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Vegetable Diseases Caused by Soilborne Pathogens

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Soilborne plant pathogens can significantly reduce yield and quality in vegetable crops. These pathogens are particularly challenging because they often survive in soil for many years and each vegetable crop may be susceptible to several species. Simultaneous infections from multiple soilborne pathogens sometimes result in a disease complex that can further damage the crop. Many diseases caused by soilborne pathogens are difficult to predict, detect, and diagnose. In addition to this, the soil environment is extremely complex, making it a challenge to understand all aspects of diseases caused by soilborne pathogens.

Special terms are used when discussing soilborne pathogens. *Pathogens* are the biological agents that cause or incite the problem. *Symptoms* are the visible reactions (e.g., root decay, tissue discoloration, crown rot, wilting of foliage, etc.) of the plant when it is infected and colonized by the pathogen. The collective manifestation of symptoms caused by the pathogens is the *disease*. In contrast to a symptom, a *sign* is the visible evidence of the presence of the pathogen itself (e.g., mycelial growth, large sclerotia, bacterial ooze, or nematode cysts). *Inoculum* is the biological object (e.g., spore, mycelium, sclerotium, cells) that is able to infect the host and cause the disease. The term *soilborne pathogens,* therefore, can be defined as *pathogens* that cause plant *diseases* via *inoculum* that comes to the plant by way of the soil.

The most familiar diseases caused by soilborne pathogens are probably rots that affect belowground tissues (including seed decay, damping-off of seedlings, and root and crown rots) and vascular wilts initiated through root infections. A few soilborne pathogens, however, cause foliar diseases with symptoms and damage appearing on aboveground parts of plants. For example, the lettuce anthracnose pathogen survives in the soil in the form of tiny resting structures *(microsclerotia).* When raindrops splash pathogen-laden soil particles onto lettuce leaves, the fungus moves onto the plants and causes a leaf spot disease. Similarly, the soilborne pathogen *Sclerotinia sclerotiorum* survives in soil as sclerotia. Under certain environmental conditions, the sclerotia produce tiny mushroom-like structures (apothecia) that release aerial spores; these spores then land on susceptible foliage and cause a foliar disease.

Because soil ecology is so complex, it is also important that we define the ecological roles of soilborne pathogens. Soilborne pathogens can generally be divided into *soil inhabitants* (those able to survive in soil for a relatively long time) and *soil invaders* or *soil transients* (those only able to survive in soil for a relatively short time). Many soilborne plant pathogens also can function and live as non-pathogenic soil organisms under certain conditions. If these pathogens are in contact with dead and decaying plant tissues, they can grow and survive on these substrates and thus be seen as *saprobes* or *saprophytes* (organisms that live on decaying organic matter).

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MAJOR PATHOGEN GROUPS

The agents that cause soilborne diseases make up a diverse group. Fungi, which are multicellular microorganisms, cause most soilborne vegetable diseases and so are considered the most important pathogen group. Plant-pathogenic fungi fall into five main taxonomic classes based on morphological and biological characteristics: Plasmodiophoromycetes, Zygomycetes, Oomycetes, Ascomycetes, and Basidiomycetes. Some species of Ascomycetes and Basidiomycetes form a second type of spore that is asexually produced. These asexual stages are placed in an additional, separate class, the Fungi Imperfecti. Notable Oomycetes pathogens include *Aphanomyces, Bremia, Phytophthora,* and *Pythium.* Important Ascomycetes are *Monosporascus* and *Sclerotinia.* Examples of soilborne Fungi Imperfecti pathogens are *Fusarium, Rhizoctonia,* and *Verticillium. Plasmodiophora brassicae* (causal agent of clubroot disease of brassicas) and *Spongospora subterranea* (causal agent of powdery scab of potato) are the main soilborne Plasmodiophoromycetes pathogens. Many soilborne fungi persist in soil for long periods because these organisms produce resilient survival structures like melanized mycelium, chlamydospores, oospores, and sclerotia. The thin-walled mycelium typical of many fungi survives for only a short time in the soil.

Bacteria are single-celled organisms that have rigid cell walls but lack a membrane-bound nucleus. Fewer diseases are caused by soilborne bacterial pathogens than by fungal pathogens. Examples of such bacteria are *Erwinia, Rhizomonas,* and *Streptomyces.* Pathogens in the *Pseudomonas* and *Xanthomonas* groups usually persist in the soil for only a short time.

There are few soilborne viruses that affect vegetable crops. Viruses are subcellular entities composed of genetic material with a surrounding protein coat. Once the genetic material of a plant virus is inserted into a host cell, it causes the cells to manufacture more virus particles. Virus disease symptoms include stunting of the plant, tissue distortions, and discolorations of foliage and fruit. Soilborne viruses generally survive only in the living tissues of the host plant or in the nematode or fungal vectors that transmit them to the plant hosts. Lettuce big vein disease, for instance, is caused by the Mirafiori lettuce virus; the virus is present inside a primitive soil fungus *(Olpidium brassicae)* that moves in soil water, attaches itself to lettuce roots, and transmits the virus. Another example of a soilborne virus that affects vegetables is the lettuce necrotic stunt virus (LNSV). This is an unusual case in that LNSV has no known biological vector, but is found in river water and in soils contaminated by such water.

Nematodes are tiny, nonsegmented roundworms. Soilborne plant-parasitic nematodes spend most of their lives in the soil, either as external feeders on plant roots or as residents inside roots. Nematodes affect crops by reducing plant vigor and growth. In an affected field, some plants will be heavily infested and others will not, with the result that the overall crop will mature unevenly or the quality of the produce will be lower. In soil, plant parasitic nematodes either live freely or are present as eggs or durable cysts. Root knot nematodes (*Meloidogyne* species) cause a general reduction in vigor for many plant species and can cause severe distortions and swellings of roots, particularly affecting the marketability of root crops such as carrots. Cyst nematodes (*Heterodera* species) can survive in the soil for long periods because the mature body of the female cyst nematode dries in the form of a leathery cyst, protecting the eggs within. Needle nematodes *(Longidorus africanus)* feed on the growing points at the tips of the roots, causing root tips to swell and causing roots to fork or branch out. Stubby root nematodes (*Paratrichodorus* species) reduce the length of roots.

BIOLOGY OF SOILBORNE PATHOGENS

Survival. A soilborne pathogen's ability to survive in soil depends in part on the biological group to which it belongs. Few bacterial pathogens are true, long-term soil inhabitants; most survive for limited periods as saprobes on plant debris or roots, or directly in the soil. These species' bacterial cells do not produce resilient endospores and the vegetative cells are not particularly resilient in adverse environments. Some species survive by secreting slimy material that dries to form protective layers around the cells, enabling them to withstand unfavorable conditions.

Fungal pathogens survive in soil as saprobes on host plant debris or on other types of organic matter present in soil, or as free-living organisms living directly in the soil. Many of these fungi produce resilient survival structures on organic materials; the structures are released into the soil by tillage operations and through decomposition of the infected material. Survival structures can withstand low or high temperature extremes, dry conditions, and periods when no suitable host is present. Environmental factors, however, may affect how long the survival structures remain viable. The sclerotia of some root-infecting pathogens can be sensitive to desiccation. Low soil temperatures can be detrimental to pathogens that are adapted to warmer conditions. Such conditions can limit the development of pathogens such as *Macrophomina phaseolina* on beans and *Sclerotium rolfsii* on various crops.

Distribution of pathogens in soil. The horizontal and vertical distribution of soilborne pathogens depends on production practices, cropping history, and a variety of other factors. Along a vertical axis, the inoculum of most root pathogens lies within the top 10 inches of the soil profile, the layers where host roots and tissues and other organic substrates are found. On the horizontal plane, distribution of inoculum in a field is usually aggregated in areas where a susceptible crop has been grown: survival structures produced in diseased tissues are likely to remain in the area where the affected hosts have grown.

Because tillage operations involve fragmenting, moving, and burying plant residues, tillage can result in the vertical and horizontal redistribution of pathogens. Pathogen propagules can be moved both deeper and shallower in the soil profile. Deeper-placed propagules can have adverse effects on the survival of these structures. On the other hand, exposure to heat, cold, and drying may kill pathogens that have been brought to the soil surface. On a horizontal scale, tillage redistributes inoculum that was at first present in just a few infested areas and spreads it throughout the field. Eventually, the inoculum produced after each susceptible crop could be spread to previously uninfested areas, contributing to increased disease on succeeding crops. The greatest concentration of nematodes usually occurs in the top 6 inches of soil, though nematodes have been recovered from as deep as 4 to 5 feet. Nematode distribution in fields is irregular and usually dictated by the presence of host roots and root exudates and the movement of soil.

Factors that influence infection. Many factors in the soil influence the activity of soilborne pathogens and diseases: soil type, texture, pH, moisture, temperature, and nutrient levels are among them. Soil is a porous mixture of inorganic particles, organic matter, air, and water. *Soil texture,* which results from the size of mineral particles, and *soil structure,* which is the arrangement of soil particles into groups *(aggregates),* significantly influence the development of root disease. Well-aerated, well-drained soils create conditions that discourage root diseases. Soils that drain poorly, however, tend to favor the survival and distribution of soilborne pathogens such as *Pythium*, *Phytophthora,* and *Aphanomyces.* Fusarium and Verticillium wilts can also be more severe in wet soils than in dry soils. Only a few root diseases are favored by drier soils (for example, common scab of potato caused by *Streptomyces scabies*).

Soil pH is another important factor influencing the development of certain soilborne diseases. A classic example is clubroot disease of crucifers caused by *Plasmodiophora brassicae*. Clubroot is a major problem in acidic soils (5.7 pH or lower). The disease is dramatically reduced when the pH rises from 5.7 to 6.2 and is virtually eliminated at soil pH values greater than 7.3 to 7.4. This disease, which once posed a major threat in the Salinas Valley, has been managed for decades by liming the soil to raise the pH. Similarly, common scab of potatoes is favored by a pH of 5.2 to 8.0 but is reduced dramatically by soil pH values lower than 5.2.

Soil temperature is generally a less critical factor for soilborne problems on vegetable crops. Colder soil temperatures usually slow pathogen development and reduce the severity of disease. Under warmer temperatures, pathogens grow and develop more rapidly and can cause more disease. Melon vine decline (caused by *Monosporascus cannonballus*) and sudden wilt (caused by *Pythium aphanidermatum*) are two cucurbit diseases that are favored by high temperatures.

Another factor that has a major influence on soilborne disease is plant nutrition. The effect of nitrogen has received the most extensive study. High levels of soil nitrogen increase the growth rates of crops, enhance the growth of tender, succulent plant tissue, and prolong the plants' vegetative phase. Plants in this condition may be more vulnerable to attack by some soilborne pathogens. Low levels of soil nitrogen weaken plants and also predispose them to attack by some pathogens.

The type of nitrogen fertilizer can also indirectly affect soil pH and thus have an effect on soilborne diseases. The positive charge on an ammonium ion allows it to be adsorbed by plant roots, resulting in the release of hydrogen ions into the surrounding soil. These additional hydrogen ions lower the soil's pH; consequently, diseases that are more common in acidic soils increase in severity when ammonium nitrogen fertilizer is applied.

In contrast, nitrates can favor other diseases by altering the virulence and growth of the pathogens and by increasing host susceptibility. These effects can be seen with the vascular wilt pathogens. Research indicates that an increase in nitrate levels can increase the severity of Verticillium wilt but reduce that of Fusarium wilt; however, higher ammonium levels can cause Fusarium wilt to be more severe. Other soil nutrients may also have an affect on soilborne diseases, but they have not been studied as extensively as nitrogen.

Ecology. Soilborne pathogens share the soil environment with many other organisms and compete with them for limited resources. In addition, many of the microorganisms in soil are directly or indirectly antagonistic to soilborne pathogens. *Direct antagonism* takes place when, because of the environmental niche it occupies in the soil environment, an organism excludes a pathogen from the soil, or when an organism parasitizes soilborne pathogens. With *indirect antagonism,* the microflora may release substances that are toxic to the pathogen. In some soils, called *suppressive soils,* antagonistic microflora suppress the activity and development of soilborne pathogens to such a great extent that they significantly reduce the instance of plant disease. Researchers are attempting to create suppressive soil conditions deliberately by introducing microorganisms into the soil or by incorporating certain crop residues that enhance microbial growth and diversity. An example of this research is the recent use of broccoli residue to enhance suppression of *Verticillium dahliae* and *Sclerotinia minor* pathogens.

DIAGNOSING SOILBORNE DISEASES

Diagnosing a soilborne disease, in general, is not much different from diagnosing a disease that occurs on aboveground plant parts. Here are a few procedures that may prove useful:

- Prepare a list of known suspected soilborne pathogens. A particular crop being grown in a specific region generally is susceptible to a relatively short list of soilborne pathogens. By compiling this list ahead of time, you can narrow the group of pathogens to watch for (see Table).
- Carefully examine all parts of affected plants. Complete observation of roots, crowns, and other belowground plant parts is essential. You have to consider the symptoms that you observe aboveground together with the belowground symptoms in order to get a complete picture of a plant's condition.
- Watch for symptoms that occur in noticeable patterns, non-random distributions, or in association with physical features at the sites. For example, if symptomatic plants are associated with irrigation patterns or areas of excess water, that information can influence your diagnosis.
- Collect a representative sample for laboratory analysis. Plants must be carefully dug up so as to preserve roots and other belowground plant parts. The sample should consist of a sufficient number of diseased plants showing typical symptoms as well as a few healthy specimens for comparison. A qualified plant diagnostic laboratory can then confirm the actual cause of the soilborne disease.
- Keep a record of the soilborne diseases that you confirm at each site. This type of historic record can be especially useful later on because soilborne pathogens tend to persist for long periods of time. If you know which pathogens have been observed in a field, you can make better crop rotation decisions.

SOILBORNE DISEASE CONTROL STRATEGIES

Management of soilborne diseases depends on a thorough knowledge of the pathogen, the host plant, and the environmental conditions that favor infection. In order for a disease to develop, all three factors must be present. The *pathogen* (a virulent, infectious agent) must have viable inoculum, such as zoospores, available to infect the host. The *host* (a susceptible plant) must be exposed to the pathogen's inoculum, and be physiologically susceptible to infection. Finally, the *environmental conditions* must be favorable for the infection of the plant and growth of the pathogen. For example, the soil must be saturated with water for a certain period of time in order for water molds to develop and infect roots. An understanding of these pathogen-host-environment dynamics will help you devise a disease management strategy.

An effective disease management option must be economical: that is, the value of the crop saved must exceed the cost of control. For this reason, assessments of disease incidence, disease severity, and potential crop loss are key factors when considering control strategies. The careful, regular monitoring of fields and the thorough examination of symptomatic plants are essential steps. The timing of control measures is also critical. Management of a destructive disease such as Phytophthora root rot may require early implementation of appropriate management measures. Besides being economically sound, a management strategy should also be simple, safe, inexpensive to apply, and sufficiently effective to reduce diseases to acceptable levels. Few management options possess all of these desirable qualities, however, so it usually is best to integrate multiple management options (e.g., planting resistant varieties, following beneficial cultural practices, and applying disease-control materials).

Table. Important soilborne diseases and examples of management strategies*

Crop	Disease	Pathogen	Symptoms and signs	Examples of management†
Apiaceae				
Carrot	Bacterial soft rot	*Erwinia carotovora, E. chrysanthemi*	Soft, sunken, dull orange lesions on taproots or rot of lower portions of taproots.	Plant in well-drained soil. Avoid overwatering, especially during warm weather.
	Cavity spot	*Pythium violae*	Small, elliptical, superficial lesions on taproots.	Apply fungicides. Plant in well-drained soil.
	Cottony rot	*Sclerotinia sclerotiorum*	Soft, watery rot of stems and foliage. Profuse white mycelium and black sclerotia.	Apply fungicides. Provide ventilation down rows by trimming foliage. Deep plow to bury sclerotia.
	Crown rot	*Rhizoctonia solani*	Dark brown sunken lesions near crowns.	Avoid planting into fields with undecomposed crop residue.
	Phytophthora root rot	*Phytophthora* species	Aboveground stunting, wilting, death. Darkened, rotted roots.	Avoid overwatering. Plant in well-drained soil.
	Root dieback	*Pythium* species	Forking and stubbing of taproots.	Plant in well-drained soil. Use pre-plant fungicides.
	Root knot nematode	*Meloidogyne* species	Aboveground stunting and yellowing. Galls on deformed, stunted roots.	Rotate with small grains. Plant early in desert regions.
	Southern blight	*Sclerotium rolfsii*	Soft, brown rot of taproots with white stringy mycelium and brown sclerotia the size of mustard seeds.	Deep plow to bury sclerotia. Rotate with grain crops.
Celery	Crater spot	*Rhizoctonia solani*	Brown-red, sunken lesions on lower petioles.	Avoid planting into fields with undecomposed crop residue. Avoid moving soil onto crowns during cultivation. Put transplants at proper depth. Apply fungicides.
	Fusarium yellows	*Fusarium oxysporum* f. sp. *apii*	Plant stunting, yellowing of foliage. Brown discoloration of vascular tissue.	Use resistant cultivars. Select fields without a history of the disease.
	Pink rot	*Sclerotinia sclerotiorum*	Soft, watery, pink to brown rot on lower stems. Profuse white mycelium and black sclerotia.	Apply fungicides. Use drip irrigation.
Asteraceae				
Lettuce	Anthracnose	*Microdochium panattonianum*	Tan leaf spots and lesions on leaves. Spots are irregular and angular in shape. White-pink spores develop in the spot centers. Disease is initiated from soilborne inoculum, but later spreads via airborne spores.	Apply fungicides. Select fields without a history of the disease.
	Big vein	Mirafiori lettuce virus	Distorted, enlarged leaf veins that are abnormally cleared. Leaf and head formation can likewise be distorted.	Disease is typically more severe in the spring, so avoid infested fields until later in the summer. Use resistant cultivars.

Table. *Continued*

Crop	Disease	Pathogen	Symptoms and signs	Examples of management[†]
	Bottom rot	*Rhizoctonia solani*	Petioles and leaves in contact with soil develop irregular, brown, sunken lesions. Lesions later break down and decay, with the rot moving up into the plant.	Avoid planting in fields that have undecomposed crop residues.
	Corky root	*Rhizomonas suberifaciens*	Yellow patches on main tap roots. Patches later turn brown-green and rough and corky. Plants may be stunted.	Use resistant cultivars. Avoid using excess nitrogen. Transplant the lettuce instead of direct-seeding. Plant lettuce in the spring.
	Fusarium wilt	*F. oxysporum* f. sp. *lactucum*	Aboveground stunting, collapse. Brown discoloration of vascular tissue.	Select fields without a history of the disease.
	Lettuce dieback	Lettuce necrotic stunt virus	Lower leaves of Romaine cultivars turn bright yellow, sometimes with brown necrotic spots. The newer, inner leaves are noticeably green and thick. Plants can be severely stunted.	The pathogen is an unusual virus that has no known vector. The virus is spread in water and soil. Plant Romaine in fields without a history of the disease.
	Lettuce drop	*Sclerotinia minor*	Aboveground stunting, collapse. Soft and rotted crowns. Profuse white mycelium and small (1/8 inch) black sclerotia form on crowns.	Apply fungicides at thinning. Select fields without a history of the disease. Deep plow to bury sclerotia.
	Lettuce drop	*Sclerotinia sclerotiorum*	Aboveground stunting, collapse. Soft and rotted crowns. Profuse white mycelium and large (1/4 inch or larger) black sclerotia form on crowns. Airborne ascospores also cause leaf infections.	Apply fungicides at rosette stage.
	Verticillium wilt	*V. dahliae*	Aboveground stunting, collapse. Black discoloration of vascular tissue.	Select fields without a history of the disease.
Brassicaceae Cole crops	Bottom rot	*Rhizoctonia solani*	Dark, discolored lesions on leaves touching soil. Only occurs on brassicas that form heads.	Keep bed tops dry.
	Clubroot	*Plasmodiophora brassicae*	Aboveground stunting, death. Roots are severely swollen and deformed. Symptomatic roots often rot.	Do not plant brassicas. Apply lime for a soil pH >7.3.
	Cyst nematode	*Heterodera* species	Uneven growth and maturity of plants. Tiny white to brown cysts on roots.	Rotate crops.
	Fusarium yellows	*Fusarium oxysporum* f. sp. *conglutinans*	Aboveground stunting, wilting, death. Brown discoloration of vascular tissue. Occurs primarily on cabbage.	Use resistant cultivars.
	Phytophthora root rot	*Phytophthora megasperma*	Aboveground stunting, wilting, death. Darkened, rotted roots.	Avoid overwatering. Plant in well-drained soil.

Table. *Continued*

Crop	Disease	Pathogen	Symptoms and signs	Examples of management†
	Verticillium wilt	*Verticillium dahliae*	Aboveground stunting, wilting, death. Black discoloration of vascular tissue.	Use resistant cultivars. Plant susceptible cultivars in winter.
	White mold	*Sclerotinia sclerotiorum, Sclerotinia minor*	Soft, watery rot on stems in contact with soil. Decay also occurs on aboveground foliage. Profuse white mycelium and black sclerotia.	Deep-plow prior to planting so sclerotia are buried.
	White rust	*Albugo candida*	White blister-like pustules on leaves. Inoculum for this foliar disease comes from oospores in soil.	Do not plant susceptible brassicas. Apply fungicides.
	Wirestem	*Rhizoctonia solani*	Stunting, wilting, death of transplants. Hypocotyls are discolored, decayed, rotted. Brown mycelium present on decayed areas.	Avoid deep placement of transplants. Keep bed tops dry. Avoid planting into fields with undecomposed crop residue.
Chenopodiaceae				
Spinach	Damping-off	*Fusarium oxysporum, Pythium* species, *Rhizoctonia solani*	Poor stands. Wilting and death of emerged seedlings. Discolored, rotted roots and crowns.	Plant in well-drained soil. Avoid overwatering. Apply fungicides for *Pythium*.
Cucurbitaceae				
Cucumber, Melons, Squash	Charcoal rot	*Macrophomina phaseolina*	Water-soaked green stem lesions that later turn tan. Profuse gumming on stems. Small, black structures (pycnidia) in lesions.	Avoid stressing plants. Rotate with grains.
	Damping-off	*Pythium* species, *Rhizoctonia solani*	Water-soaked lesions on roots and stems. Wilting, death.	Avoid overwatering.
	Fusarium wilt	*F. oxysporum* f. sp. *melonis* (musk melon), *F. oxysporum* f. sp. *niveum* (watermelon), *F. oxysporum* f. sp. *cucumerinum* (cucumber)	Dark brown lesions on one side of stems. Brown discoloration of vascular tissue.	Use resistant cultivars.
	Melon vine decline	*Monosporascus cannonballus*	Vines collapse. Black, round structures (perithecia) on dead roots.	Avoid planting in infested fields. Avoid overwatering and stressing of plants.
	Root knot nematode	*Meloidogyne* species	Aboveground stunting and yellowing. Galls on deformed, stunted roots.	Preplant chemical treatment, postplant treatment with oxamyl.
	Sudden wilt	*Pythium aphanidermatum*	Vines collapse. Water-soaked beige to orange lesions on roots.	Avoid overwatering.
Fabaceae				
Bean	Ashy stem blight	*Macrophomina phaseolina*	Black sunken lesions on stems near soil line.	Avoid stressing plants.
Pea	Damping-off	*Pythium* species, *Rhizoctonia solani*	Water-soaked lesions on roots and stems. Wilting, death.	Avoid overwatering.

Table. *Continued*

Crop	Disease	Pathogen	Symptoms and signs	Examples of management†
	Fusarium root rot	*Fusarium solani* f. sp. *phaseoli*	Brown-red lesions on hypocotyls.	Use tolerant cultivars.
	Root knot nematode	*Meloidogyne* species	Aboveground stunting and yellowing. Galls on deformed, stunted roots.	Rotate with small grains. Use resistant cultivars.
Liliaceae				
Alliums	Damping-off	*Pythium* species, *Rhizoctonia* species	Poor stands. Wilting and death of emerged seedlings. Discolored, rotted roots and crowns.	Plant in well-drained soil. Avoid overwatering. Apply fungicides for *Pythium*.
	Fusarium basal rot	*Fusarium oxysporum* f. sp. *cepae*	Chlorosis and dieback of foliage. Brown discoloration of bulbs. Rotted roots and basal plates.	Use a 4-year crop rotation. Use resistant cultivars.
	Pink root	*Phoma terrestris*	Roots turn pink, then purple. Roots wither and eventually die. Bulbs are stunted.	Use a 3- to 6-year crop rotation. Use resistant cultivars. Solarize the soil.
	Stem & bulb nematode	*Ditylenchus dipsaci*	Tan discoloration and rot of stems, bulbs, and basal plates. Aboveground stunting, collapse of plant.	Use non-infested or disinfested sets and seed.
	White rot	*Sclerotium cepivorum*	Yellowing and eventual death of foliage. Decayed roots. Stunted and dead plants. White mycelium and black sclerotia on infected bulbs.	Use sanitation. Use pathogen-free garlic "seed." Soil fumigation, solarization, and fungicides provide partial control. Select fields without a history of the disease.
Asparagus	Fusarium wilt	*Fusarium oxysporum* f. sp. *asparagi*	Yellowing of foliage, stunted plants. Brown discoloration of vascular tissue.	Use sanitation. Use pathogen-free transplants.
	Phytophthora crown and spear rot	*Phytophthora* species	Soft brown lesions above and below the soil line. Affected areas on shoots are flattened.	Avoid overwatering. Plant in well-drained soil.
Solanaceae				
Pepper	Damping-off	*Phytophthora* species, *Pythium* species, *Rhizoctonia solani*	Poor stands. Wilting and death of emerged seedlings. Discolored, rotted roots and crowns.	Plant in well-drained soil. Avoid overwatering. Apply fungicides for *Pythium*.
	Phytophthora root rot	*Phytophthora capsici*	Aboveground stunting, wilting, and death. Darkened, rotted roots.	Avoid overwatering. Plant in well-drained soil.
	Verticillium wilt	*Verticillium dahliae*	Aboveground stunting, wilting, and death.	Use a 3-year crop rotation. Brown discoloration of vascular tissue.
Potato	Black dot	*Colletotrichum atramentarium*	Rotting of below ground stems and stolons. Black dot-like sclerotia visible in lesions.	Use pathogen-free "seed."
	Charcoal rot	*Macrophomina phaseoli*	Stem lesions that result in aboveground wilting and yellowing.	Avoid dry soils. Use pathogen-free "seed."

Table. *Continued*

Crop	Disease	Pathogen	Symptoms and signs	Examples of management†
	Fusarium dry rot	*Fusarium sambucinum*	Extensive, dry, brown internal decay of tubers.	Avoid wounding tubers. Apply fungicides to seed tubers.
	Leak	*Pythium* species	Water-soaked areas in tubers that are separated from healthy tissue by a dark boundary line. Affected tissue turns brown to black with exposure to air. In severe cases, only the skin of the tuber remains.	Avoid wounding tubers. Let skins mature before harvest.
	Pink rot	*Phytophthora erythroseptica*	Cream-colored decay of tubers that turns pink on exposure to air. Affected areas in tubers are delimited by dark lines.	Plant in well-drained soil. Avoid overwatering, especially late in the season.
	Powdery scab	*Spongospora subterranean*	Purple-brown pustules that darken with masses of dark brown spore balls.	Use a 3 to 10 year crop rotation. Use pathogen-free "seed." Plant in well-drained soil.
	Rhizoctonia canker (Black scurf)	*Rhizoctonia solani*	Red-brown stem lesions. Yellowing of foliage if lesions girdle stems. Aerial tubers. Leafrolling.	Use pathogen-free "seed." Apply fungicide "seed" treatments. Black sclerotia on tuber surfaces.
	Root knot nematode	*Meloidogyne* species	Aboveground stunting and yellowing. Galls on deformed, stunted roots.	Rotate with small grains.
	Silver scurf	*Helminthosporium solani*	Light brown circular spots with indistinct margins. Affected areas have a silvery sheen.	Use pathogen-free "seed." Apply fungicide "seed" treatments.
	Verticillium wilt	*Verticillium dahliae*	Aboveground stunting, wilting, and death. Brown discoloration of vascular tissue.	Use pathogen-free "seed."
	White mold	*Sclerotinia sclerotiorum*	Soft, watery rot on stems. Profuse white mycelium and black sclerotia.	Avoid using excessively high rates of nitrogen fertilizers. Minimize wetting of foliage.
Tomato	Damping-off	*Phytophthora* species, *Pythium* species, *Rhizoctonia solani*	Poor stands. Wilting and death of emerged seedlings. Discolored, rotted roots and crowns.	Plant in well-drained soil. Avoid overwatering.
	Fusarium foot rot	*Fusarium solani*	Brown lesions on tap or major lateral roots. Chlorosis and necrosis of leaves.	Use sanitation to avoid moving the pathogen.
	Fusarium wilt	*Fusarium oxysporum* f. sp. *lycopersici*	Aboveground stunting, wilting, and flagging of individual branches. Brown discoloration of vascular tissue.	Use resistant cultivars.
	Phytophthora root rot	*Phytophthora* species	Aboveground stunting, wilting, and death. Darkened, rotted roots.	Avoid overwatering. Plant in well-drained soil.
	Root knot nematode	*Meloidogyne* species	Aboveground stunting and yellowing. Galls on deformed, stunted roots.	Rotate with small grains.

Table. ***Continued***

Crop	Disease	Pathogen	Symptoms and signs	Examples of management†
	Verticillium wilt	*Verticillium dahliae*	Aboveground stunting and wilting. Brown discoloration of vascular tissue.	Use resistant cultivars.
	White mold	*Sclerotinia sclerotiorum*	Soft, watery rot on stems. Profuse white mycelium and black sclerotia on bleached areas of affected stems.	—

*For more complete information on these and other soilborne diseases and for more details on disease management options, refer to the *Pest Management Guidelines* found on the UC Statewide IPM Program web site (http://www.ipm.ucdavis.edu).

†General control measures that apply to almost all soilborne diseases, such as soil fumigation and crop rotations, are not listed for every entry.

DISEASE-CONTROL OPTIONS

Host resistance. Disease-resistant plants are an obvious and effective control measure because resistance to many pathogens can be both complete and long lasting. A plant can express resistance through the action of a single gene that confers immunity (resistance to certain races of Fusarium wilt, for example) or through multiple genes that result in a broad resistance to many pathogens. Single-gene resistance, called *vertical resistance,* limits both the initial level of infection and the production of inoculum. This sort of resistance can be overcome, however, by new strains of the target pathogen. Multiple-gene resistance, called horizontal resistance, allows some disease to develop but limits it to a tolerable level. Use resistant cultivars whenever they are available.

Cultural controls. There are three areas of focus for cultural control: helping plants avoid contact with pathogens, reducing inoculum in the host plant's environment, and creating environmental conditions that are unfavorable to disease development. Cultural controls that reduce host-pathogen contact include the use of fields that have no history of the soilborne disease of concern, the inhibition of pathogen spread from infested soil to uninfested fields, the use of seeds that do not harbor pathogens above acceptable established thresholds or the use of disease-free seeds and transplants, and the planting of seeds and transplants to proper depths.

Cultural methods that reduce inoculum levels in the environment include crop rotation, proper irrigation, good sanitation, and soil solarization. Certain cover crops (mustard species) and brassica crops (such as broccoli) can also help reduce soilborne pathogen populations; when incorporated into the soil, residues from these plants release chemicals that either directly inhibit pathogens or enhance soil microflora populations that subsequently compete with pathogens. To create conditions unfavorable for disease development, a grower can use optimum plant spacing to reduce relative humidity around plants, provide good soil drainage through proper soil preparation and irrigation practices, use mulches to physically isolate aboveground plant parts from contact with the soil, and fertilize the crop properly to prevent stressed or overly succulent plants. A good example of a specific cultural practice is the now-widespread use of drip irrigation in vegetable crops. Drip irrigation usually allows for a more precise delivery of water, resulting in better water management, reduced soil saturation, and a lowered risk of soilborne diseases such as root rots.

Disease-control chemicals. Agricultural chemicals and other disease-control materials are options that you can sometimes integrate into a strategy to manage soilborne pathogens. Pre-plant fumigants (e.g., methyl bromide, chloropicrin, or metham sodium) are often highly successful in reducing soilborne inoculum, though their use is expensive and strictly regulated. Fungicide-treated seed is an important tool against certain seed and seedling diseases. In some situations, a fungicide applied to the soil or to plants can be an effective disease management tool. For example, the application of fungicides to spinach seed lines at planting can effectively prevent damping-off caused by *Pythium.* One way to control lettuce drop caused by *Sclerotinia minor* is to apply fungicides to plants at the thinning stage. For most soilborne pathogens, however, field-applied fungicides usually are not very effective.

Classical biological controls are also under development. In this approach, a product containing a viable antagonistic organism is applied to combat the target pathogen. This type of treatment is under development, but is not yet available or effective for most soilborne diseases of vegetables.

FOR MORE INFORMATION

You'll find detailed information on many aspects of vegetable production and plant diseases in these titles and in other publications, slide sets, videos, and CD-ROMs from UC ANR:

Commercial Greenhouse Vegetable Handbook, publication 21575
Growing Field Crops: Vegetables, Melons, and More, CD-ROM 3413
UC IPM Pest Management Guidelines, various publication numbers for individual crops

To order these products, visit our online catalog at http://anrcatalog.ucdavis.edu. You can also place orders by mail, phone, or FAX, or request a printed catalog of publications, slide sets, videos, and CD-ROMs from

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