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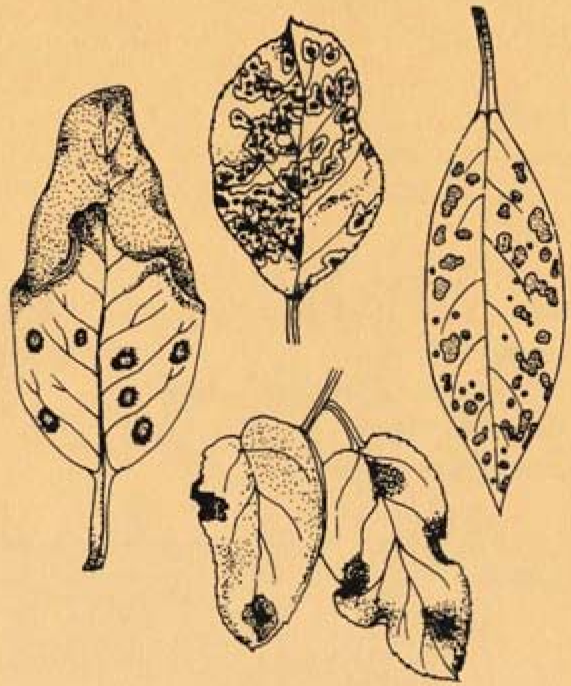
Plant Diseases



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Plant Diseases

What is a Plant Disease?

Many attempts have been made to define what a plant disease is, but all definitions have to be qualified to some extent. A plant disease is not a tangible object as is an insect or a weed. It does not have absolute, fixed dimensions but varies in its appearance in a great many ways.

Broadly defined, a plant disease is any condition in which a plant is different in some way from a normal (i.e., healthy) plant in either structure or function. The diseased plant may be shorter, have more branches or fewer leaves than normal—it differs in structure. It may wilt and die prematurely, or not produce flowers or fruit—it differs in function.

Plant diseases affect all plants to some extent. They generally cause minor damage, but when all of the required interacting and contributing factors are present, they can be catastrophic. Famines caused by blights and mildews are recorded from biblical times. Late blight of potatoes led to the great famine in Ireland in the mid-1800s, and chestnut blight eliminated the American chestnut as a commercial tree in the United States in a few decades. In commercial crops, even minor losses to disease can be serious.

The science that deals with the nature and control of plant diseases is called plant pathology. Plant pathology also involves other sciences, such as mycology, bacteriology, plant physiology, nematology, virology, etc.

Although disease is sometimes referred to as a condition, it is not a static, constant condition but an ever-changing one. Disease is a series of changes in the plant caused by some agent. It is physiological, affecting all or part of the functions of the plant. It is abnormal to the plant and not the normal termination of some particular function (for example, normal dropping of leaves). Diseases are always harmful to the plant in the long run even though there have been attempts to benefit from certain diseases. Examples are the virus-induced color break in tulip and the virus-caused shortening of internodes of cherries.

The causal agent of a disease has a prolonged influence as compared to the sudden, instantaneous effect of an injury. It is necessary to distinguish between disease and injury and not confuse normal life processes, such as maturation and falling of leaves, with diseases. One common confusion is that causal agent and disease are the same. Some believe that a fungus, bacterium or nematode is a disease, but it is not. It is a causal agent of a disease.

The agent causing a plant disease is called a plant pathogen whether the agent is living (parasitic) or nonliving (nonparasitic), but usually the term pathogen is restricted to the former.

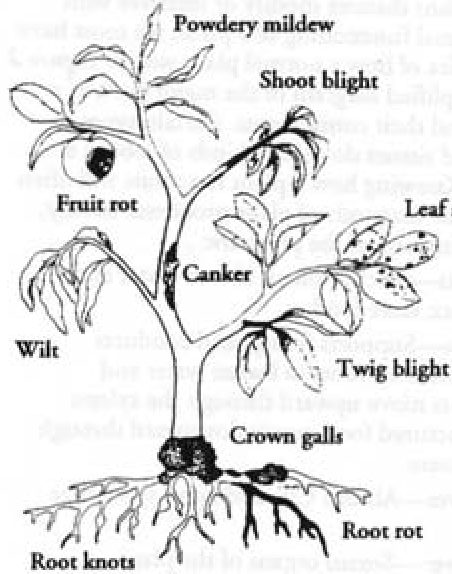

Figure 1
Disease Symptoms

How are Diseases Classified?

Plant diseases can be classified or categorized in a number of ways. One of the earliest and most popular ways is to separate diseases on the basis of the crop affected. Thus, there are diseases of tree fruits, small fruits, vegetables, forest trees, cereals and grasses, ornamentals, etc. Another system is to categorize diseases on the basis of the causal agent. In this system we have fungus diseases, bacterial diseases, virus diseases, nematode diseases, nutrient deficiencies, etc. Other ways diseases can be classified are on the plant part affected, e.g., root diseases, stem diseases or leaf diseases; or on the symptom or symptoms produced, such as blights, mildews, decays or mosaics.

The name applied to a given plant disease generally includes three significant pieces of information: (1) the plant attacked, (2) the plant part affected and (3) how it is affected. For example, peach leaf curl, alfalfa leaf spot, potato leaf roll and black stem rust of wheat, are names that help to develop a mental image of how a disease affects a plant. *Figure 1* illustrates some of the ways that the name of a disease is often derived from the way the plant is affected.

How Do Plants Work?

Since plant diseases modify or interfere with the normal functioning of a plant, we must have some idea of how a normal plant works. *Figure 2* is a simplified diagram of the major parts of a plant and their components. Certain types of cells and tissues do certain kinds of jobs in a plant. Knowing how a plant functions will often aid in the diagnosis of plant problems. Briefly, the main parts of the plant are:

Roots—Anchor plant; absorb water and nutrients; store food.

Stem—Supports foliage and conducts nutrients from roots to leaves; water and nutrients move upward through the xylem; manufactured food moves downward through the phloem.

Leaves—Absorb CO_2 and light; synthesize sugar.

Flower—Sexual organs of the plant.

Fruit—Reproduce the plant.

For a plant to grow and develop normally, mineral nutrients must be obtained from the soil. These nutrients are dissolved in the soil water and absorbed by root hairs which are simply extensions of the epidermal cells. The dissolved nutrients then diffuse inward to the xylem cells where they can move upward in the plant.

Secondary roots originate from the pericycle which is meristematic tissue like the cambium of the stem. These secondary roots force their way through the cortex and cause small natural wounds through which some disease agents can enter.

Nutrients move up the plant in the xylem of the stem. The stem serves mainly a supporting role to elevate leaves from the ground where they are effectively exposed to sunlight. In woody plants, there is a layer of meristematic cells called the cambium which gives rise to xylem, or water-conducting tissue, on the inside and to phloem, or food-conducting tissue, on the outside. Bark develops from the outer cells of the phloem.

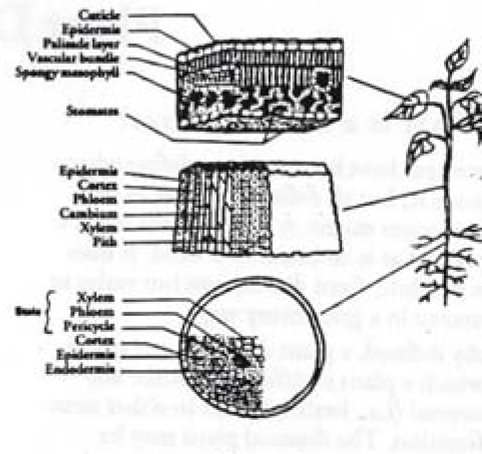

Figure 2
Parts of the Plant

The leaf is the food factor of the plant. The nutrients from the soil move upward in the xylem and into the leaf veins. These veins terminate at the leaf margin as special structures called hydathodes. The nutrients diffuse out of the xylem in the veins into the palisade and mesophyll cells. These cells contain the green pigment called chlorophyll. The plant surface is covered with a one-cell-thick layer called the epidermis. On the leaves and some stems, the epidermis is covered by a waxy cuticle. Also, on the leaf surface, especially on the underside, are natural openings called stomata, through which gases are exchanged with the atmosphere. Carbon dioxide in the air moves through the stomata into the openings in the spongy mesophyll and diffuses into these cells. Here, carbon dioxide and water, in the presence of light, are converted into the simple sugar, glucose, with oxygen as a by-product. This process is called photosynthesis.

The glucose diffuses through the cells into the phloem of the leaf vein. From here it is transported to various parts of the plant to be used for growth and energy, or it is stored as glucose or one of many other compounds. The oxygen diffuses back into the chambers of the mesophyll and out into the atmosphere.

Seven major plant functions can be identified that are affected by disease. *Table 1* lists these functions and some of the types of diseases affecting them.

In considering how diseases affect plants and how control measures are brought into play, it is necessary to have some idea of how plants and their parts are organized. *Figure 3* illustrates the various levels of organization of plants. Diseases are usually described in terms of how they affect cells, tissues or organs. Cells are killed, tissues are over- or underdeveloped, and leaves and other organs are blighted, curled, chlorotic, and so on.

The basic unit in the plant is the cell. Cells of a given type are united to form a tissue which is an aggregate of cells which perform a similar function, such as xylem, phloem or cambium. Different tissues combine to form organs, which are usually recognizable parts of the plant. In an organ such as the leaf, the tissues contained are epidermis, phloem, xylem, mesophyll, etc. Finally, the various organs (leaves, stems, roots, blossoms, fruit) make up the individual plant.

To control a plant disease, consideration may be given to the individual plant, especially if it is an ornamental tree or shrub, but more often a population of plants such as a field or an orchard is treated.

A population is an aggregate of like individuals. In some cases, as in forests or rangelands, plant communities are treated in which there are combinations of different plants in a natural association even though the target of the control measure is a single plant species. The highest level of plant organization is the biome. This includes all of the plant life (and many include the animals) in a large geographic area. For example, the western coniferous forests comprise a biome. It is rare when the biome is considered in the control of a plant disease.

What Causes Plant Diseases?

The definition of plant disease is very broad and includes all possible causes, as long as the four criteria previously listed are satisfied, i.e., a process, physiological, abnormal and harmful. The causes can include a wide range of nonliving agencies, such as toxic chemicals or adverse weather conditions as well as a variety of living organisms.

For example, insects that produce galls on plant parts are true causal agents of diseases. Insects, however, are generally omitted from the field of plant pathology and covered in the science of entomology.

Plant diseases can be divided into two broad groups based on their cause.

Nonparasitic diseases are induced by some nonliving agency such as nutrient deficiency,

Table 1
Plant Function Affected by Disease

Plant Function Affected	*Diseases Involved*
Food storage—storage organs with high sugar and starch content	Soft rots, seed decays
Mobilization—conversion of starch to sugar and movement to growing points	Damping off, seedling blights
Root growth—roots develop and absorb water and nutrients from soil	Root rots, nematodes
Shoot growth—development of stems, branches, leaves	Galls, cankers, blights
Water transfer—movement of water and nutrients from roots to leaves	Vascular wilts
Photosynthesis—manufacture of food in leaves	Leaf blights, mildews, mosaics
Translocation—movement of food manufactured in leaves to growing points and storage organs	Stem rusts, yellows viruses

extreme cold or heat, chemicals (air pollutants, pesticides, excess fertilizer, etc.), mechanical damage, lack of water, soil compaction and many others. These diseases cannot be transmitted to healthy plants and their control depends almost entirely on correcting the condition (usually something in the environment).

Parasitic diseases are caused by living organisms which derive their food by growing in close association with plants. The most common causes of parasitic diseases are fungi, bacteria, viruses, viroids, mycoplasmas and nematodes. A few seed-producing plants, such as the mistletoes and dodder, can also cause plant diseases.

Although the definition of disease may include all plant difficulties regardless of the cause, most plant pathologists are concerned with those diseases caused by living agents, especially fungi, bacteria, viruses or nematodes. Organisms that obtain their food from other organisms may be classed as saprophytes or parasites. **Saprophytes** are organisms that derive their food from dead organisms. **Parasites** derive their food from living organisms.

The degree to which organisms depend on live or dead tissue for nourishment affects their ability to survive and cause plant diseases, and the ease with which they are controlled.

Organisms that can live only on dead organisms (or substrate) are obligate saprophytes and do not cause plant diseases. Most are beneficial to people. Many plant pathogens live primarily as parasites on live tissue but under some circumstances they have the ability (or faculty) to develop on dead tissue. They are called facultative saprophytes. The apple scab fungus is a typical example.

Another large category of plant pathogens live mainly as saprophytes but have the faculty to develop on live tissue in some cases. *Rhizoctonia solani* is a good example of a facultative parasite. This group of organisms can survive for long periods of time without a live host plant and, therefore, is more difficult to control than an organism more dependent on live tissue.

Organisms that can live, or at least can only complete their developmental cycle, on living tissue are called obligate parasites. They are obliged to live on this type of substrate. All obligate parasites, by their nature, are plant pathogens. This group includes all of the rust and smut fungi, as well as the downy and powdery mildews, all viruses and some seed-producing plants such as the dodders. ***Figure 4*** illustrates the interrelationships of these categories.

The concept of how plant pathogens act on their substrate (food material) to cause a disease is sometimes difficult to describe. The development of disease is an undesirable side effect of the process of the pathogen deriving nutrients for its growth and development. It may help to compare the way plant pathogens get their nourishment with the way animals do.

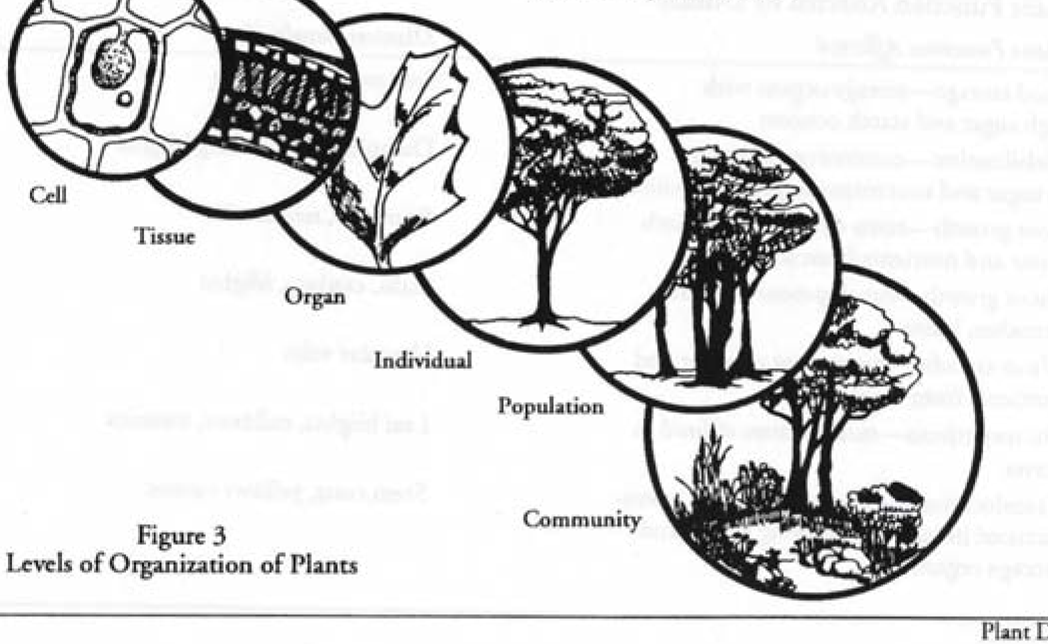

Figure 3
Levels of Organization of Plants

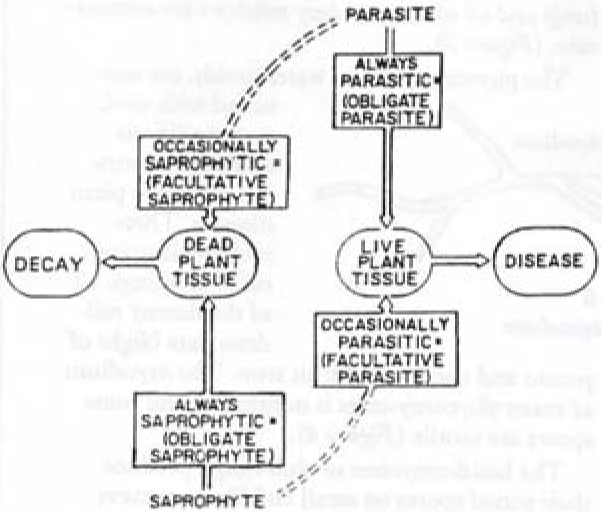

Figure 4
Categories of Plant Diseases

Most animals ingest their food—take it into a central receptacle. Here enzymes act to break it down, and nutrients are absorbed by the surrounding tissues of the animal. Waste products pass from the tissues into the central cavity and are discharged into the air, water or soil surrounding the animal. In this way the waste products are scattered or diluted and eventually decompose and are recycled. This is illustrated in *Figure 5A*.

This procedure is almost reversed with plant disease agents because, instead of engulfing their food material, they are surrounded by it, as shown in *Figure 5B*. In the process of extracting nutrients, the organism excretes enzymes into the food substrate, and the material is dissolved to some extent. Nutrients are absorbed by the organism and used for growth and energy. Waste products are excreted into the surrounding substrate where, rather than being diluted, they may be concentrated. These wastes may include hormones, enzymes and toxic substances that bring about the death or malformation of cells and tissues, thereby producing the symptoms of disease.

The fungi probably comprise the largest single group of causal agents of plant disease. Fungi are plants that lack the green coloring (chlorophyll) found in most seed-producing plants and, therefore, cannot manufacture their own food. There are approximately 100,000 species of many types and shapes. Only about 8,000 species cause plant diseases. Most are microscopic, but some, such as the mushrooms, are quite large.

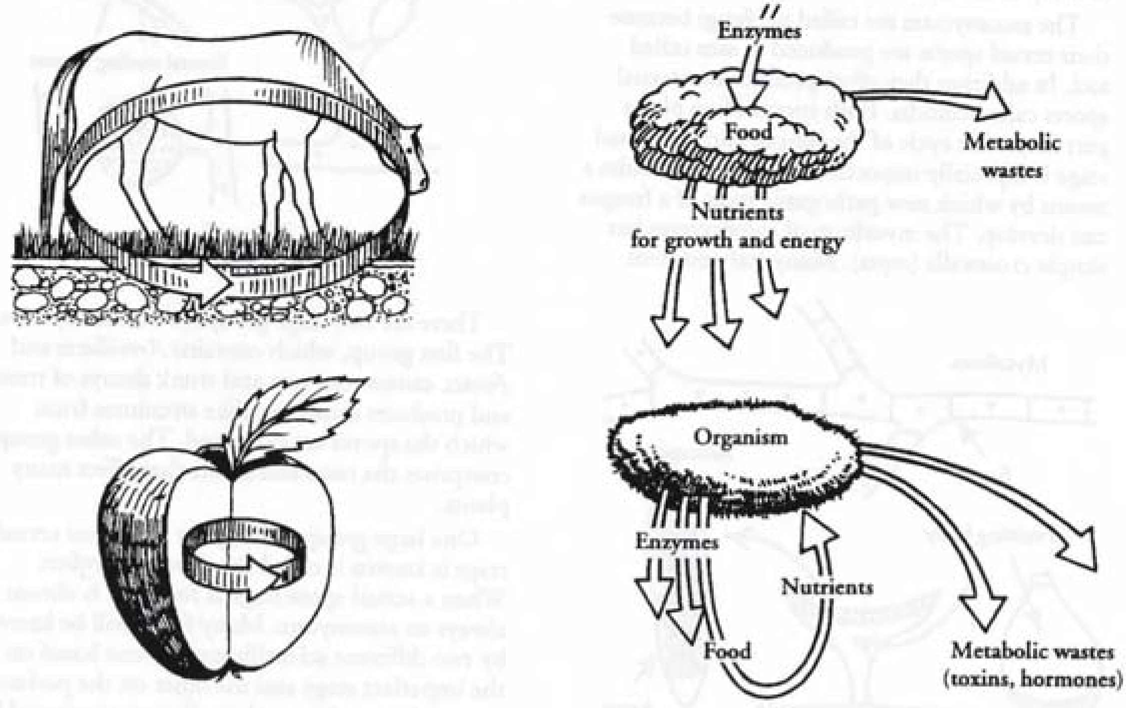

Figure 5
Comparing Ways of Getting Nourishment

Most fungi reproduce by spores, which vary greatly in size and shape. When spores germinate, they usually give rise to threadlike filaments known as hyphae. Hyphae are the growing structures of fungi excreting enzymes, absorbing nutrients and releasing chemical materials that induce diseases. In mass, the hyphae are called mycelium (*Figure 6*).

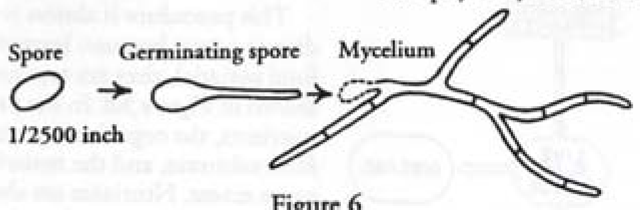

Figure 6
How Fungi Reproduce

Major Groups of Fungi

The fungi are divided into four groups on the basis of their vegetative growth (mycelium) and how their spores are produced. The relationship of a fifth group, the myxomycetes, to the other fungi is questioned by some scientists and, at most, they are distant relatives. Only one disease of importance in Connecticut is caused by a myxomycete. This is club root of cabbage and related crops. Fungi are classified mainly on the basis of microscopic features and are difficult to identify in the field.

The ascomycetes are called sac fungi because their sexual spores are produced in sacs called asci. In addition they often produce nonsexual spores called conidia. Both spores often play a part in the life cycle of the fungus and the sexual stage is especially important, because it provides a means by which new pathogenic races of a fungus can develop. The mycelium of ascomycetes has simple crosswalls (septa). Many leaf and stem fungi and all of the powdery mildews are ascomycete. (*Figure 7*).

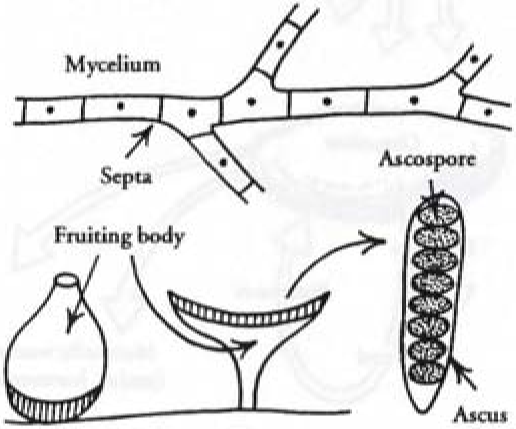

Figure 7
Ascomyceles

The phycomycetes, or water molds, are associated with cool, wet conditions and cause a number of serious plant diseases. These include damping-off of seedlings, all of the downy mildews, late blight of potato and collar rot of fruit trees. The mycelium of many phycomy-cetes is nonseptate and some spores are motile (*Figure 8*).

The basidiomycetes or club fungi, produce their sexual spores on small clublike structures called basidia. Many basidiomycetes have septate mycelium that also bear clamp connections. As with the ascomycetes, the sexual spores of the basidiomycetes are important in the development of new races of pathogenic fungi (*Figure 9*).

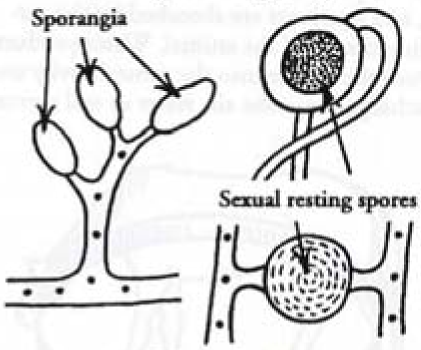

Figure 8
Phycomycetes

There are two large groups of basidiomycetes. The first group, which contains *Armillaria* and *Fomes*, causes root rots and trunk decays of trees and produces mushroomlike structures from which the spores are produced. The other group comprises the rusts and smuts that affect many plants.

One large group of fungi for which no sexual stage is known is called the *Fungi Imperfecti*. When a sexual spore stage is found, it is almost always an ascomycete. Many fungi will be known by two different scientific names, one based on the imperfect stage and the other on the perfect or sexual stage. Many plant diseases are caused by imperfect fungi (*Figure 10*).

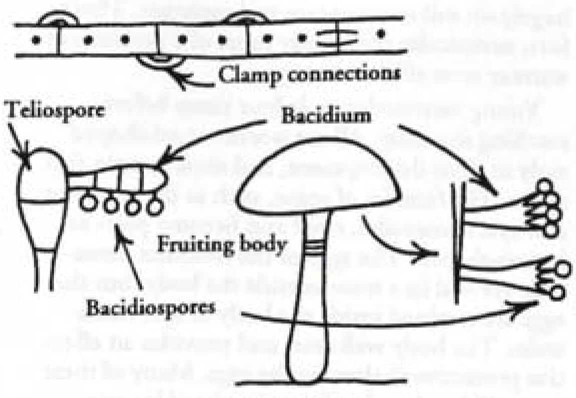

Figure 9
Basidiomycetes

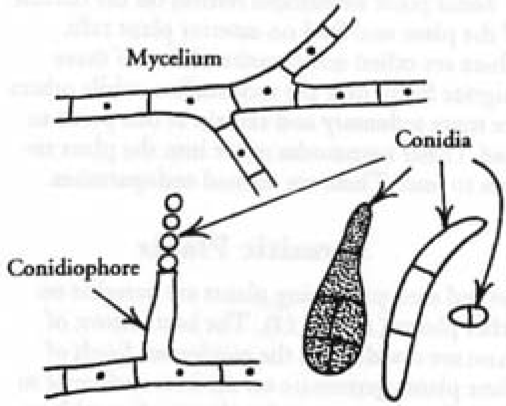

Figure 10
Fungi imperfecti

Bacteria

Bacteria (*Figure 11*) are very small, one-celled organisms that reproduce by simple fission. They divide into two equal parts, each of which becomes a fully developed bacterium. This type of reproduction may lead to a rapid buildup of a population under ideal conditions. For example, if a bacterium divides every 30 minutes—a generation time not especially short for some bacteria—a single cell could produce 281,474,956,710,656 offspring in 24 hours.

Because of their limited size and development, bacteria are unable to penetrate the protective surface of the plant and must enter through natural openings, such as stomates, nectaries or hydothodes, or through wounds.

About 200 species of bacteria cause plant diseases. Several species of *Pseudomonas* and *Xanthomonas* cause leaf spots and shoot blights of various horticultural crops. *Agrobacterium tumefaciens* causes crown gall of roses, fruit trees and other woody plants. *Erwinia* species cause soft rots of fruits and vegetables, and one species causes fire blight, a serious disease of apples and pears.

One organism, *Streptomyces scabies*, is classed as a higher bacterium and is the only one of this group to cause a serious plant disease, common scab of potato.

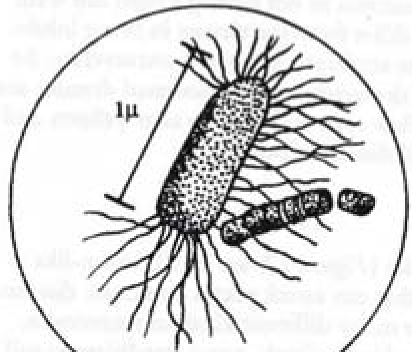

Figure 11
Typical Bacteria

Viruses and Virus-like Organisms

Viruses that cause plant diseases number only about 300 species but these cause some of our most destructive plant diseases. Viruses are so small that they cannot be seen with the ordinary microscope and are generally detected and studied by their effects on selected indicator plants. Viruses are considered by most scientists to be living organisms while a few think of them only as highly organized molecules. Structurally, they can be either rods or spheres. Both forms consist of a central core of nucleic acid and an outer coating of protein material. The infective portion of the virus particle is the nucleic acid core with the protein shell serving as a protective cover.

Viruses can reproduce only in living cells and must be moved by some means from plant to plant. Many viruses are transmitted by sucking insects, such as aphids and leafhoppers. Some viruses are easily transmitted mechanically by rubbing leaves of healthy plants with juice from diseased plants or by pruning tools. A few viruses are transmitted in pollen. Big vein of lettuce virus is transmitted by a soil-borne fungus, and a few viruses are transmitted by nematodes. Viruses cause very serious problems in plants that are propagated by bulbs, roots and cuttings, because the virus is easily carried in the propagation material.

In recent years, several diseases previously thought to be caused by viruses have been shown to be caused by very small bacteria-like organisms called mycoplasms. These organisms differ from the true bacteria in not having a rigid cell wall, and they differ from the viruses in being inhibited by the antibiotic substance tetracycline. So far, all of the mycoplasma-associated diseases are of the yellow type and include aster yellows and western-X disease of peaches.

Nematodes

Nematodes (*Figure 12*) are small, worm-like animals that can attack plants and cause diseases. There are many different kinds of nematodes, some attacking animals, some free-living in soil and water. About 1,000 species are known to attack plants. While nematodes vary greatly in size, those causing plant diseases are relatively small, barely visible to the unaided eye. All plant parasitic nematodes possess a hard, piercing spear or stylet by which they puncture plant cells and feed on the cell contents. In the process of feeding, the nematodes inject toxic material into the plant and cause symptoms of disease.

All plant nematodes reproduce by laying eggs. The number of eggs produced by one female and the number of generations in a season depend largely on soil temperature and moisture. Therefore, nematodes are usually more of a problem in warmer areas of the country.

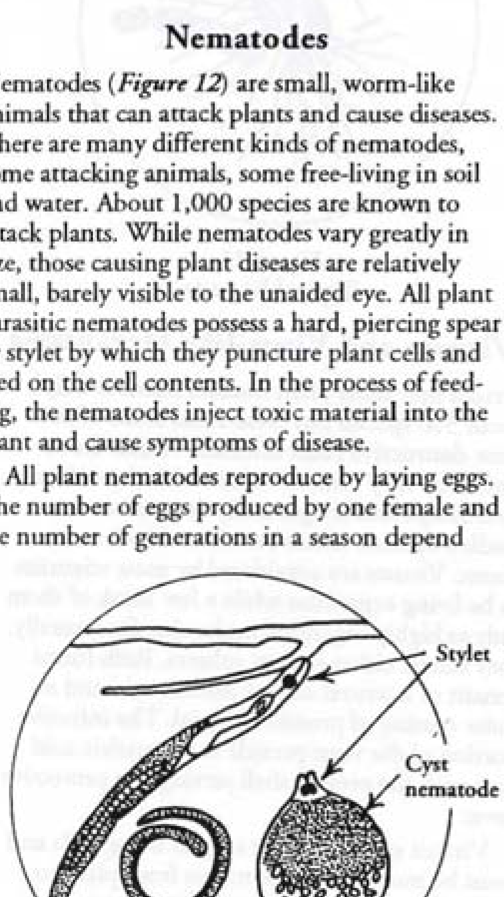

Figure 12
Nematodes

Young nematodes molt four times before reaching maturity. All are worm- or eel-shaped early in their development, and most remain that shape. The females of some, such as the rootknot and cyst nematodes, swell and become pear- or lemon-shaped. The eggs of the rootknot nematode are laid in a mass outside the body, but the eggs are retained inside the body of cyst nematodes. The body wall dries and provides an effective protective shelter for the eggs. Many of these eggs will hatch only when stimulated by excretions from roots or susceptible plants.

Some plant nematodes remain on the outside of the plant and feed on exterior plant cells. These are called ectoparasites. Most of these migrate freely over the root surface, while others are more sedentary and remain at one point to feed. Other nematodes move into the plant tissues to feed. These are termed endoparasites.

Parasitic Plants

Several seed-producing plants are parasitic on other plants (*Figure 13*). The best known of these are dodder and the mistletoes. Seeds of these plants germinate on the host surface or in the soil and penetrate the plant surface with an infection peg. The vascular or conductive system of the parasite fuses with the vascular elements of the host and the parasite is able to siphon off for its own use food material manufactured by the host.

Dodder is the only serious seed-producing parasite on plants in Connecticut. It is treated as a weed rather than a plant pathogen.

How are Diseases Recognized?

When a pathogen acts upon the host cells or tissues, changes begin to take place. Some of these are submicroscopic and not easily observed. As the changes in the host plant become more obvious, visible symptoms become apparent. Symptoms of disease are wilted foliage, death of cells and tissue, enlarged shoots or stems, yellow foliage, etc.

Symptoms by themselves may not allow an accurate diagnosis of a plant disease because several distinctly different causal agents may pro-

Figure 13
Parasitic Plants

duce identical symptoms. However, symptoms used with other evidence, plus experience, can often produce a satisfactory diagnosis.

The type of symptoms produced often indicates not only how the plant is affected but also may suggest the type of pathogen involved. There are three general types of symptoms. **Necrosis** involves the death of cells, tissue or organs and may result in specific symptoms such as blights, leaf spots, cankers and the like. Necrotic symptoms are probably those most readily seen. **Hypotrophy** is the underdevelopment of cells, tissues, or organs which produces such specific symptoms as stunting of a plant or chlorosis, which is the failure of chlorophyll to develop. This category of symptoms is often the least easily recognized. **Hypertrophy** is the overdevelopment of cells, tissues or organs and often is quite conspicuous, especially when the specific symptom is a large gall or witches'-broom.

More than one type of symptom may comprise the symptom picture (or syndrome) of a disease. The primary symptom may be hypotrophy but a secondary symptom may be necrosis.

The pathogen frequently produces structures as part of its growth and these are called signs of the disease. They are more specific than symptoms and are more valuable diagnostic aids, provided they can be correctly identified. The bacterial ooze associated with fire blight and cucumber wilt and the sclerotia of the white cottony mold (Sclerotinia) of beans are signs of disease. Unfortunately, the detection and identification of signs often requires specialized knowledge and techniques. This is not always available in the field, and specimens must be taken or sent to a diagnostic laboratory for further examination.

Control measures are directed at the causal agent rather than the diseased plant, therefore, it is important that the cause by correctly identified. Symptoms and signs alone are not always enough for such a diagnosis and additional, sometimes complex, tests must be made.

How to Diagnose Plant Diseases

When something goes wrong with a plant, whether it's in a field, a forest or a flower pot, someone wants to know what is the matter and how the problem can be corrected. In most cases, it is too late to control a disease on a plant once the disease appears, but control measures may be started to keep the disease from spreading to other plants. Even if control measures are not available, there is a sense of well-being in simply knowing what the problem is and what its future development might be.

Before control measures can be applied, the cause of the problem must be determined. It would be useless to apply a fungicide to a plant if the problem is caused by an insect or nematode.

Accurate diagnosis of a plant disease usually requires correct identification of the causal agent.

Similarities of symptoms produced on the same plant by completely different agents frequently make the use of symptoms alone inadequate. Yet, the specialized techniques and knowledge required to isolate and identify many disease agents force us to rely largely on symptoms.

Most diagnosis of plant diseases, and especially diagnosis in the field, must be based on reactions of the plant rather than on the presence and identification of the causal organism, because of the microscopic nature of the organisms that cause plant disease.

Despite the limitations of symptoms for the diagnosis of many plant diseases, certain categories of symptoms are definite clues to certain types of plant diseases. (It should be noted that there are always exceptions.)

Steps to Follow

In the diagnosis of a suspected plant disease there is a logical and convenient series of steps to follow.

1. Identify the plant affected. If possible, include the scientific name as well as the common name because the same common name may have been used for several distinctly different plant species. The common name cedar is an example of the same common name being applied to several genera of plants. Eastern red cedar is *Juniperus*, western red cedar is *Thuja*, Port Orford cedar is *Chamaecyparis*, incense cedar is *Libocedrus* and Atlas cedar is *Cedrus*. Here are five different genera of plants, all of which carry the common name of cedar.

   Many times it is useful to know the variety of the plant in question because some varieties are resistant to certain diseases. For example, some varieties of tomatoes are resistant to certain strains of the soil-borne wilt diseases caused by *Fusarium* and *Verticillium*. Therefore, it makes good sense for people with small gardens to plant only wilt resistant varieties. Rutgers and Big Boy, though popular varieties, are susceptible to both diseases, whereas Better Boy and Rutgers VF are resistant. Some of the tomato varieties are resistant to only one of the wilt diseases. This is noted on the seed packet.

2. Carefully examine the diseased area, whether a bench in a greenhouse or a large field. Note how the diseased plants are distributed over the affected area. Are they uniformly distributed or localized in certain spots? Definite patterns of distribution, such as at the edges or the center of a greenhouse bench, or along roadways, fences, corners or low spots in a field, frequently indicate climatic, soil factors, or toxic chemicals but do not necessarily exclude parasitic causes. If an examination is not possible, ask questions.

   Is only one type of plant affected or are many unrelated plants involved? If more than one type of plant is affected, parasitic diseases are probably not involved. Rather, one should suspect climate or chemicals.

   Are all of the plants in a field or planting affected? Parasitic diseases progress with time and rarely afflict 100 percent of the host plants at one time. Diseases are usually at a relatively low level (less than 10 percent). When a problem affects all, or almost all, of a plant population, the cause of the problem is likely a soil condition (deficiency or toxicity), result of adverse climate (drought, frost, hail, etc.), toxic chemical (air polluntant, herbicides, excess fertilizer) or unfavorable cultural practices.

   How did the disease develop in the affected area? Did it appear overnight? If so, suspect a climatic factor such as frost or the application of a toxic chemical. However, if the condition started at one point and spread slowly in extent and severity, a parasitic disease is probably responsible.

   Obtain a record of environmental conditions that preceded the appearance of the disease. Check for short periods of below-freezing temperature or prolonged drought periods. Did hail or lightning occur? Air pollutants might have been involved. If so, information on air inversions and prevailing winds will be helpful in explaining the pattern of damage.

   Has there been any treatment that could have resulted in plant injury? Some types of herbicides can distort foliage on plants some distance away from the site of application because their root systems have intercepted the downward movement of the herbicide. Excessive amounts of fertilizers can cause similar damage to plants, especially if the soil is dry.

3. Determine the appearance of a typical diseased plant. Do not base the symptom picture

entirely on the early stages of disease nor on a plant that has deteriorated to a point that secondary organisms have obscured the primary cause of the problem. Ideally, the symptom picture should be a composite based on the progression of symptoms from earliest to latest.

Always compare the typical diseased plant with a healthy or normal plant, since normal plant parts are sometimes mistakenly assumed to be evidence of disease. Examples are the brown, spore-producing bodies on the lower surface of leaves of ferns. These are the normal propagative organs of ferns. Also in this category are the small, brown, clublike tips that develop on arborvitae foliage in early spring. These are the male flowers, not deformed shoots. Small galls on the roots of legumes, such as beans and peas, are most likley nitrogen-fixing nodules essential to normal development and are not rootknot nematodes.

The leaves of some plants, such as sycamore, or some species of rhododendron are covered by a conspicuous fuzz. This is sometimes thought to be evidence of disease, but it is a normal part of the leaf. Varieties of some plants i.e., ivy and euonymus, have variegated foliage that may resemble certain mosaic diseases. These examples illustrate the importance of knowing what the normal plant is before attributing some characteristic to disease.

Premature dropping of needles by conifers frequently causes alarm. Conifers normally retain their needles for two to six years and lose the oldest gradually during each growing season. This normal needle drop is usually not noticed. However, prolonged drought or other factors may cause the tree as a whole to take on a yellow color for a short period and may accelerate needle loss. If the factors involved are not understood, this often causes alarm. The needles that drop or turn yellow are actually the oldest needles on the tree, and their dropping is a defense mechanism which results in reduced water loss from the foliage as a whole.

Note the portion or parts of the plant affected. Is it the roots, leaves, stem, flowers or fruit? Is the entire plant involved?

4. Determine the primary symptoms of the condition under study. Symptoms are expressions of the affected plant that indicate something abnormal and are grouped into three general classes.

Underdevelopment of tissues or organs. Examples are stunting of plants resulting from shortened internodes, failure of chlorophyll or other pigments to develop, failure of flowers to develop or misshapen leaves.

Overdevelopment of tissues or organs. Galls and witches'-brooms are good examples of overdevelopment. The profuse flowering of plants suffering from root diseases is another type of overdevelopment.

Necrosis or death of plant parts. This is the most noticeable of the three types of symptoms. Examples are shoot and leaf blights, leaf spots and fruit rots.

Diagnosis of a disease up to this point requires no special equipment other than a hand lens and knife.

5. Disease signs provide clues. Signs of disease are structures produced by the causal agent of that disease. Since signs are more specific than symptoms, they are much more useful in the accurate diagnosis of a disease. For example, distortion of leaves and shoots usually points to damage from a hormone-type herbicide such as 2,4-D, but similar symptoms can be produced by frost, viruses, some fungi, insects and nutrient deficiencies.

Discovery and identification of signs of disease may require special equipment and knowledge, but many signs can be found with only a hand lens and a knife.

The presence of spore-producing bodies on cankers; mycelial mats of the shoestring fungus, *Armillaria mellea*; bacterial ooze from a wilted cucumber stem; masses of rust spores; and the gray-white mycelium of powdery mildew are all signs of different diseases.

6. Isolate and identify causal agent. Sometimes neither symptoms nor signs are specific or characteristic enough to pin down the cause of a disease. Then additional specialized techniques are required to isolate and identify the causal agent.

Isolation of bacteria and fungi usually requires that small pieces of diseased tissue be placed on a nutrient medium. The organisms growing out of the tissue are then isolated in pure culture. However, many disease-producing organisms (especially those called obligate parasites) cannot grow on artificial media, but can grow only on living tissue. Obligate parasites require other special methods for their isolation.

Invasion of diseased tissue by saprophytic organisms often makes isolation of the primary cause of disease difficult, if not impossible. Because of their ability to grow rapidly and utilize the artificial substrate more efficiently than can many disease organisms, these saprophytes may rapidly overgrow and crowd out the primary pathogen on synthetic media. Experienced plant pathologists overcome this difficulty by isolating from the margins of the diseased tissue and by employing selective media which favor growth of the pathogen.

Assuming that isolation has been successful and there is reasonable certainty the primary cause of the disease is isolated, there is still the problem of identifying the organism. There are 20,000 to 40,000 species of bacteria and fungi, as well as many viruses and even higher plants that cause disease. The characteristics upon which their identification is based are often complex and not easy to determine. Frequently only a specialist who deals with a very small group of organisms can correctly identify the disease organism in question.

Viruses are especially difficult to identify because their submicroscopic size makes them too small to be seen except by an electron microscope. Their identification usually is based on the reactions (i.e., symptoms) of selected hosts called indicator plants and on their physical and chemical properties. The determination of all characters requires special knowledge and techniques.

The primary interest of the grower is usually to control a given disease. Only after positively identifying the disease can the best control measures be employed.

After all of the previously mentioned information has been successfully collected, the available literature should be consulted to determine what is already known about this disease. In some cases, little or no information may be available on the particular disease in question. In such instances, control efforts are based on recommendations made to control similar diseases. Diseases new to a region have often been studied in other parts of the world and sufficient information on which to base control measures may be found in the reports of these studies.

How Do Diseases Develop?

The development of any parasitic disease is critically dependent on the life cycle of the pathogen. The life cycles of all disease organisms are greatly influenced by environmental conditions affecting both the host and the pathogen. Temperature and moisture are probably the most important factors that affect the severity of plant diseases. They not only influence the activities of the disease organism, but also affect the ease with which a plant becomes diseased and the way the disease develops.

The development of a pathogenic organism to initiate a disease follows the same general steps whether the pathogen is a fungus, bacterium, virus, nematode or seed-plant, or whether it is an obligate or facultative parasite or saprophyte. ***Figure 14*** gives a typical disease cycle.

As an example, start with a diseased leaf that has carried a fungus over the winter. In the spring, as the temperature becomes warmer, this fungus will begin to develop and form spores. This mass of spores is called inoculum.

As the fungus spores mature, they are discharged into the atmosphere where they are distributed by wind or water. Some eventually land on healthy leaves of a susceptible host plant. This step of moving inoculum to the infection court, or point where infection can occur, is called inoculation. Until the inoculum begins to grow, it is fairly resistant to the action of toxic chemicals or other adverse conditions. Once the inoculum arrives at the infection court, several things may happen to it. Conditions may be extremely adverse and the inoculum is killed, or it may be washed off by rain. It may start to develop and be affected by adverse conditions.

If environmental conditions are favorable, the inoculum will begin to develop; spores germinate, eggs hatch and bacterial cells multiply. It is during this incubation stage that the inoculum is most vulnerable to chemicals or other unfavorable conditions. It should be mentioned that the term incubation is used here to indicate the development of the pathogen, but in plant pathol-

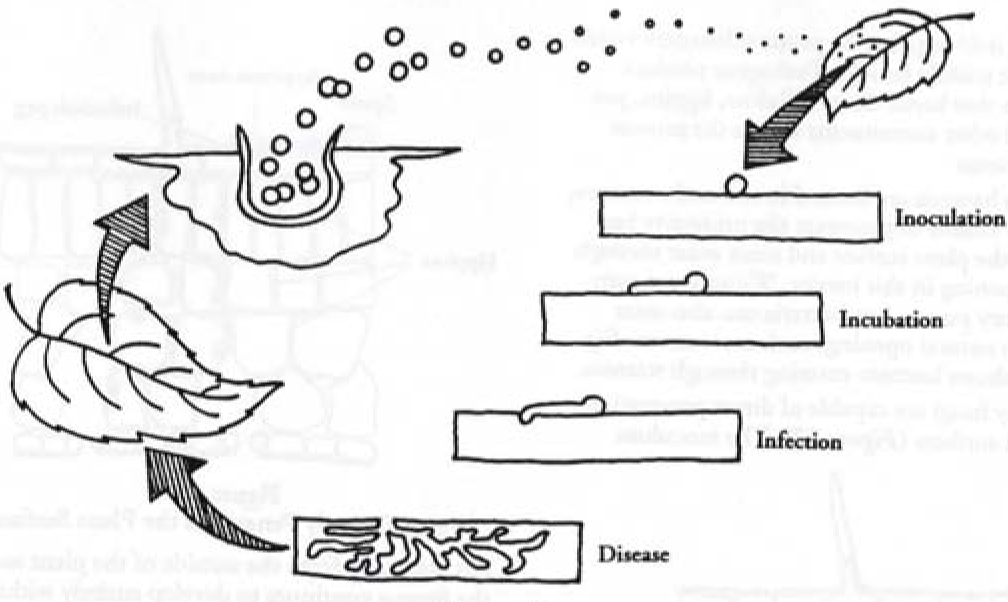

Figure 14
Typical Disease Cycle

ogy, incubation is also used to describe that phase of disease development from infection to symptom expression.

At some point in the development of the inoculum, the pathogen penetrates the plant's protective barriers and invades the plant tissues to begin the stage called infection. This is the real beginning of disease, but the plant is not yet diseased. Only when the plant responds to the invasion of the pathogen in some way, i.e., cells die or multiply abnormally, has disease developed.

Once the pathogen is inside the plant, it is protected from outside influences by the plant itself. Therefore, it is important that control measures, especially chemicals, be directed at the vulnerable stage of the pathogen. This is usually during incubation. How pathogens enter and affect plant cells and tissues is shown by illustrating a cross section of a leaf. *Figure 15* is much simplified but shows the major features.

The outer protective coating of leaves and other plant parts is a waxy cuticle. Under this is a single layer of cells which makes up the upper and lower epidermis. Some of these epidermal cells may be modified or give rise to leaf hairs of various types. There are also specialized epidermal cells that form openings called stomates or stomata into the leaf tissue. Between the two epidermal layers may be one or more kinds of cells having various functions. These cells, at least in their early development, are alive and contain cytoplasm, a nucleus and vacuoles, all components of living cells. This is shown as the stippled areas of the cells and illustrates that the cytoplasm of one cell can be connected to that of adjacent cells through small pores in the cell walls. It is by this means that virus particles move from one cell to another.

The cell wall is made up of cellulose and sometimes contains lignins or other materials. The

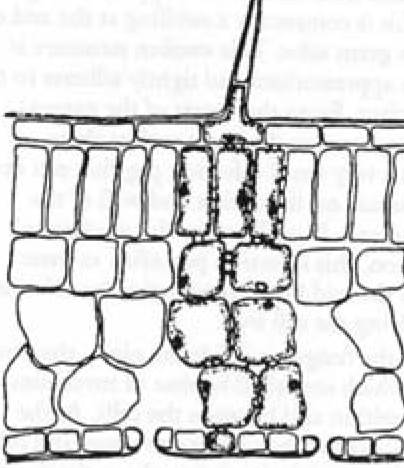
Figure 15
Cross Section of a Leaf

cells are held together by pectic substances which form the middle lamella. Pathogens produce enzymes that break down cellulose, lignins, pectins and other constituents and in the process cause disease.

Since bacteria are limited in size and structure, they are unable to penetrate the protective barriers of the plant surface and must enter through some opening in this barrier. Wounds are common entry points, but bacteria can also enter through natural openings such as stomates. *Figure 16* shows bacteria entering through stomata.

Many fungi are capable of direct penetration of plant surfaces (*Figure 17*). The inoculum

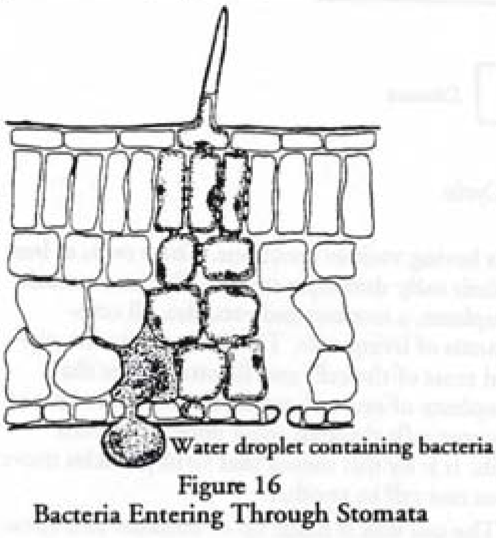

Figure 16
Bacteria Entering Through Stomata

develops for a brief period of time on the plant surface, and then an infection apparatus begins to form. This is commonly a swelling at the end of the spore germ tube. This swollen structure is called an appressorium and tightly adheres to the plant surface. From the center of the appressorium and next to the plant surface there develops a very small infection peg that can exert great pressure on the cuticle and wall of the epidermal cell. In addition to the mechanical penetration, this infection peg often excretes enzymes that aid in the penetration by softening or dissolving the cell wall.

Once the fungus is inside the plant, the fungus strands which are called hyphae or mycelium, develop within and between the cells. As the hyphae elongate, they excrete enzymes and other metabolic materials that bring about the disease. Eventually the spore and other parts of the fun-

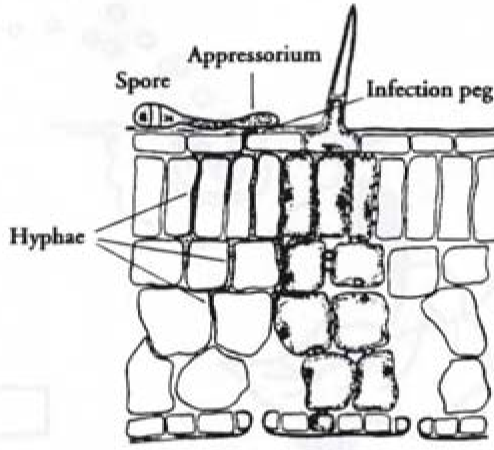

Figure 17
Fungi Directly Penetrates the Plant Surface

gus disappear from the outside of the plant and the fungus continues to develop entirely within the plant tissues until it reaches maturity and produces spores.

A specialized type of infection takes place with the powdery mildew fungi (*Figure 18*). The spore germinates, an appressorium and infection peg is produced and penetration occurs as in *Figure 17*. The fungus remains confined to the epidermal cells where it forms specialized absorbing structures called haustoria. Instead of the external mycelium disappearing, it continues to develop and expand, forming new infection pegs and extending the infection. Whereas most pathogenic fungi develop within the protective surface of the plant, the powdery mildews develop on the

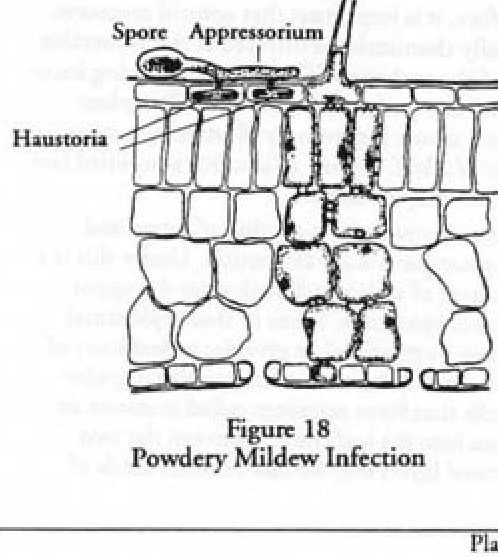

Figure 18
Powdery Mildew Infection

outside and, thus, are subject to chemical control after infection has occurred. Most fungus diseases are difficult or impossible to control once inside the plants.

The concept that a disease is not a tangible object but is a process resulting from the interaction of a pathogen upon a host plant is important. Equally important is the concept that this interaction must take place under favorable conditions for disease to occur. It is generally recognized that three ingredients must be present for a disease to develop. There must be a host plant susceptible to disease, there must be a causal agent and the environment must be favorable for disease to develop. This concept also illustrates the basic principles of plant disease control, since eliminating any one of the three ingredients will prevent disease development. Using resistant varieties or nonsusceptible species, eliminating the causal agent with chemicals or other protective barriers or modifying the environment so that it is less conducive to disease development will do much in reducing diseases.

To illustrate the interrelationships of the three ingredients, imagine three overlapping circles, each representing one of the three ingredients. These three circles are free to move in any direction. Only when the three overlap will disease develop (*Figure 19*). If all conditions are ideal, the circles will be almost one on top of the other (*Figure 19c*). This would represent a very severe disease situation or epidemic. If conditions are average or moderate, only a small portion of each circle would overlap the others (*Figure 19b*) and the disease situation would be mild. This would be an endemic disease. If one or more of the ingredients is not present under otherwise favorable circumstances, the circles do not overlap (*Figure 19a*) and no disease occurs.

Each of these three main components of disease consists of many variables. The host plant may vary in it susceptiblity to disease. It also serves as a source of inoculum that can infect other plants. Its age, vigor and stage of growth may influence the development of disease. The host plant, by shading the soil or removing nutrients, may modify the environment. The host plant, by acting as a genetic screen, is also essential in modifying the pathogen and giving rise to new races and strains. The population or density of plants may be a deciding factor whether a disease remains minor or explodes to epidemic proportions. Even the nature of the rootstocks on a grafted plant may influence disease development in the top.

The causal agent may vary in its ability to cause disease or in its relative aggressiveness as a pathogen. The length of time a pathogen survives away from the host plant and its ability to reproduce are important to its survival and subsequent development of disease.

Host plants can vary in their genetic makeup, and so can causal agents. Pathogenic variation is a common occurrence in some pathogenic fungi, such as rusts and smuts. The quantity or mass that a pathogen produces may be a critical factor in its ability to cause disease. The Armillaria root rot fungus must build up on dead substrates such as roots and stumps before it can invade living roots. Sometimes associations of certain organisms will produce a different or more serious disease than can be produced by either alone.

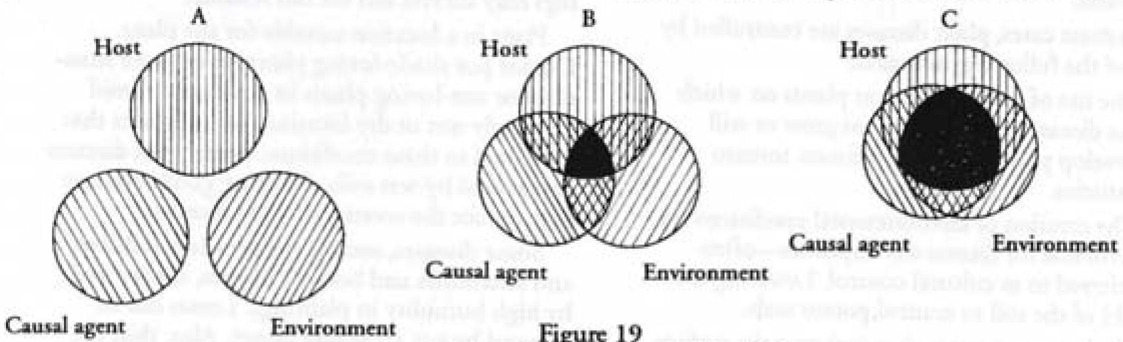

Figure 19
Diagram Showing the Interaction of Host, Causal Agent and Environment
where (A) there is no disease,
(B) there is a low level or endemic disease,
and (C) where there is severe or epidemic disease

The environment consists of many components, but temperature and moisture are probably the two most consistently influential factors.

How are Plant Diseases Controlled?

The ultimate concern about a plant disease is to reduce or eliminate the economic or aesthetic loss it causes. This is called the control of a disease. Plant disease control involves one, or more, of four basic principles. These are exclusion, eradication, protection and resistance.

Exclusion involves measures to prevent a disease organism from becoming introduced into and established in an area where it does not occur. Plant quarantines are one means of exclusion.

Eradication is the elimination of a pathogen from an area, usually when it has limited or restricted distribution.

Protection consists of the placement of a protective barrier, usually a chemical, between the plant and the pathogen.

Resistance involves the use of plants that are not susceptible to the disease. Immunity is the ultimate degree of resistance and is usually not obtained in genetic programs aimed at developing resistance in a given plant. The level of resistance may vary considerably depending on a large number of factors, such as age of the host plant, aggressiveness of the pathogen, relative favorability of the environment, etc. Very often, a plant variety or selection that is resistant to disease lacks desirable qualities wanted for commercial purposes.

In most cases, plant diseases are controlled by one of the following measures:

- The use of disease-resistant plants on which the disease organism cannot grow or will develop poorly, i.e. wilt resistant tomato varieties.
- The creation of environmental conditions unfavorable for disease development—often referred to as cultural control. Lowering the pH of the soil to control potato scab.
- Placing a protective chemical over the surface of the plant—often referred to as chemical control.

Cultural Control of Plant Diseases

Many diseases can be controlled by cultural practices alone. Such practices include:

- Selection of resistant or tolerant varieties of plants.
- Proper establishment of plants.
- Rotating planting locations.
- Maintenance operations, such as raking and destroying fallen leaves, thinning, pruning and regulating fertilizer and water.

These are things every gardener should do. They can also be very effective ways to control plant diseases.

What to Plant

Some plants do well only in certain areas. Always be sure that a plant is adapted to the area. Avoid planting exotics that have special requirements or limitations. Temperature is usually the most limiting of these requirements, but other factors such as moisture, soil type and soil acidity must also be considered.

The establishment and survival of plants depends largely on the vigor of the planting stock, whether it is a seed, bulb or plant. Always buy healthy material.

How to Plant

A little extra time spent in establishing a plant will pay dividends in reducing replacement and maintenance later. Prepare a good seedbed or planting hole. Don't just dig a hole, throw the seed or plant into it and cover it up. Sloppy plantings may survive but are not reliable.

Plant in a location suitable for the plant. Do not put shade-loving plants in exposed situations or sun-loving plants in the shade. Avoid extremely wet or dry locations or use plants that are suited to these conditions. Many root diseases are favored by wet soils. Creating good drainage may reduce the severity of these diseases.

Some diseases, such as the powdery mildews and sclerotinia and botrytis blights, are favored by high humidity in plantings. Losses can be reduced by not crowding plants. Also, thin the plants to permit free air circulation and allow sunlight to reach the lower parts of the plant and soil.

Plant at the most suitable time of the year to insure survival and good growth of the plant.

Check with local nursery operators or Cooperative Etension personnel as to the best planting time.

Routine Care of Plants

Diseased branches and shoots should be removed and destroyed before the pathogen can spread. In routine pruning, always remove diseased or unthrifty growth first and then prune to develop and shape the tree or shrub.

Many disease organisms carry over from one season to the next on fallen leaves. It is advisable to collect and dispose of diseased foliage. Do not include diseased material in the compost heap because of the danger of survival of disease organisms and their subsequent spread.

Maintain a balanced fertilizer and watering program and avoid extremes of either. Some diseases, such as certain cankers, are more prevalent on plants that are underfertilized or suffering from drought. However, other diseases, such as rusts and powdery mildew, are more severe on succulent growth. High nitrogen levels and abundant moisture will favor these diseases. Excess soil moisture may also lead to root rot problems.

Chemical Control of Plant Diseases

A large number of chemicals are used to fight plant diseases, but some of these are not suitable for home use because they are extremely poisonous or very costly. However, there are some very effective pesticides that are safe and economical for use in the home garden.

The control of many plant diseases is not simple. To do an effective job we must have the answers to four questions:

- What organism is causing the disease?
- What chemical to use?
- When to apply the pesticide?
- How to apply it?

Chemicals used to control plant diseases are generally called fungicides but correctly these include only those chemicals that kill or retard the development of fungus pathogens. Those that control bacteria are bactericides and those controlling nematodes are called nematocides (or nematicides). Chemicals that are nonselective and kill all or a large range of organisms are sometimes called biocides.

The ideal pesticide should have at least the following four characteristics, although these ideals are not always satisfied:

- The lethal dosage of chemical used should be low. This minimizes the amount of material that must be applied and reduces the chances of causing damage to nontarget organisms and reduces the amount of any persistent chemical in the environment.
- The chemical must be noninjurious to the host. Many fungicides can damage plants under certain conditions such as high or low temperatures, stage of plant growth, reaction with other chemicals, etc. Recommendations attempt to take this possibility into account and try to use the most efficient concentration that will result in the least plant damage.
- The material should adhere to the plant surface. Since protection frequently is required continuously for a prolonged period, a chemical that sticks well to the leaf or other surface will lessen the number of times that a pesticide need be applied. However, even if adhesion is excellent, new growth develops and some leaves and other parts already sprayed will expand to produce unexposed surfaces. Therefore, applications usually need to be made more or less periodically through the period of possible infection.
- The chemical should be inexpensive. This is a relative value but since the need for controlling a disease often is decided by economic justification, cost of treatment may be the determining factor.

When is the Best Time to Apply Chemicals?

The basis for most chemical disease control programs is to apply a protective film of the chemical to the plant surface before the disease organism has had a chance to invade the plant tissues. Once it has invaded, it is usually unaffected by the chemical. Dusts and sprays must not be applied too early or else the protective covering may be lost by washing, aging or new growth. Understanding the life history of the disease agent is essential for good disease control practice.

The development of most diseases is related to the growth of the plant and to the weather. Consequently, a protective chemical should be kept on the plant from the time the inoculum is present until it is no longer of economic importance. In addition, spray after each period of wet weather, if the disease is a serious problem.

While most diseases are controlled during the active growing period of the plant, a few diseases, such as peach leaf curl, can be controlled effectively only by spraying when the tree is completely dormant, usually between leaf fall and before bud break in the spring.

How Should the Chemical be Applied?

The right amount of chemical must be used to get good control, but too much can injure the plants.

The equipment to be used will depend on what is available. Whether to use a dust or spray will depend on the equipment available and the disease to be controlled. In general, sprays are cheaper, easier to apply and more effective than dusts.

Regardless of whether a dust or spray is used, it is important to completely cover the plant, especially the lower and inner leaves and the undersides of leaves.

Most chemicals used to control plant diseases are protectants and must be applied before infection occurs to protect the plant from invasion by a pathogen. A few are classed as eradicants since they can eliminate an established infection to some extent. These materials generally remain at the point they are applied and do not move in the plant.

There recently have been developed a number of systemic fungicides that can be absorbed by the foliage or other parts of the plant and move within the plant to some degree. These systemics may be protectants or eradicants, or both.

Fumigants are chemicals that are applied usually as a liquid or solid but which convert to a gaseous form. They are most commonly used to control soil-borne fungi and nematodes. These are not available to the nonlicensed person in Connecticut. Any questions on their use should be referred to a specialist.

Fungicides Used in Plant Disease Control

The chemicals used for controlling plant diseases are many and varied and are categorized in several ways. One way is to group them according to their use, i.e., seed treatment, foliar sprays, dusts, soil fumigants, etc. However, it is useful to know something of the chemical nature of the material and grouping these pesticides may be based on either their active chemical component or their chemical base, i.e., copper fungicides, carbamates, etc.

The most widely used method of classifying disease control chemicals is by the active or basic element or ingredient. Copper fungicides are among the oldest with Bordeaux mixture being the first. Its fungicidal value was discovered about one hundred years ago and it is still used to some extent today. Bordeaux mixture illustrates how fungicides work. It is a mixture of copper sulfate and lime to form copper hydroxide. Copper sulfate alone is very soluble in water and if a solution is sprayed on a plant, it is very phyto-toxic (toxic to the plant). Copper hydroxide, however, is practically insoluble in water and will not cause damage to the sprayed plant. However, enough copper goes into solution from the copper hydroxide to kill fungus spores and will control plant disease organisms without harming the plant.

Elemental sulfur is actually the oldest of the fungicides on record and reference to the pest-averting sulfur occurred as early as 1000 B.C. It is still used today, mainly for the control of powdery mildew. Sulfur can also cause plant injury, especially at warm temperatures. The polysulfides, particularly lime-sulfur, are used both as protectants and eradicants.

The mercury fungicides were developed in the early 1900s and had been widely used: the inorganic mercuries primarily as disinfectants and the organic mercuries as protectants and eradicants. These are no longer available.

The carbamate fungicides are all built on a carbamic acid base, primarily as ethylene dithiocarbamates. They vary depending on the metallic element associated with them. Ferbam is the iron salt, zineb and ziram are zinc salts, maneb contains manganese and nabam is the sodium salt. Thiram is a nonmetallic carbamate fungicide.

Fungicides, as do other pesticides, may have at least three names for their identification. These are the chemical name, common or coined name, and trade or proprietary name or names. For example, the fungicide, zineb, has the chemical name of zinc ethylenebisdithiocarbamate. Everyday use of this name is impractical, and so zineb has been adopted as the common or coined name. On the market, zineb can be found under a number of trade names including Dithane Z-78, Parzate C, Polyram Z and several others.