CHAPTER **THIRTEEN**

PLANT DISEASE DIAGNOSIS AND MANAGEMENT

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Contents

13 PLANT DISEASE

Learning Objectives

- Learn the history of plant diseases in the United States
- Learn the basic disease concepts, including signs and symptoms
- Learn the disease cycle
- Learn the difference between biotic and abiotic agents

Introduction

Plant pathology or phytopathology is the study of plant diseases and their control. Plant pathologists study plant diseases caused by biotic (living) agents like fungi, bacteria, viruses, nematodes, and parasitic plants, but they also study plant disorders caused by abiotic (nonliving) agents like nutrient imbalances, air pollution, and other unfavorable growing conditions. Learning how to diagnose plant disease involves more than just matching pictures of plant symptoms on the internet or in a book with those afflicting the plant sample in your hand. Many plant conditions cause symptoms that look similar. Being able to diagnose plant problems is a skill developed over time. Indeed, building knowledge about plants and plant diseases is a trial-and-error progression, one heavily reliant on repetition.Learning the process helps a Master Gardener make the correct diagnosis, which likely will resolve an Extension client's plant issues.

As a Master Gardener, your primary goal is to educate. The diagnosis you arrive at is an opportunity to help Extension clients understand proper plant growth requirements and to suggest sustainable measures to prevent plant disease.

History of Plant Disease

As evidenced by biblical references to the blasting and mildewing of plants, plant diseases have had profound effects on humankind throughout the centuries. Secular

observers documented the effects more systematically. For example, Greek philosopher Theophrastus (370–286 BC) was the first to describe maladies of trees, cereals, and legumes that we currently classify as leaf scorch, rot, scab, and cereal rust diseases. The Romans were also aware of rust diseases in their grain crops. They celebrated Robigalia (an agricultural festival that honored the growing season) by sacrificing reddish-colored dogs and cattle in an attempt to appease the rust god Robigus.

Subsequent technological discoveries proved more beneficial. After the microscope's invention in the early seventeenth century, naturalists began investigating fungi and bacteria associated with plants. In 1665, Robert Hooke illustrated rust in a drawing that had developed on a rose leaf, the first published illustration of the disease. Despite artistic contributions like these, as well as his and others' improvement of the optical tool, belief in the theory of spontaneous generation hampered advances in the study of diseases until as late as the mid-eighteenth century. Adherents of this theory believed that pathogenic or disease-causing microorganisms were symptoms of disease rather than its origin.

Plant diseases have caused widespread famine and displaced millions throughout history. Potato late blight fungal epidemics so devastated Ireland from 1845 to 1848 that death and migration accounted for the loss of nearly one-third of the Emerald Isle's population between 1845 and 1860. In 1861, a German botanist, Anton de Bary, proved that a fungus (*Phytophthora infestans*) was the causal agent. This was a milestone in the study of plant diseases since it proved that a fungus indeed caused a plant disease. Two years later, Louis Pasteur proposed his germ theory of disease, which officially disproved the theory of spontaneous generation, forever changing the way modern science investigates disease.

SIGNIFICANCE OF PLANT DISEASE IN THE UNITED STATES

A few examples of plant disease epidemics that triggered devastating plant losses in the United States include the following:

- Chestnut blight, introduced in 1904, virtually eliminated chestnut trees from North America.
- Citrus canker, introduced in 1910 (and a closely related bacterium called citrus bacterial spot discovered in 1984), resulted in the destruction of millions of citrus trees.
- White pine blister rust, introduced in 1912, caused large economic losses in the timber industry.
- Dutch elm disease, introduced in 1930, continues to destroy large numbers of elm trees today from the East Coast to the Pacific Northwest.

Because imported diseased plant materials initiated these epidemics, plant quarantine laws were passed by the US Congress in 1912. The Animal and Plant Health Inspection Service (APHIS) has quarantine inspectors stationed at points of entry into the United States, as well as at certain interstate points, to intercept incoming produce likely to carry new plant pathogens.

Disease Concepts

WHAT IS A DISEASE?

Healthy plants develop and function to the maximum of their genetic potential. When continuous irritation of a disease-causing agent interferes with normal development and plant functions, plants are considered diseased. Thus, a simple way to define a plant disease is a change in the host plant that causes abnormal growth or a disruption of normal plant function. Diseases may be biotic (living) or abiotic (nonliving).

Diseases are among the most important factors that significantly diminish growth and yield. In addition to a reduction in growth, yield, and the economic or aesthetic value of a plant or plant product, diseases may lead to the death of a plant or destruction of an entire crop. Diseases may interfere with absorption and translocation of water and nutrients from the soil, reduce the photosynthetic efficiency of a plant, interrupt the translocation of photosynthetic products, or interfere with reproduction and the storage of food reserves in a plant.

CAUSAL AGENTS OF DISEASE

Diseases in plants are caused by biotic pathogens such as fungi, bacteria, phytoplasmas, spiroplasmas, viruses, viroids, and/or abiotic factors that are environmental (like frost) or chemical (herbicide damage). Plant diseases can be grouped by the causal agent involved (fungal diseases, bacterial diseases, viral diseases, nematode diseases, etc.), the plant part affected (root disease, seedling disease,

leaf disease, stem disease, flower disease, fruit disease, tuber disease, etc.), or the types of symptoms shown (damping off, wilts, leaf spots, cankers, blights, galls, root knots, mosaics, storage rots, etc.).

SIGNS OF DISEASE

Signs are the visible parts of a pathogen or its products seen on a host that help diagnosticians identify a pathogen. Examples of some common disease signs include the following:

bacterial slime, flux, or ooze. Bacterial discharge that oozes out of plant tissue. It may be gooey or dry.

conk. A fungal fruiting structure formed on woody plants.

cyst. The swollen egg-containing female body of certain nematodes; it can generally be seen on the outside of infected roots.

fruiting bodies. The reproductive portion of a fungus that contains the spores.

mycelia. A mass of hyphae (fungal threads).

rhizomorphs. Shoestring-like hyphae found under the bark of stressed and dying trees.

Although not considered a disease, some signs of damage that could lead to plant problems later include girdling roots or bark damage.

SYMPTOMS OF DISEASE

Symptoms are the visible reactions of a plant to a disease that may suggest a causal agent. However, different disease agents can cause similar symptoms on the same host. It is important to remember that insect feeding can also cause disease-like symptoms on plants.

abnormal coloration. Change in the color of plant tissue.

abscission. Dropping of leaves, flowers, or fruit by a plant.

canker. The formation of sharply delineated, dry, necrotic, localized lesions on a stem.

decline. Progressive decrease in plant vigor.

defoliation. Loss of leaves or foliage.

desiccation. Drying out of plant tissue.

dieback. Progressive death of shoot, branch, or roots, starting at the tips.

distortion. Malformed plant tissue.

flagging. Wilting and/or death of plant parts, usually starting at the tips of a branch or stem.

fruit drop. The shedding of unripe fruit from a tree.

gall. Abnormal localized swelling or enlargement of a portion of a leaf, root, or stem.

gummosis. Exudation of gum or sap.

leaf scorch. Drying of leaf tissues, often along the leaf margin.

leaf spot. Spot or lesion on a leaf.

The Disease Cycle

Plant diseases are the exception rather than the rule. For infectious disease to develop, a series of events referred to as the **disease cycle** must occur: inoculation, penetration, establishment of infection (this includes invasion of the host), growth, reproduction, dissemination, and survival. Pathogens in temperate climates must have a way of overwintering when their host plants are dormant or absent. In perennial plants, pathogens can survive in infected plant parts such as roots, bulbs, stems, and bud scales. Because annual plants die at the end of the growing season, pathogens survive within insects and seeds or as resistant spores.

INOCULATION

The first step of the disease cycle is inoculation. This occurs when a pathogen comes in contact with a susceptible host. Pathogens that find susceptible hosts and can cause infections are referred to as **inoculum**. Wind, water, insects, and animals can carry inocula to host plants.

PENETRATION

Following inoculation, penetration of a host may occur. Some pathogens, including many fungi or nematodes, penetrate a plant by mechanical means. Others may enter a plant passively through wounds, stomata, or other natural openings. Penetration does not always result in infection. For penetration to result in infection, three factors — a host, a pathogen, and an environment — must coincide (as represented in the disease triangle, Figure 1).

INFECTION

Infection requires inocula to establish continuous contact with a susceptible host plant to create a parasitic relationship. The interaction between a

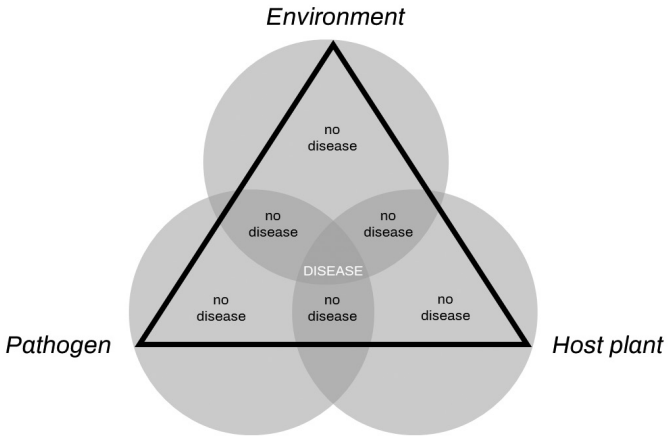

Figure 1. Plant disease triangle.
Adapted from Figure 4 in Moore et al. (2019).

host plant, pathogen, and environment with time will determine the occurrence and severity of a disease.

For a disease to occur, the following three conditions must be met:

1. The host plant must be of a susceptible species or cultivar and at the right stage of development (susceptible host).
2. The pathogen must be of a virulent race or strain and must be present in sufficient numbers (inoculum potential). The presence of appropriate vectors or other agents of dispersal may also be necessary.
3. The environmental conditions must be favorable for disease development. These include temperature and humidity; wind and moisture levels; light; soil texture, structure, and pH; the density of the planting and air movement; and the plant's nutritional status (mineral deficiency or excess).

If these three conditions are favorable and infection does occur, a pathogen may release enzymes which manifest themselves as symptoms in or on a plant. The period between infection and manifestation of symptoms is known as the **incubation period**. This period can last days or even years. Some infections may be localized while others are systemic, affecting an entire plant. Many pathogens reproduce during the infection stage.From there, pathogens disseminate to other plants.

DISSEMINATION

Pathogen dissemination occurs in a variety of ways — through plant debris, equipment, irrigation water, rain, wind, seed, soil, insects, animals, and more. Understanding the various aspects of a host plant, a pathogen, and environment, as well as their interaction, is essential to implement an effective disease management strategy.

Diseases Caused by Biotic Agents

FUNGI

In most areas of the eastern United States that receive ample rainfall (40 inches or more precipitation annually) and develop high humidity, fungi are the most impactful cause of plant disease. Depending on a gardener's location in Idaho, annual precipitation may be only 11–27 inches with low humidity during the growing season; hence, occurrences of fungal diseases are limited.

Fungi are divided into two main types: **saprophytic fungi** that feed on decaying organisms and **parasitic fungi** that feed on living organisms. Fungi have chitin in their cell walls, which adds rigidity and structural support. They lack chlorophyll; consequently, they have no ability to manufacture their own food and must obtain their food from another source. The body of a fungus is a branched filamentous structure known as **mycelium**. One single thread is called a hypha (plural = hyphae). Most fungi reproduce through spores. Many fungi overwinter as fruiting structures on dead plant tissue. Fungi damage plants by killing cells and causing stress to the plant. Examples of plant symptoms caused by fungi are cankers, leaf spots, mildew, and root rots.

BACTERIA AND PHYTOPLASMAS

Bacteria (singular = bacterium) and phytoplasmas are single-celled microorganisms. A bacterium does have a cell wall but does not have a nucleus and reproduces by cell division. Phytoplasmas are a type of bacteria that lack distinct cell walls. Bacteria can infect all parts of a plant but require an opening for entry. Bacteria break down plant cell walls so that the contents can be utilized. Some bacteria produce enzymes that break down plant tissue to create soft rots or water-soaked symptoms that appear as wet, dark, and usually sunken and/or translucent areas. Some common bacterial issues found in Idaho include slime flux and several species of *Erwinia* and *Pseudomonas*.

Table 1. Comparison of fungal versus bacterial symptoms.

Symptom Description	Fungal	Bacterial
Water-soaked appearance	No	Yes
Texture	Dry	Papery
Smell	No	Yes
Pattern	Circular, target-like	Irregular, angular
Disintegration	No	Yes
Color changes	Red, yellow, purple halo	No
Structure of pathogen	Mycelia	No

One simple test to determine if an infection is bacterial or fungal is to place the cut portion of an infected plant stem into a clean clear glass of water. After 30–60 seconds, you may notice oozing or cloudiness emanating from the plant part. This bacterial stream is a sign of a bacterial infection. Refer to Table 1 for other ways to help determine if an infection is caused by a fungal or bacterial agent. Keep in mind that there are exceptions to these generalities.

Under favorable conditions, bacteria reproduce very rapidly and can cause serious damage in a short period of time. Bacterial cells can be spread through rain, irrigation, contaminated seed, insects and animals, or by garden implements such as pruning tools. Bacterial diseases are relatively difficult to control with pesticides because there are very few chemicals registered for use that are effective against them. Some commonly encountered bacterial diseases found in Idaho are crown gall of rose, grape, apple, cherry, and other ornamental plants; fire blight of apple and pear; soft rot of potato; ring rot of potato; and aster yellows.

VIRUSES

Viruses are noncellular crystalline particles composed of protein and nucleic acids which can only be seen with an electron micrograph. Because they are obligate parasites that require a host to survive, viruses are transmitted from one plant to another via a vector. Vectors can be humans, animals, insects, parasitic plants, or nematodes. An example of a virus spread by an insect is curly top virus found in tomatoes and beans. This virus is spread by the beet leafhopper. Viruses cause mosaic-like patterns, spots, mottling, crinkling, and other malformations of plant tissues. Because viruses are systemic, infected plants must be destroyed so that they do not serve as a source for vectors and thus prolong the spread of the virus. There are no chemical cures for viral plant infections.

NEMATODES

Nematodes are microscopic roundworms that live in soil or water; they multiply and survive as eggs or cysts. Most nematodes are saprophytes, but some infect living plants and cause diseases. Most plant parasitic nematodes feed on the underground parts of the plants (roots, tubers, bulbs, etc.), causing lesions or root knots. However, a few nematodes also affect the buds, leaves, flowers, and stems of plants. Some nematodes are vectors of plant viruses. Nematodes can be spread through contaminated planting material, manure, soil, water, machinery, and other garden implements. Some examples of plant parasitic nematodes are root knot nematodes of tomatoes, potatoes, and beans; root lesion nematodes of corn and potatoes; stubby root nematode of corn; stem and bulb nematodes of onion; and foliar nematode of chrysanthemum.

PARASITIC PLANTS (FLOWERING)

Several flower-and seed-producing plants live as parasites on other plants (host plants). They derive their nutrition from their host and adversely affect the host plant's growth and yield. Dodder, for example, parasitizes several garden plants. It begins life as a green plant that photosynthesizes. It parasitizes a host plant by inserting tube-like structures called haustoria to draw nutrition from the host's tissues. It then loses its green color and original shape and grows into a tangled mass of orange or yellow vining strands that entwine and lay on top of the host plant. Dodder produces abundant seeds that ensure its propagation and spread. Another example of a parasitic plant is dwarf mistletoe, which is found on conifers.

Diseases Caused By Abiotic Agents

A variety of environmental and cultural factors can cause diseases in plants. Since these diseases occur in the absence of pathogens, they do not spread from a diseased plant to a healthy plant.

HIGH OR LOW TEMPERATURES

When plants or plant parts are exposed to high temperatures for prolonged periods, symptoms of scorching or scalding may develop. Examples include summer leaf scorch and sunscald on fruits. Similarly, low temperatures can damage sensitive tissues or entire plants. Some common examples of low-temperature damage are southwest injury on young tree trunks; frost damage on vegetables plants or fruit tree blossoms and fruit; russet ringing on apple and pear fruits; and winter injury of evergreen foliage.

HIGH OR LOW SOIL MOISTURE

Too much moisture due to excessive watering, poor drainage, ponding, or flooding may cause plants to turn yellow or show stunted growth. Potted indoor plants, for example, may show poor development or root rots if kept overly wet. Seedlings become vulnerable to damping-off fungi under high-moisture conditions. Overwatered deciduous trees like maples can exhibit premature fall coloration in early to midsummer. With some indoor or greenhouse-grown plants, low temperatures and excessive soil moisture can encourage a condition known as **edema**, an abiotic disease. Edema causes small, corky warts that are rust, tan, or green colored to develop on the underside of leaves and stems. At the other end of the spectrum, low moisture or drought conditions can lead to poor plant development, leaf rolling, wilting, desiccation of plant tissues, and plant death.

HIGH OR LOW LIGHT INTENSITY

High light intensity can cause plant foliage to burn, especially in Idaho's higher elevations. Even when the plant tag recommends "full sun," that location may not be advisable for plants grown at elevations above 2,000 feet. Low light conditions, however, for indoor plants or sun-loving plants grown under the canopies of larger plants, can lead to etiolation, lack of foliage, and spindly or lanky growth.

SOIL OXYGEN

One factor limiting landscape plant growth is low soil oxygen. This condition is naturally found in the dense structure of heavy clayey soils, but it is also seen in soils that have been compacted. Soils can be mechanically compacted by constant foot or vehicle traffic or from water droplets pounding on bare soil for years from sprinkler irrigation. A large percentage of plant disorders in landscapes can be attributed to soil compaction. Low oxygen levels in soils also occur when excess water displaces oxygen in soil pore spaces. Symptoms of soil oxygen deficiency may include chlorotic, wilted, or necrotic leaves and/or leaf drop usually starting from the bottom up or from the interior outward.

AIR POLLUTION

Certain chemicals, such as ozone, sulfur dioxide, and nitrogen dioxide are released into the air from factories, power plants, and automobile exhausts. These chemicals can accumulate in the atmosphere in sufficient concentrations to cause plant damage. Ozone damage, for example, often appears in the form of mottling, chlorosis, spots, and bleaching of young leaves. This problem is common in certain regions where high ozone concentrations exist in city smog. In Idaho, however, plant damage due to air pollution is not common.

NUTRIENT DEFICIENCIES

Plants require sixteen elements to thrive. Carbon, hydrogen, and oxygen are derived from the air and water. The remaining thirteen nutrient elements are taken up by plant roots from the soil. These nutrient elements are divided, depending on the amount used by plants, into primary, secondary, and trace nutrients. The primary nutrient elements are nitrogen, phosphorus, and potassium. The secondary nutrient elements are calcium, magnesium, and sulfur. The trace nutrient elements are iron, boron, copper, zinc, manganese, molybdenum, and chlorine. A deficiency or lack of any one of these essential nutrients will result in an abiotic disease symptom. The specific symptom that presents will depend on the plant species and the deficient nutrient. If not corrected, a prolonged chronic deficiency of any essential plant nutrient can affect growth and yield and can lead to plant death. In home gardens, a calcium deficiency causes, in part, blossom-end rot of tomatoes. In southern Idaho landscapes, alkaline soils instigate iron chlorosis, a common malady often seen on the region's trees and shrubs.

MINERAL TOXICITY

The presence of excessive amounts of certain minerals in the soil can lead to mineral toxicity in plants. The extent of injury will depend on the mineral, its concentration, and the plant species. Excessive amounts of sodium salts in the soil, for

example, can lead to sodic-affected soil. These types of soils, frequently called black alkali, are often hydrophobic and highly alkaline (pH 8.3 or higher), which interferes with a plant's absorption of certain nutrient elements. Plants growing in very acidic soils, however, can be injured by metal toxicity from plant-available aluminum, manganese, or iron.

UNFAVORABLE SOIL pH

Although many plants can grow in a rather wide range of soil pH, plants grown in an unfavorable pH will usually show poor growth and a mineral deficiency or toxicity symptom. For example, iron deficiency symptoms are commonly seen in southern Idaho where the soil pH is mostly alkaline. Under high soil pH–conditions like these, iron in the soil becomes unavailable to plants, thus inducing interveinal chlorosis. If the malady remains uncorrected for a prolonged period, the plant may die. Figure 2 shows the availability of plant nutrients relative to soil pH.

IMPROPER CULTURAL PRACTICES

Any cultural practice performed incorrectly or at the wrong time can result in plant damage. Plant injury can result from numerous erroneous practices, like applying improper amounts of fertilizer, pesticides, or even water. Insecticides applied on a hot sunny day can burn the leaves of some plants. Root damage can result from deep cultivation and from being twisted in a pot-bound condition. African violet leaves, for example, when sprinkled with very cold water, can develop leaf damage in ringed patterns that resemble some virus symptoms.

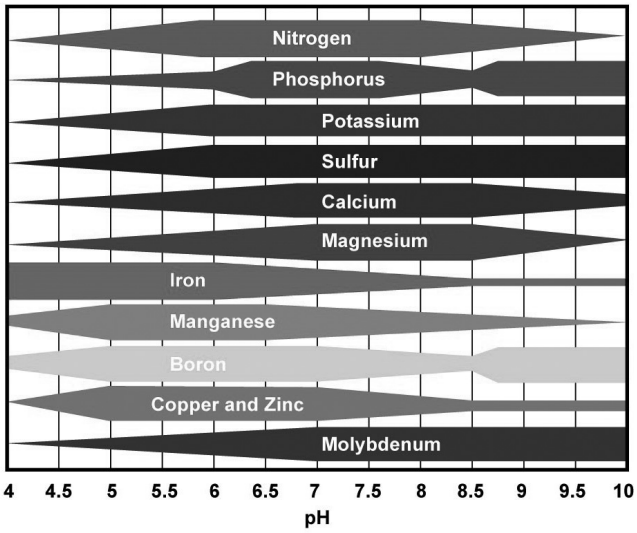

Figure 2. pH effects on nutrient availability. From "Pioneer Talks Crops" 2016.

Further Reading and Resources

BOOKS

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WEBSITES

Oregon State University Extension Service, "Plant Diseases," **https://extension.oregonstate.edu/pests-weeds-diseases/plant-diseases.**

University of Idaho Extension, **https://www.uidaho.edu/extension.**

Utah State University Extension, "Yard and Garden," **https://extension.usu.edu/yardandgarden/index.**

Washington State University Extension, Master Gardener Program, "Gardening in Washington State" (blog), **http://gardening.wsu.edu/.**

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Groundwater — To protect groundwater, when there is a choice of pesticides, the applicator should use the product least likely to leach.

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