**Plant Disease Management for Organic Crops**

All species of plants, wild and cultivated a like, are susceptible to disease. The occurrence and prevalence of plant diseases vary from season to season, depending on the presence of the pathogen, environmental conditions, and the crops and varieties grown. Some plant varieties are particularly subject to outbreaks of diseases; others are more resistant to them. Plant diseases create challenging problems in commercial agriculture and pose real economic threats to organic farming systems. Plant pathogens are constantly changing and mutating, resulting in new strains and new challenges to growers. Also, given the local, regional, and international movement of seed, plant material, and farming equipment, new and introduced pathogens periodically enter the organic farming system to cause new disease problems. Disease management is complicated by the presence of multiple types of pathogens. For any one crop the grower must deal with a variety of fungi, bacteria, viruses, and nematodes. If a plant pathogen is present, the severity of the disease it causes will be determined by the level of infestation, by environmental conditions, and the susceptibility of the crop. Organic farmers rely primarily on preventive, cultural, and integrated methods of disease management and to some extent biological and chemical control measures too. It is unlikely that all diseases can be avoided by utilizing any one of these management strategies alone. However, the damage of many plant diseases can be greatly reduced by the integration of these practices.

## **Types of Plant Disease Pathogens**

A plant disease is any physiological (functional) or structural abnormality that is caused by a living organism. Organisms that cause a disease are referred to as **“pathogens,”** and affected plants are referred to as **“hosts.”** Disease causing pathogens include fungi, bacteria, viruses, phytoplasmas (obligate parasitic bacteria), or nematodes. **An infectious agent** is capable of reproducing within or on its host and spreading from one susceptible host to another.

### **Fungi**

Fungi are the most abundant group of plant pathogens. These multicellular organisms are typically microscopic. The “body” of a fungus is composed of filament-like threads called “hyphae.” Masses of hyphae are called “mycelia.” When large enough, these masses can be seen without the aid of a microscope. Powdery mildew is one example of a disease in which fungal mycelia is visible. Fungi reproduce via spores, which can be produced sexually or asexually. Some fungi produce spores within sexual fruiting structures (ascocarps, pustules, mushrooms) or asexual fruiting structures (pycnidia, acervuli). Once a fungal spore makes contact with a plant surface, it germinates, much like a seed, as long as conditions are favorable for the pathogen.

### **Bacteria**

Bacteria are microscopic organisms typically composed of single cells. Due to their small size, a high-magnification microscope is required to observe bacteria. Occasionally, when a large number of cells are present, plants may be observed “oozing” bacteria and other organic byproducts. Bacteria are capable of rapid reproduction through a process known as binary fission. In this process, one cell divides to become two, then two divide to become four cells, and so on. Unlike fungi, bacteria are not able to penetrate plant tissue directly. They must infect via wounds or natural plant openings such as stomata. Free water is required for infection. Once inside plants, bacteria begin to reproduce immediately.

### **Viruses**

Virus is a strand of DNA or RNA, consisting of a nucleic acid wrapped in a thin coat of protein.  Once viruses enter host cells, they “hijack” plants and “instruct” cells to produce more virus particles. As plant cells are converted from their normal function and processes (such as cell division or chlorophyll production), changes in plant growth and development may be observed. Plant viruses do not move in and out of plant tissue as readily as fungal and bacterial pathogens. They require vectors (such as insects or humans) to carry them from one plant to another. After entry into plant cells, reproduction begins. Viruses spread throughout plant hosts, infecting all plant parts (systemic infection). Viruses are dependent upon live hosts for replication, thus disease progresses slowly.

### **Phytoplasmas**

Phytoplasmas are extremely small bacteria-like plant pathogens. While they are similar to bacteria, phytoplasmas differ in their **inability to survive without a host**, their smaller size, and their lack of cell walls. Phytoplasmas rely on insect vectors, such as leafhoppers, for transmission into hosts. During feeding, leafhoppers acquire phytoplasmas from infected host phloem (nutrient-conducting vascular system) and introduce them into healthy tissue.

### **Nematodes**

Plant parasitic nematodes are microscopic roundworms that primarily infect roots, but a few occur in foliar portions of plants. While there are many species of nematodes, only a few are known to parasitize plants. Nematodes reproduce via eggs that result from either the mating of a male and a female or by the female alone. Symptom development occurs as a result of extracted cellular contents or other plant damage. Nematodes may remain on the exterior of roots during feeding (stubby-root nematode) or penetrate plant tissues completely to feed while inside plants (dagger nematode).

**Principles of Disease Control (Basic Terms)**

1. **Exclusion**– prevent entry and establishment
2. **Elimination**– removal or reduction of pathogen
3. **Avoidance**– alter time and place of cultivation
4. **Protection**– treat the plant to prevent infection
5. **Resistance**– use plants genetics to limit infection and disease development
6. **Therapy**– curative (medicinal) measures to limit pathogen

## **Cultural Control of Crop Diseases**

Cultural practices are invaluable (vital) tool that a grower should consider in designing an integrated disease control system. Cultural control aims to prevent contact with the pathogen, to create environmental conditions unfavorable to the pathogen, or to reduce the amount of pathogen inoculum available to the infected crop plants. Some cultural control practices include host eradication, crop rotation, sanitation, tillage, improving crop growth conditions, and selection of resistant cultivars to name a few. The remainder of this section discusses ways of improving plant growth and creating environments in the field that discourage spread of pathogens from one host to another.

### **Site Selection**

A grower can incur significant losses if susceptible crops planted in fields known for having a history of soil pathogens. Plant-pathogenic fungi such as *Armillaria*, *Fusarium* (the wilt-causing species), *Plasmodiophora*, *Sclerotium*, and *Verticillium* are true soil inhabitants and will persist in soil for many years, even in the absence of a plant host. Soil borne fungi such as *Phytophthora*, *Pythium*, and *Rhizoctonia* often are much more widespread, so site selection might be less of an option in avoiding these pathogens. If possible, avoid planting crops in low-lying, wet areas given the higher incidence of soilborne diseases.

### **Selection of Resistance Cultivars**

The use of resistant cultivars is one of the most important and economical components of an integrated disease management program. Resistant cultivars offer one of the most successful approaches to the control of pathogens of many crops, especially those diseases that cannot be controlled by other means. The term resistance usually describes the plant host's ability to suppress or retard the activity and progress of a pathogenic agent, which results in the absence or reduction of symptoms.

### **Planting Pathogen-free and High-quality Seed**

Planting pathogen-free and high-quality seed is a critical first step in managing diseases. This is particularly important for vegetatively propagated material such as tubers, bulbs, and slips. True seed can also contain pathogens, however, and all can serve as the source of entry of pathogens into new areas.

### **Adjust Crop Planting to Disrupt Pest Habitat**

Crop planting can be adjusted both in space and time to reduce the development of large pest populations.

#### **Timing of Planting Dates**

Alternating the time of planting to avoid high levels of pathogen inoculum or conditions conducive for development of a particular disease can lead to reduced severity of some crop diseases. For example, early-planted fields of soybeans may have a greater incidence of seedling blights caused by *Fusarium solani* and *Pythium*if planted early in cool and wet soils. The incidence of these two diseases can be reduced by delaying planting until the soil warms up.

#### **Seeding Practices**

Deeper seeding may promote germination but it also lengthens the (usually) susceptible pre-emergence seedling phase. Smuts and seedling diseases caused by *Fusarium* spp. and *Rhizoctonia* spp. are more serious if seeds are planted too deeply. Similarly, potato seed pieces are more readily attacked by *Rhizoctonia*if planted too deeply.

### **Crop Density**

Crop density can exert considerable influence over disease incidence due to the ease with which the pathogen inoculum can be transferred closely between closely spaced plants. In closely planted crops, temperatures are more uniform, humidity is higher, and foliage is wetter for longer periods of the day, all of which provides favorable conditions for pathogen infection and subsequent development. Diseases such as downy mildew and Sclerotinia stem rot (white mold) are greatly, affected by high humidity.

### **Crop Rotation**

Some pathogens that causes diseases survive in the soil from year to year in one form or the other, usually as sclerotia, spores, or hyphae. Continuously cropping the same crop builds up the population levels of any soilborne pathogen of that crop that may be present. The populations can potentially build up so large that it becomes difficult to grow that crop without yield losses. However, by rotating crops soilborne pathogens will eventually decline without a suitable host. The most successful rotations employ intervals between susceptible crops, which are longer than the known survival period of pathogens. Crop rotations are typically for a definite time-period (usually 2 or 3 years in most cases). A longer time-period of four to six years may be required for control of some diseases of brassicas, potatoes, and cotton. The crop rotation may also include a fallow period in which land is “rested” from production.

### **Tillage Practices**

Deeply burying infested crop debris and pathogen survival structures by moldboard plowing reduces disease incidence. For this to work, the residue must be buried deeply enough that it is not pulled back up during seedbed preparation and cultivation. Burying diseased material is especially useful against pathogens that produce sclerotia and those that infect only aboveground plant tissue. However, deep, full inversion plowing decreases soil health by burying beneficial organisms that live in the top few inches of the soil profile.

### **Eradication of Hosts to Reduce Level of Inoculum**

Crop plants remaining from previous seasons, weeds or wild plants may act as hosts providing a source of inoculum (a substances containing live microbial cells) in the new growing season. For example, grasses such as *Hordeum leportnum* (grass like barley) are hosts of the wheat take-all fungus *Gaeumannomyces graminis.* Many dicotyledonous weeds are infested with root-knot nematodes (*Meloidogyne* spp.) and other nematodes.

### **Intercropping**

The incidence of disease is often less in **mixed plantings** than in monocultures because the distance between similar plants is greater than in more intensive growing systems so it is less likely that propagules or vectors of pathogens will successfully move from one host to another. The intervening plants pose physical barriers to the dissemination of aerial pathogens or their vectors. However, the incidence of disease may be higher in intercropped plantings.

### **Physical Removal and Destruction of Crop Residues**

Crop residues provide suitable substrates for many pathogens. Physically removing and destroying (e.g., burning, burying, etc.) crop residues are important cultural control practice performed during intercrop periods. The effect of destroying crop residues on particular pathogens depends on the type of crop (annual, perennial, or harvested product), the extent of the cropping area and the survival mechanisms and host ranges of the target pathogens.

### **Sanitation in Preventing the Build-up of Pathogens**

Wash soil off of farm equipment, including brushing off soil particles from shoes. These practices are especially important to prevent movement of soilborne pathogens such  *Sclerotinia sclerotiorum*(causal agent of White mold), *Phytophthora capsici*, *Verticillium dalhiae,*and different species of *Fusarium*. A power washer is an important piece of equipment in the battle against these diseases.

### **Cover Crops**

Disease suppressive cover crop rotations may provide an additional tool for managing soilborne diseases. The effect, however, is highly variable, differing between locations, and between years. At least three mechanisms are at work.

### **Mulching**

Mulching, the application of a covering layer of material to the soil surface, is a commonly used cultural practice, especially in horticulture. Natural materials used for mulching include **cereal straw and stalks, crop debris, sawdust, leaves, grass, compost, and manure**. When crop residues are used as mulch they provide many pathogens with a food source as well as an environment in which to live and reproduce and can, therefore, increase the incidence of a disease.

### **Irrigation Management**

Irrigation management is clearly an important factor when it comes to disease control. Regardless of the irrigation method a grower chooses (furrow, sprinkler, or drip), timing and duration of irrigations should satisfy crop water requirements without allowing for excess water.

### **Plant Nutrition**

A properly nourished plant is able to withstand or tolerate the attack of pathogens much better than a plant that has nutrient deficiencies or has been excessively fertilized. For example, fertilizing with phosphates can delay the onset, and lessen the severity of take-all in barley (*Gaeumannomyces graminus*) and reduce the incidence of potato scab (*Streptomyces scabies*).

## **Soil Solarization for Controlling Soilborne Diseases**

Soil solarization is a hydrothermal process for controlling soilborne diseases in soil prior to planting crops. Effective control of soilborne plant pathogens (plant parasitic nematodes, fungi, and some bacteria) is a serious challenge to organic farmers. Crop rotation or selection of new sites can be effective for preventing soilborne some diseases. However, where susceptible crops are repeatedly planted, soilborne disease problems often develop and persist. Soil fumigants can be used to control soilborne diseases but there is a significant environmental risk, a negative impact on beneficial soil microorganisms, and generally not approved for use in organic crop production.

### **Principles**

Soil solarization captures the radiant energy of sunlight under clear polyethylene film. The transparent film allows short-wave radiation from the sun to penetrate the plastic. Once the light passes through the plastic and is reflected from the soil, the wavelength becomes longer and cannot escape through the plastic. The trapped light facilitates heating of the soil to temperatures detrimental to most living organisms.

### **Site Selection and Preparation**

Shady areas should be avoided because temperatures likely will not reach lethal levels. The soil to be solarized must be worked up to seed-bed condition—that is, cultivated until it's friable with no large clods or other debris on the soil surface.

### **Film Selection and Application**

Different types of plastic sheets are available, mainly differing in their thickness (insulation) and ability to let light through (transparency). Black, opaque, or translucent (reflecting) plastics are not suitable for solarization because instead of letting radiation pass through and heating the underlying soil, solar energy is absorbed and radiated back into the air and only slight warming of the covered soil occurs. **Thin, transparent plastic sheets** appear to achieve the best results—between 0.5 to 4.0 mil (mil or thou is a unit to measure the thickness). Thinner (0.5 to 1 mil) films conduct more heat, but are more susceptible to tearing and have a shorter life than thicker films. Often growers will use two layers of thin plastic sheeting separated by a thin insulating layer of air increases soil temperatures and the overall effectiveness of a solarization treatment. Agricultural films for commercial application are often treated with ultraviolet (UV) inhibitors to delay film breakdown.

### **Considerations in Solarization**

The main disadvantage of solarization is its potential negative impact on beneficial soil microorganisms since they will meet the same fate as their harmful counterparts. But recovery is usually attained quickly through rapid recolonization because beneficial microorganisms appear better suited to utilize substrate and nutrients freed by solarization than their harmful counterparts.

### **Effect on Soilborne Pathogens**

Soil solarization is effective against fungal pathogens such as *Verticillium*spp. (wilt), *Fusarium*spp. (several diseases), and *Phytophthora cinnamomi*(*Phytophthora*root rot), and bacterial pathogens such as *Streptomyces scabies*(potato scab), *Agrobacterium tumefaciens*(crown gall), and *Clavibacter michiganensis*(tomato canker).

## **Biorational Control of Crop Diseases**

Organic growers have available a large array of biorationals that may be applied for the management of crop diseases. Biorationals typically used to control crop diseases include:

1. **Microbials:** include live organisms (e.g., beneficial bacteria, fungi, nematodes, and viruses) and/or their fermentation products as the active ingredient.
2. **Minerals:** Minerials include sulfur, lime-sulfur, various forms of copper, and potassium bicarbonate.
3. **Spray oils**: Spray oils include **petroleum-derived oils** (referred to as “narrow-range oils”); oils derived from plant and fish sources; and essential oils, such as wintergreen, clove and rosemary.

Preventive, cultural, mechanical, and physical methods must be the first choice for pest control, and conditions for use of a botanical or synthetic material permitted on the National List must be documented in the organic system plan.

### **Minerals**

Sulfur and copper are the disease control materials most applied on organic farms. Elemental sulfur may be used for a broad range of diseases in a wide variety of plants. Copper products must be applied in a way that minimizes copper accumulation in the soil. Among the copper products allowed are copper sulfate, copper hydroxide, copper octanoate, copper oxide, and copper oxychloride. Bordeaux mix (copper sulfate combined with hydrated lime) and lime-sulfur are also permitted. Potassium bicarbonate, a relatively new product as a fungicide is also permitted. Each of these products and their uses are summarized in Table 13.1 and described in more detail in the following sections.

#### **Application of Minerals**

The frequency of application of any mineral-based pesticides is related to its residual time, or the time required for the product to degrade in the environment. Synthetic materials, approved for organic crop production, in general have a short residual time. On the other hand, this short residual time also limits most concerns about build-up in the soil that are associated with some commercial products. Effective control requires that the application of materials begin prior to conditions favorable for disease development or immediately following the first symptoms of disease.

#### **Bordeaux Mixture**

Bordeaux mixture is a mixture of copper sulfate (bluestone), calcium hydroxide (hydrated spray lime or slaked lime), and water that can be used as both a bactericide and fungicide on apples, pears, and some stone fruits. Bordeaux mixture prevents pathogen growth by disrupting enzyme function. It works as a preventative measure and has no systemic activity, so applications need to be made prior to infection. Sulfur is only fungicidal, but Bordeaux mixture also is bactericidal, which means that it can be effective against disease caused both by fungi (such as powdery mildew, downy mildew, and various anthracnose pathogens) and by bacteria (such as bacterial leaf spots and fire blight). Bordeaux mixture owes part of its success to its ability to persist through spring rains and adhere to plants. Bordeaux mixture comes in several formulations.

#### **Fixed Copper**

Fixed copper is a term that refers to several relatively insoluble formulations of copper that are somewhat less phytotoxic and are more convenient to use on crops than Bordeaux mixture. The term “fixed” copper refers to copper products that are formulated or tank-mixed in such a way as to create relatively insoluble or “fixed” deposits of copper on plants. Fixed copper formulations release less copper ions and are generally less injurious to plant tissues (safer to use) than copper sulfate or Bordeaux mixture. The activity and potential phytotoxicity of these formulations are proportional to the amount of actual metallic copper each contains, the rate and timing of application to the crop, the phenological stage of the plant and pathogen, and the weather conditions after application. Copper-based materials work by disrupting enzyme function after copper ions contact bacterial or fungal cells. Once dried on the plant surface, copper will be reactivated by rain until it is completely washed off. Copper has only preventative or protectant activity, so applications need to be made prior to infection.

#### **Lime Sulfur and Liquid Lime Sulfur**

Lime sulfur is a mixture of calcium polysulfides formed by adding elemental sulfur to boiling water slurry of calcium hydroxide. It is usually in a liquid formulation. The active compound, hydrogen sulfide, gives lime sulfur an unpleasant rotten egg smell that may remain in the field for over a week.

#### **Sulfur**

Sulfur is a non-systemic contact and protectant fungicide, making it only effective in a protective or preventative schedule based upon predicted infection periods. It also has some secondary acaricidal (mite suppressive) activity. Sulfur becomes toxic to fungal cells by inhibiting respiration, disrupting proteins, and chelating heavy metals.

#### **Potassium Bicarbonate**

Potassium bicarbonate (baking soda) is a contact fungicide killing spores and hyphae on plant surfaces within minutes of application. This is achieved by several modes of action including changing leaf surface pH, fungal spore dehydration, and causing potassium imbalances. Multiple modes of action results in less risk of resistant fungal strains developing. As such, it offers an alternative to sulfur.

### **Microbials**

Microbials, also called as biological pathogens or biological control agents, contain microbes like bacteria, viruses, or fungi that produce toxins that are harmful to pathogens. While the active ingredients of microbials are generally approved for organic production (Organic Materials Review Institute,OMRI listed) because of their natural origin, certain formulated products are prohibited because the inert ingredients or procedures used in making the product are prohibited. A list of commonly used microbials for controlling plant pathogens can be found in Table 13.2.

#### **Application of Microbials**

The successful application of microbials hinges upon the grower having an in-depth understanding of the biology of the target plant pathogen(s). Microbials, also known as biological control agents (BCAs), are registered for use by the Environmental Protection Agency (EPA) and have labels very similar to those for chemical pesticides. BCAs can be hazardous to the applicator and all safety equipment recommended on the label should be used.

### **Spray Oils**

Spray oils include certain fractions of petroleum oils (narrow-range oils), which are considered synthetic and allowed for disease control. “Narrow-range oils” are defined as petroleum derivatives—predominately of paraffinic and napthenic fractions. Narrow-range oils are allowed for both dormant and growing season uses for disease control. Allowed oils can also be derived from plant and fish sources. Plant oils are primarily derived from seeds (e.g., soybean, cottonseed, sesame, and canola), while fish oils are by-products of the fish processing industry. Approved products may not contain any prohibited inert components.

#### **Application of Spray Oils**

To combat plant fungal pathogens, oils generally must be applied prophylactically prior to infection. Repeated applications of oils may be needed to achieve desired levels of control. Although generally considered safe, oils can injure susceptible plant species. Symptoms of plant injury (phytotoxicity) may be acute or chronic. They can include leaf scorching and browning, defoliation, reduced flowering and stunted growth. Phytotoxicity may be associated with plant stress, ambient temperature and humidity, and application rate. It can vary among plant species and cultivars.

## **References**

1. Barker, Allen V. 2010. Science and Technology of Organic Farming. CRC Press: Boca Raton, Florida.  
2. Baker, Brian. 2012. Organic Practice Guide. In: Organic Production Handbook (Karen McSwain, ed.). Pittsboro, North Carolina: Carolina Farm Stewardship Association.  
3. Beckerman, Janna. 2008. Using Organic Fungicides. Purdue University, Purdue University Cooperative Extension Service: Lafayette, Indiana. Publication BP-69-W.  
4. Caldwell, Brian, Eric Sideman, Abby Seaman, Anthony Shelton, and Christine Smart. 2013. Resource Guide to Organic Insect and Disease Management. 2nd ed. Cornell University, New York State Agricultural Experiment Station: Geneva, New York.  
5. Cao, Chunxue, Sunjeong Park, and Brian B. McSpadden Gardener. 2010. Biopesticide Controls of Plant Diseases: Resources and Products for Organic Farmers in Ohio. Ohio State University, Ohio State University Extension Columbus, Ohio. Publication SAG-18-10.  
6. Coleman, Pamela. 2012. Guide for Organic Crop Producers. Appropriate Technology Transfer for Rural Areas (ATTRA): Fayetteville, Arkansas.  
7. Davies, Gareth and Margi Lennartsson, eds. 2005. Organic Vegetable Production: A Complete Guide. The Crowood Press: Wiltshire, United Kingdom.  
8. Damicone, John. 2012. Soil Solarization for Control of Soilborne Diseases. Oklahoma State University, Oklahoma State University Cooperative Extension Service: Stillwater, Oklahoma. Publication EPP-7640-2.  
9. Dimitri, Carolyn, Loni Kemp, Jane Sooby, and Elizabeth Sullivan. 2012. Organic Farming for Health and Prosperity. Organic Farming and Research Foundation: Santa Cruz, California.  
10. Eshenaur, Brian and Robert Anderson. 2004. Managing the Greenhouse Environment to Control Plant Diseases. University of Kentucky, University of Kentucky Cooperative Extension Service: Lexington, Kentucky. Publication PPFS-GH-01.  
11. Gugino, Beth K. and Alyssa A. Collins. 2015. Disease Management. In: Penn State Organic Crop Production Guide (White, Charlie White, Mary Barbercheck, and William Curran, eds.). State College, Pennsylvania: The Pennsylvania State University. Publication: AGRS-124.  
12. Hagan, Austin K. and William S. Gazaway. 2000. Soil Solarization for the Control of Nematodes and Soilborne Diseases. Alabama A&M University and Auburn University, Cooperative Extension. Publication ANR-713.  
13. Koike, Steven T., Calvin Fouche, Mark Gaskell, Jeff Mitchell, and Richard Smith. 2000. Plant Disease Management for Organic Crops. University of California, Vegetable Research and Information Center: Davis, California. Publication 7252.  
14. Krueger, Romy and Robert McSorley. 2009. Solarization for Pest Management in Florida. University of Florida, Institute of Food and Agricultural Sciences: Gainesville, Florida. Publication ENY-902.  
15. McMullen, Marcia P. and H. Arthur Lamey. 2001. Plant Diseases - Development and Management. North Dakota State University, North Dakota State Extension Service: Fargo, North Dakota. Publication EB-31, Revised.  
16. Narayanasamy, P. 2013. Biological Management of Diseases of Crops, Volume 2: Integration of Biological Control Strategies with Crop Disease Management Systems. Springer Science: New York, New York.  
17. Peck, Gregory and Ian Merwin. 2010. A Grower’s Guide to Organic Apples. Cornell University, Cornell University Cooperative Extension: Ithaca, New York. Publication #223.  
18. Pokharel, Ramesh. 2011. Soil Solarization, An Alternative to Soil Fumigants.  
19. Raudales, Rosa E. and Brian B. McSpadden Gardener. 2008. Microbial Biopesticides for the Control of Plant Diseases in Organic Farming. Ohio State University, Ohio State University Extension Columbus, Ohio. Publication HYG-3310-08.