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PPA-41

Fundamental Principles of Plant Pathology for Agricultural Producers

Paul Vincelli, Extension Plant Pathologist

All crop plants produced in Kentucky have the potential to become diseased under certain conditions. Diseases of crops can affect yield and/or quality of the harvested commodity, which can impact profitability and increase the risks of farming.

A plant is diseased when it is affected by some agent that interferes with its normal development. Some disorders are caused by noninfectious factors, such as temperature extremes or nutrient deficiencies. However, this publication focuses on diseases caused by infectious organisms.

Diseased plants exhibit a variety of symptoms. These symptoms can include stunting, yellowing, wilting, twisting, reddening, browning, blighting, root rot, fruit rot, and other abnormalities. Accurate diagnosis is important to effectively control a plant disease. Until a disease is properly diagnosed, a grower may waste time and money trying to correct a problem with an unknown cause. Once a disease is diagnosed, appropriate control practices can be selected. Diagnosis is an art as well as a science, and experience is important. Your local Extension agent can provide information on identification and management of crop diseases.

Infectious Organisms that Cause Diseases

Plant diseases can be caused by fungi, fungus-like organisms (FLO), bacteria, viruses, nematodes, or parasitic seed plants.

Fungi and Fungus-like Organisms

Fungi and fungus-like organisms (water molds) are the most common infectious organisms causing plant disease. Many of these organisms are microscopic; however, some produce structures that either alone or *en mass* are visible to the unaided eye. Fungi and fungus-like organisms feed on living plants and/or on dead organic matter. When they attack living plants, disease can result.

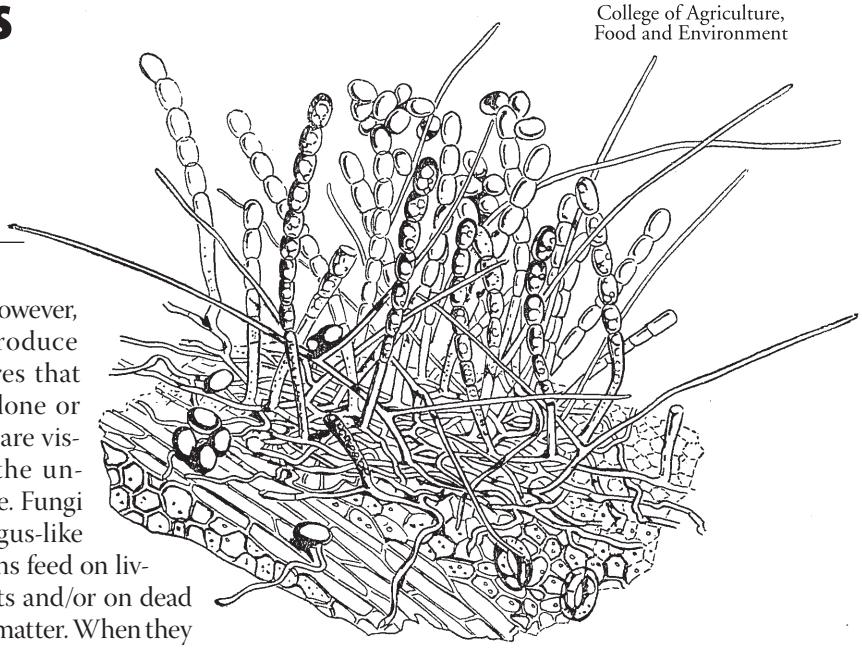


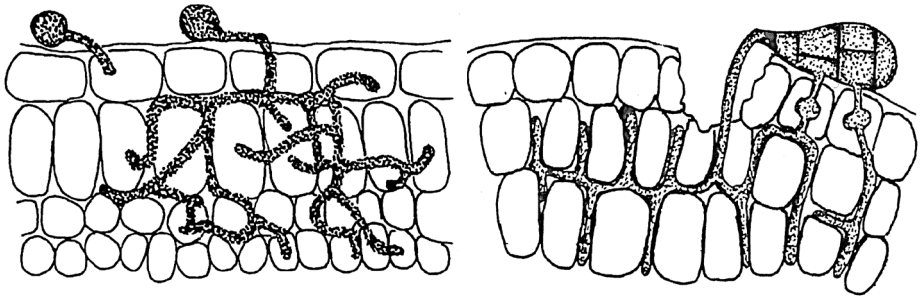
Figure 1. An illustration of microscopic chains of barrel-shaped spores, which are produced by a powdery mildew fungus infecting a leaf. The spores illustrated here are spread by air currents.

These organisms usually produce spores (Figure 1), which can begin an infection when carried to a plant. Spores can be spread from plant to plant by wind, water, insects, birds, and equipment. Adequate moisture and the right temperature are required for the spores to begin new infections. Microbes may be able to penetrate plant host tissues directly or through natural openings; however, a wound is sometimes needed as a point of entry (Figure 2). Plant diseases caused by fungi and FLO are common during wet, humid seasons. Survival between growing seasons can occur in one or more of the following ways: in crop residues, weeds, soil, seeds, live buds, or in crops or weeds growing south of Kentucky.

Some of these organisms have the ability to reproduce very quickly under the right environmental conditions. An infection that began from one spore may produce millions of spores in just a few days. Others reproduce slowly and may take one or two years to complete a disease cycle.

Infections of plants by fungi and FLO can cause a variety of types of diseases, including leaf diseases (Figure 3), wilts, root rots, crown rots, stem rots (Figure 4), and other diseases.

Figure 2. A microscopic view of plant infection by spores of various fungi. Some fungi can infect plant tissue through unwounded surfaces (left). Sometimes, fungi can infect best through wounds (right) or natural microscopic pores in plants.



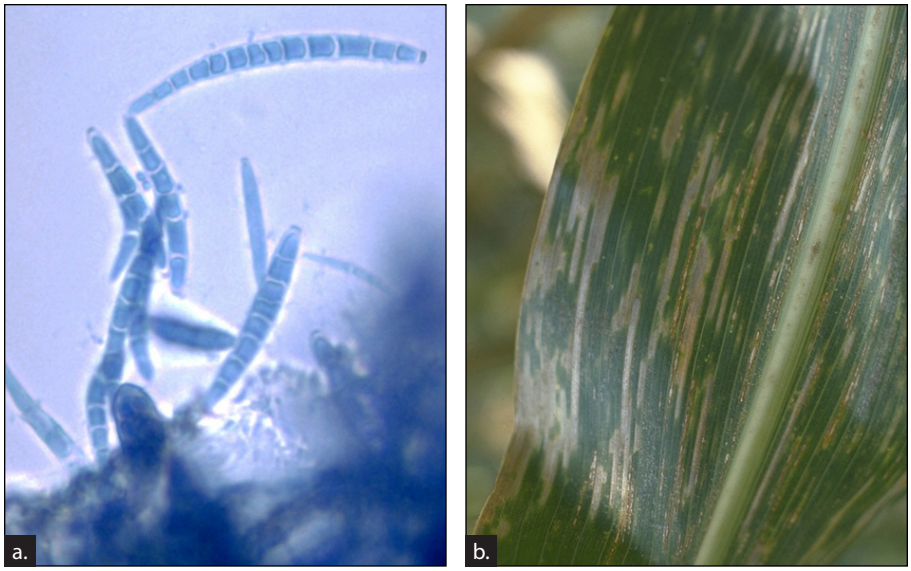


Figure 3. Gray leaf spot, caused by the fungus *Cercospora zeae-maydis* (a), affects corn foliage. Yield loss can result when the upper leaves are killed during grain fill. Individual lesions on leaves are rectangular (b).



Figure 4. *Phytophthora nicotianae* is a fungus-like organism (a) that causes black shank of tobacco (b). Plants with rotted roots and stems (c) suffer from lack of water and nutrients, and they may eventually die.

Bacteria

Bacteria are single-celled microscopic organisms that can attack living plants and cause plant diseases. Bacteria can be carried from plant to plant in droplets of water by wind, rainsplash, insects, and equipment (Figure 5). Phytoplasmas, which are very small bacteria without cell walls, are mainly carried from plant to plant by insects with piercing/sucking mouthparts, such as leafhoppers.

Bacteria often survive between growing seasons in crop residue, in crop seeds or cuttings, or in weeds. Phytoplasmas may also survive in their insect host.

Under warm, wet conditions, bacteria reproduce extremely quickly (Figure 5). Under conditions ideal for disease development, a single bacterial cell can give rise to 17 million daughter cells in 24 hours.

Diseases of leaves, growing shoots, and fruit are the most common types of bacterial diseases in Kentucky (Figure 6).

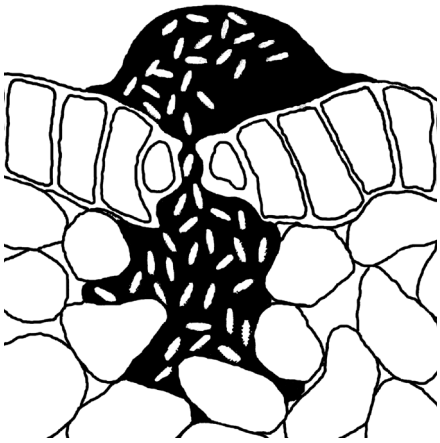


Figure 5. A microscopic view of leaf infection by bacteria (illustrated as white rods in black droplets of moisture). Bacteria multiply and spread in moisture droplets.

Viruses

Viruses are the smallest parasites causing plant disease. Because of their extremely small size, they can be seen only with an electron microscope. Structurally, viruses are nothing more than a protein shell surrounding a small amount of genetic material (Figure 7a).

Most viruses are spread by insect vectors (a vector is a living organism that transmits a pathogen). Conditions that favor large numbers of insect vectors often lead to severe virus outbreaks. Viruses may also be transmitted from plant to plant by other means, such as human hands. Most viruses survive between growing seasons in live plant tissues (weeds, crop seeds, cuttings, or trees).

Viral infections of plants cause stunting, color changes in leaves (Figure 7b), and growth distortions.

Nematodes

Nematodes are microscopic worms that live in the soil. Parasitic nematodes feed on plant roots (Figures 8 and 9). Low numbers of nematodes are not damaging to crops, but feeding by large numbers of nematodes on roots interferes with uptake of water and nutrients.

Plant nematodes often require three to four weeks or more between generations. In contrast to some fungi and most bacteria, destructive levels of nematodes take some time to develop. Once destructive levels are reached, however, even nematodes that reproduce slowly can cause serious crop damage. Nematodes are spread by anything that moves soil: boots, machinery, running water, etc. Nematodes usually survive between seasons in the soil. Typical root symptoms of nematode damage include lesions or galls (Figure 8b) that result in root dysfunction.

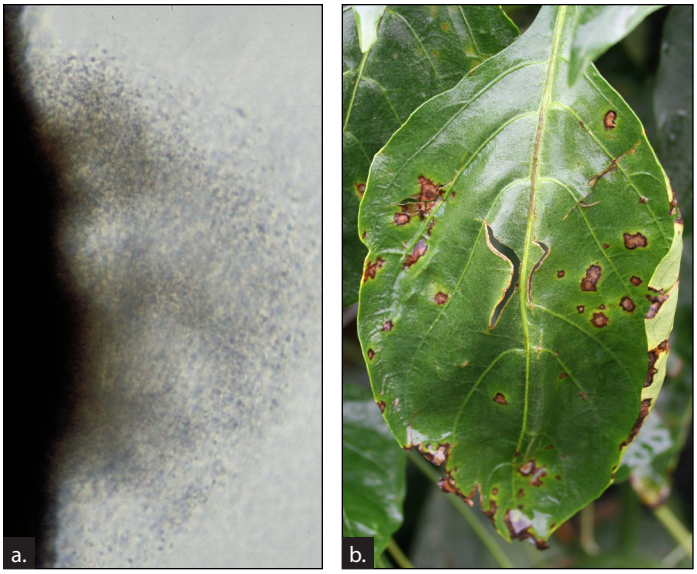


Figure 6. Bacteria streaming from a plant lesion, as seen under the microscope (a). Symptoms of bacterial spot on pepper leaves and fruits (b), a disease that may limit the success of pepper production in Kentucky.



Figure 7. Tobacco vein mottling virus (TVMV) viewed through an electron microscope, magnified 54,000 times (a). These virus particles are flexible, rod-shaped crystals of genetic material surrounded by a protein coat. Tobacco leaves infected by this virus develop vein-banding and mottling symptoms (b).

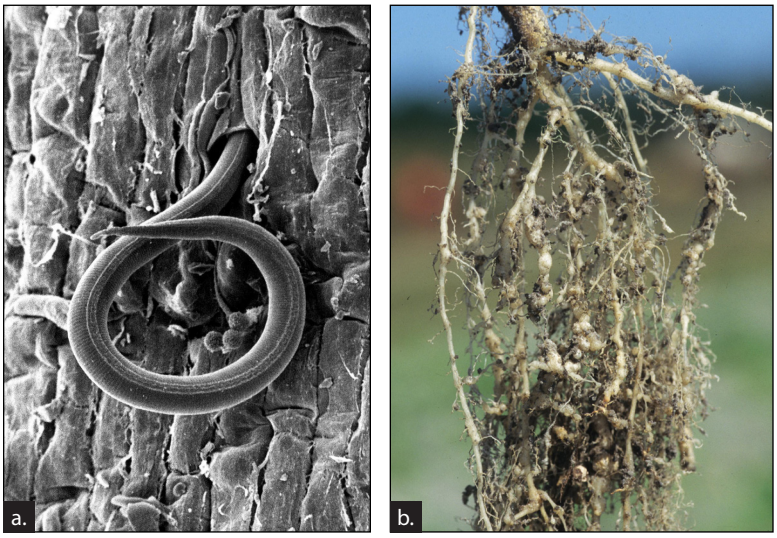


Figure 8. Scanning electron microscopic view of root knot nematode feeding on a tomato root (a). Root knot nematode galls on roots of a gourd plant (b).

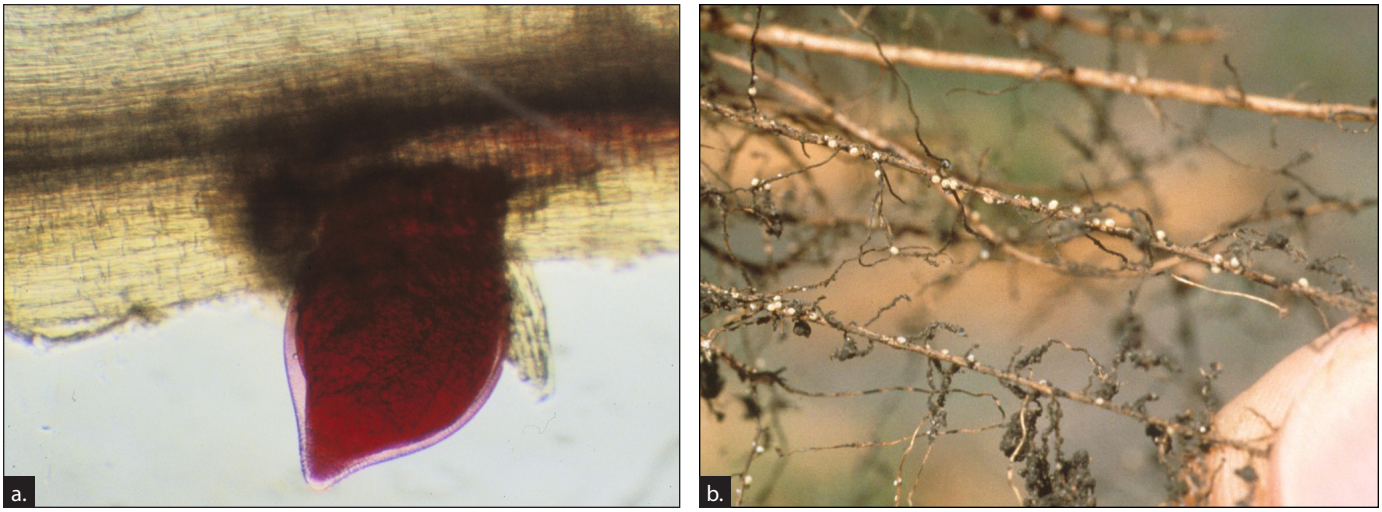


Figure 9. A microscopic view of pear-shaped soybean cyst nematode female filled with eggs (stained red) (a) and cysts appearing as white to brown specks on soybean roots (b).

Parasitic Seed Plants

Parasitic plants, such as dodder (Figure 10), require another living plant (host) to meet some or all of their nutritional needs. These parasitic plants produce seeds, which provide a means of overwintering as well as dispersal.

The Disease Triangle

A fundamental concept in plant pathology is represented by the disease triangle. Each side/angle of the triangle represents a factor required for disease development: a susceptible host, a pathogen (the agent that causes disease), and an environment favorable for disease to develop (Figure 11). All three factors must be present simultaneously for a plant disease to occur.

For example, consider blue mold of tobacco. A farmer may have susceptible tobacco plants and the weather may be cool and damp, but blue mold cannot develop if spores of the blue mold pathogen have not been carried by air currents into the crop. In this case, one factor in the disease triangle—the pathogen—is missing.

Likewise, spores may land on a field of susceptible plants, but if the weather is hot and dry, infection will not occur and blue mold will not develop. A different factor of the disease triangle—a favorable environment—is missing in this case.

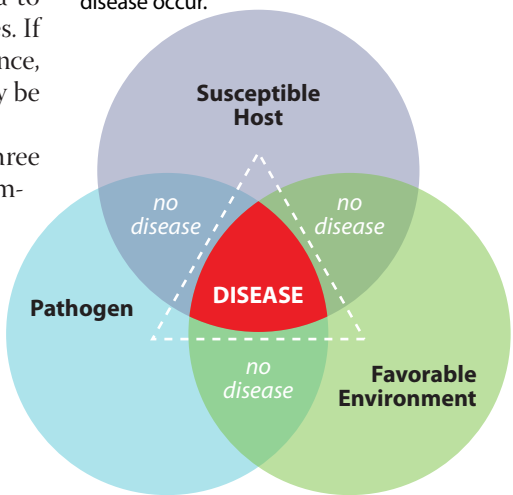


Figure 10. Dodder parasitizing alfalfa.

In many cases, the susceptible host may be the missing factor when the grower has selected a variety bred to have resistance to particular diseases. If the variety has high levels of resistance, no other management practices may be necessary against that disease.

Disease develops only when all three sides of the disease triangle are complete. Plant diseases are managed by manipulating the disease triangle: the plant, the pathogen, and/or the crop production environment.

Figure 11. The disease triangle. Only when all three criteria are present (pathogen, susceptible host, and favorable environment) will disease occur.



Managing Plant Diseases

Plant diseases can be managed through the use of appropriate cultural practices combined with resistant varieties when available. Appropriate use of pesticides in an integrated disease management plan may also be an important part of controlling certain diseases.

Cultural Practices

Several cultural practices involving the use of crop rotation and sanitation, proper planting dates and fertilization, and other practices can be an important part of a disease management program.

Crop rotation is a fundamental disease management practice. Growing the same crop in a field year after year encourages the buildup of pathogens. For example, if the black shank pathogen is present, growing tobacco every year leads to dangerously high spore levels in the field. However, when a farmer rotates to a crop other than tobacco, spores of the black shank organism begin to starve since they can only infect tobacco. Fewer spores survive each year, until eventually few remain in the soil.

Sanitation: Many important disease management practices fall under the category of sanitation. For example, removing infected prunings eliminates a source of infectious material, which can help in disease management. Plowing to bury pathogen-infested crop residue is another form of sanitation. Using steam to disinfest greenhouse pots is another example.

Planting date: Choosing the proper planting date can affect disease development. Some diseases are favored when a crop is planted too early, while others are favored by late planting. The best overall approach is to plant when environmental conditions favor growth of the plant but not growth and reproduction of the pathogen.

Improving soil structure and drainage: Poor soil drainage can create an environment favorable to certain root rot diseases. Therefore, improving soil structure and drainage can alleviate some root rot diseases.

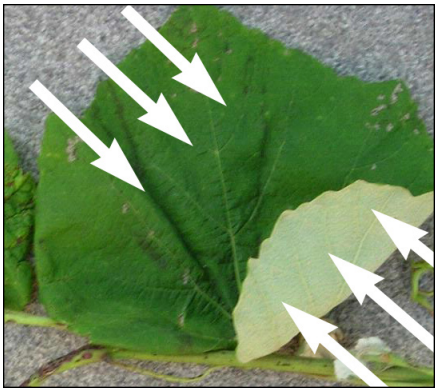


Figure 12. Uniform coverage of both upper and lower leaf surfaces is necessary for disease control using a protectant fungicide.

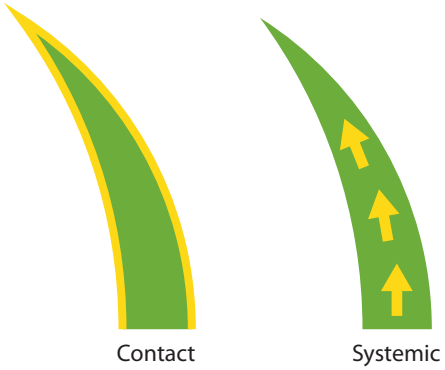


Figure 13. Contact (protectant) fungicides remain on plant surfaces. Systemic fungicides penetrate the plant.

Proper fertility is another important cultural practice for disease control. Properly fertilized plants are generally more resistant to diseases than under-fertilized or over-fertilized plants.

Other practices: Numerous other cultural practices can contribute to a disease management plan. Some examples:

- Proper plant density can affect disease development. Overcrowding of plants can lead to excess humidity around leaves, favoring fungal and bacterial diseases.
- Timely harvest can also be important, as some diseases develop on the harvested commodity only as the crop matures.
- Selecting disease-free seed is important when the seed is the source of the pathogen.

Resistant Varieties

Using crop varieties with disease resistance is one of the best disease control practices. With a highly resistant variety, a crop disease can be controlled with no added cost and no health risks to the farmer, farm workers, or environment. For example, in a field infested with cyst nematode, soybean yields can be improved by as much as 30 to 40 percent simply by selecting the proper resistant variety.

Scouting fields and identifying disease outbreaks are important steps in selecting appropriate disease-resistant varieties in future growing seasons.

Pesticides

When used properly, pesticides can be an important tool for disease control. For example, proper use of foliar fungicides in high-yield wheat can enhance farm profits. However, pesticides cannot substitute for good crop management. In fact, many diseases cannot be controlled economically with pesticides. Pesticides are the last line of defense for controlling crop diseases, not the first line of defense.

Pesticides used to control plant diseases are classified as fungicides, bactericides, and nematicides.

Fungicides are used to control diseases caused by fungi and fungus-like organisms. They may be applied to seed, soil, or foliage (Figure 12). Fungicides have either a protectant or systemic activity.

- **Protectant** (contact) fungicides remain on plant surfaces (Figure 13) and must be applied before infection occurs (Figure 14). Examples of protectant fungicides include products containing mancozeb, maneb, chlorothalonil, ferbam, captan, and thiram.
- **Systemic** fungicides penetrate and are redistributed within the plant (Figure 13). Because they penetrate the plant, systemic fungicides sometimes can be applied shortly after infection to eradicate recent infections. This activity is known as eradicant or "kickback." Examples of systemic fungicides include metalaxyl, mefenoxam, triadimefon, and thiophanate methyl. Movement of almost all systemic fungicides within the plant is upward toward plant tops and leaf tips, not downward from leaves

to roots. Some fungicides are locally systemic—that is, they penetrate the plant to a limited extent and move only a limited distance from the point of penetration.

Fungicides may be classified as either broad-spectrum or narrow-spectrum.

- **Broad-spectrum** fungicides are active against a wide variety of fungal pathogens.
- **Narrow-spectrum** fungicides are effective against just one or a few types of organisms. This distinction is important for those who might presume that any commercial fungicide will kill all types of fungi. This presumption is not true. The label is the best guide to which diseases can be controlled with a commercial product.

Bactericides are pesticides that kill bacteria. Bactericides act as protectants and must be applied before infection occurs. Bactericides cannot eradicate an existing infection. Most copper fungicides are also bactericides. Streptomycin is another bactericide labelled for certain uses.

Nematicides are used to control diseases caused by nematodes. Nematicides are usually toxic to warm-blooded animals and should only be used with extreme caution. Nematicides may be either fumigants or non-fumigants (discussed below).

Types of Application

Pesticides can be applied to seed, soil, foliage, flowers, or fruit.

Seed treatment: Fungicides are sometimes applied to seed surfaces to protect against disease.

- **Protectant** fungicides surround the newly planted seed and young seedling with a zone of fungicide. This zone acts as a toxic barrier to fungal infection and protects against seed rots and seedling disease. Protectant fungicides can also eradicate infectious spores present on the surface of the seed coat before planting.
- **Systemic** fungicides applied to seed are absorbed by the developing seedling. This absorption protects against infection by fungi causing seed rots and seedling disease. Systemic uptake of a fungicide also can eradicate some internal infections of the seed present before planting.

Common seed treatment fungicides include captan, thiram, and metalaxyl.

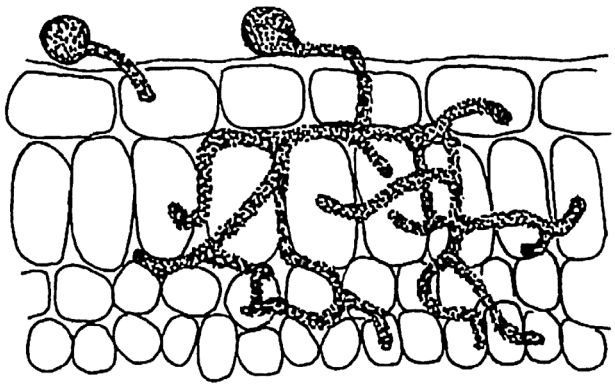


Figure 14. Protectant fungicides and bactericides must be applied before infection occurs. The fungal infections shown here cannot be eradicated using a protectant fungicide.

Soil treatment: Pesticides may be applied to the soil to control diseases caused by fungi or nematodes. Soil-applied disease-control chemicals are classified as either fumigants or non-fumigants.

- **Fumigants** are applied to the soil as liquids or granules before planting. After application, they turn into gases. These gases diffuse throughout the soil to form a fumigated zone.

  Soil conditions must be suitable if fumigants are to be effective. Generally, a soil that is in "seedbed condition" (slightly moist and friable) with a temperature between 50°F and 75°F is suitable. If the soil is too wet, the fumigant gas will not diffuse through the soil. On the other hand, if the soil is too dry, the gas will escape from the soil too quickly. Either way, fungal spores and nematodes will not be killed and poor disease control results.

  Fumigating when the soil is too cold or too warm also results in poor disease control. The fumigant may not diffuse properly in cold soils and may escape too quickly in warm soils. See label directions for instructions on proper conditions for applying fumigants. Examples of fumigants include dichloropropene, chloropicrin, dazomet, and metam sodium.
- **Non-fumigants** are applied to soil as liquids or granules. These may be applied to the seed furrow, incorporated before planting, or sprayed onto the soil and incorporated during crop growth. Soil-applied pesticides provide roots with a zone of protection against infection. Some soil-applied pesticides are systemic. Systemics applied to the soil are taken up by roots and translocated to leaves, providing roots and leaves with protection against infection.

  Fungicides sometimes applied to the soil include metalaxyl, mefenoxam, thiophanate methyl, and PCNB. Some soil-directed pesticides can move with water movement and have the potential to contaminate groundwater or surface water, especially if used improperly.

Foliage, flower, and fruit treatment: Fungicides and bactericides are sometimes applied to foliage (leaves), flowers, and/or fruits to provide protection against infection.

When applying a pesticide to foliage, the farmer should consider whether it is a protectant or systemic. If it is a protectant, it must be applied over all susceptible tissues before infection occurs (Figure 12). For example, if you are applying mancozeb to control Septoria leaf and glume blotch of wheat, the application must cover the flag leaf and glumes before infection occurs. If symptoms are showing on the flag leaf, it is too late because infection has already occurred. Even if the fungicide was applied before infection, if coverage is poor, then unprotected spots on the flag leaves and glumes may become infected later.

Systemic fungicides "translocate," or move within the plant. Thus, thorough coverage is less important with systemics. In fact, sometimes the best use of a systemic is to not spray the target tissue. For example, spraying tobacco leaves with the systemic fungicide mefenoxam (Ridomil Gold®) for blue mold control results in somewhat poor coverage. (It is also an illegal use of the product.) On the other hand, spraying the soil allows tobacco roots to absorb and translocate the fungicide. This way, mefenoxam is

uniformly distributed throughout the tobacco plant, and best control of blue mold is obtained.

Foliar fungicides sometimes must be applied several times to control a disease because fungicide deposits do not persist indefinitely. Fungicide deposits are subject to weathering from rainfall, sunshine, etc. Also, if a protectant was applied, leaves that have emerged since the last application are unprotected.

When should foliar sprays be applied? The answer depends on the disease triangle. When is your crop susceptible? When are the spores present? When do environmental conditions favor infection? Understanding the biology of the disease is important for knowing the best time to spray. Your local Extension agent can provide information on timing of pesticide applications.

Integrated Disease Management

The old saying "Don't put all your eggs in one basket" also applies to good disease control. Integrated disease management means applying a combination of techniques to achieve effective disease control. Growers should not rely on only one method to manage diseases. For example, continuous reliance on chemical methods runs the risk of pesticide resistance, not to mention the detrimental effects to the environment. Instead, practice crop rotation, use resistant varieties when available, and learn how cultural practices can be used to reduce disease pressure. Often pesticide use can be avoided by following good cultural practices.

Sources of Information on Plant Diseases

A great deal of information on plant diseases and their management is available through the University of Kentucky Cooperative Extension Service. Several websites are listed below. Contact your local Extension agent to obtain more information on plant diseases.

- **Plant Pathology Extension publications:** http://www2.ca.uky.edu/agcollege/plantpathology/extension/pubs.html
- **Integrated Pest Management publications:** http://www.uky.edu/Ag/IPM/ipm.htm

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