in various patterns as well as leaf curl. Chlorosis reduces photosynthesis, growth (stunting of plants) and yields.

*CONTROL: Since these viruses are specifically transmitted by whiteflies, control of whiteflies 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).

*NOTE: TYLCV started in Israel in the 1980's and appeared in a garden in 2007 in Phoenix. It appeared in Oct. 2010 in the CEAC Teaching Greenhouse and again in 2014-2015. But resistant & tolerant varieties were used with no losses.

<u>Tomato Yellow Leaf Curl Virus (TYLCV) – more detailed information</u>

*Has a large host range including tomato and various native plants.

*Gemini virus with small, paired, isomeric particles, each containing a circular single strand of DNA.

*Spread by *Bemisia tabaci* whitefly after at least 15 minutes of feeding.

*General symptoms: In tomatoes young leaves (apical meristem and suckers) show curling, yellowing and dwarfing of the growth. Cluster stems may also curl. Symptoms can take 2 – 4 weeks to present after initial infection (note whitefly will still be feeding on infected plants and transmitting the virus but you won't know it!). Because of the loss of photosynthetic capacity, yield can be reduced and fruit size can be smaller than normal.

*CONTROL: Use resistant varieties, and virus-free transplants.

Control whiteflies using insect screening (to exclude) and/or spray (to eliminate). Also, remove nearby virus host weeds.

<u>Tomato Spotted Wilt Virus (Tospovirus or TSWV)</u>

*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 yellow, drooping foliage (appears wilted). Fruit has 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.

VIROIDS

* Viroids are "sub-virus" particles of infectious RNA that <u>are not surrounded</u> by a protein coat. They are the smallest organisms known to cause disease.
* Although a potato disease was identified in 1922, the cause, a viroid (PSTVd), was not discovered until 1971. As of 2006 (Hammond and Owens) only 29 viroid species had been identified with sizes ranging from 239 to 401 nucleotides.
* Viroids are divided into 2 Families:

Pospoviroidae: large host range; replicates in the nucleus

Avsunviroidae: smaller host range; appear to replicate in chloroplasts

* Transmission: Viroids are able to move from cell to cell through the plasmodesmata and seem to also be able to move with photosynthates via the phloem. Since they can be in the "plant sap" created from wounds when pruning suckers, leaves, etc., they can be transmitted from plant to plant by pruning equipment, on hands, clothing, etc. and even by plant-to-plant contact. They may also be seed borne and some have been found to be "vectored" by insects, etc.

*Many economic crops are affected by viroids including potatoes, chrysanthemum, hops citrus, grape, coconut palm, apples, pears, coleus, peach, nectarine, eggplant and tomato!

* Viroids have been isolated from plants <u>growing in greenhouses</u>, including:
  - Mexican Papita Viroid (MPVd)
  - Columnea Latent Viroid (CLVd)
  - Tomato Chlorotic Dwarf Viroid (TCDVd).

Single stranded RNA Pospoviroid with 360 nucleotides closely related to PSTVd. Found in fields and greenhouses in Europe & in greenhouses in Canada, and AZ.

* General symptoms: vary with TCDVd strain, tomato variety, plant age, plant vigor and climate but include reduced growth & chlorosis of leaves in the top of the plant. Symptoms appear 3 – 6 or even 8 weeks after initial infection.
* CONTROL: Remove symptomatic plants and those touching them; use viroid-free seeds/transplants; sterilize any pruning implements, including hands; restrict greenhouse access; deep bury/incinerate/autoclave plant material.

INTEGRATED PEST & DISEASE MANAGEMENT (IPDM – as per the National IPM Network)

<u>Definition of IPDM:</u>

A sustainable approach to managing pests & diseases by combining biological, cultural, physical and chemical tools in a way that minimizes economic, health and environmental risk (i.e., using ALL methods available to prevent and/or control pests & diseases).

<u>Techniques and strategies that help prevent pests and diseases from entering gh:</u>

Hygienic measures:

*Start with clean seed and/or transplants.

*Remove and dispose of old plant material from greenhouse (source of diseases and refuge for insects).

*Solarization: increase the temperature 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, booties & hair nets" for guests; disinfect shoes/hands/tools.)
NOTE: Skimmed milk can encapsulate viruses on tools & hands, etc.!

*Prevent transmission of pests/diseases in the irrigation water by filtration, UV radiation or ozone treatment.

Mechanical measures:

*Use insect net (several sizes specific to different insect pests are available) over air intakes and/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.

Cultural practices:

*Optimize plant growth: a healthy plant is a more resistant plant.

*Optimize the environment & 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 (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.

* Use "crop rotation" – alternating host and non-host crops (not typical for gh/hp).

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 which should be disease free.

<u>Techniques and strategies that control, reduce or eliminate pests and diseases that have already become established in the greenhouse:</u>

Mechanical measures:

*Check the crop regularly for the presence of pests and diseases.

*Capture insects (best for winged/flying insects) for ID & removal:

Sticky traps: plastic or other non-porous surface covered with a sticky substance and of a certain color (most insects, including 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, cucumbers, etc.

Hot water or air on seeds/bulbs/tubers/cuttings can remove mites, nematodes, bacteria and some viruses.

Biological control: (See below for definition) Pay attention to:

*The directions for use (application, time of day, location in crop).

*The directions for storage of biologicals (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 use of "banker plants" that attract pests and can also host beneficials.

Natural control: This is the control of pests and diseases by spontaneously occurring natural enemies (e.g., chance introduction of beneficials or the colonization of beneficials by creating optimal conditions for them). This is not usually done in greenhouse hydroponics… it's too "iffy"!

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 pesticides with beneficials (Ref. 3 below).

A CLOSER LOOK AT BIOLOGICAL CONTROL

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 about 60 pest species.

<u>**History**</u>:

1926: In a greenhouse in England, a small wasp, *Encarsia formosa,* was found to be a natural parasite and a control for white flies.
Late 1930's: biological control (using *Encarsia formosa* to control white flies) was common in commercial greenhouses in England and Australia.
1940's: the insecticide DDT was introduced and the use of biological control ceased. Other chemical pesticides were also developed. Many "side-effects" found.
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 "re-entry and/or harvest restrictions", the delay time between application of pesticide re-entry and/or 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 and consumers to pesticides and pesticide residues on produce
- the use of bumble bees in the greenhouse to pollinate especially tomatoes and peppers (see Ch 6 - pesticides kill not only the pest but the bees as well!)
- the fact that vegetables produced "pesticide free" command a higher price at the market!

<u>**Three considerations for the use of biological control:**</u>

1. Biological control is an extremely "knowledge intensive" technique.
Example: For white flies on tomatoes –
The grower could spray, kill everything and that would be that OR
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, etc.

2. Introduce the beneficial(s) BEFORE the pest organism is present.
If the grower waits until the pest is noticed, populations are already rising.

The lag time between notice-order-introduction may be up to 2 weeks – time for a pest to get out of control!

This is a common practice with white fly parasitic wasps since white flies will almost always be present

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

As the pest population rises there is more food/hosts for the beneficial population which will begin rising.

As the beneficial population rises, and kills the pests, the pest population falls with less food/hosts for the beneficials.

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

<u>Three ways to introduce "beneficials" to a crop:</u>

1. **Conservation:** Attract and preserve naturally occurring beneficial organisms in the crop (best for field crops but also occurs in gh/hp, i.e., spiders!).
2. **Inoculation:** Periodic releases of small numbers of "beneficials" starting early in the season. Typically used in greenhouse hydroponics.
3. **Inundation:** Mass introductions of "beneficials" aimed at eliminating pests immediately, especially when pest populations are high.

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