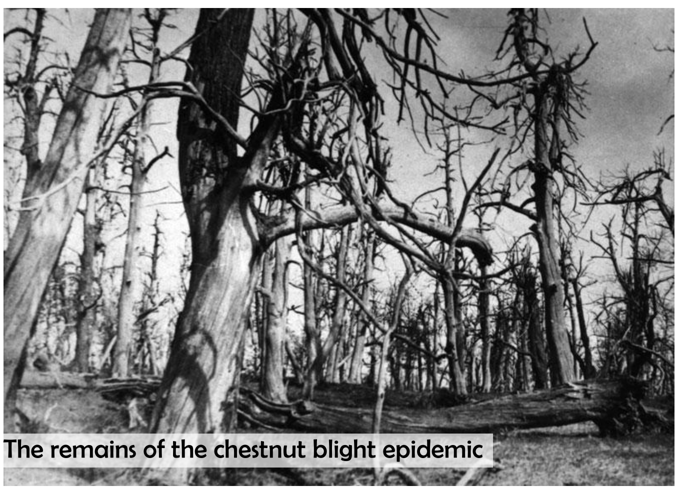
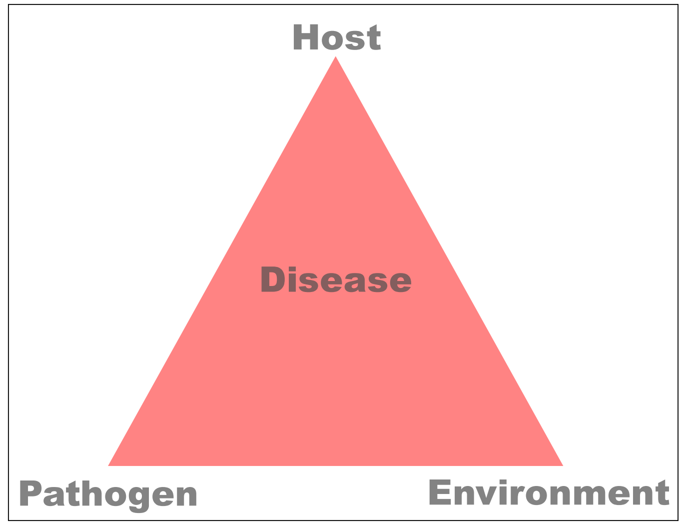
Forest Diseases

Forest Pathology

Tree diseases are the leading cause of timber losses each year in the U.S. In fact, the average total loss of timber due to disease-caused mortality and growth loss nearly equals the losses caused by all other stress agents combined. Diseases have and will continue to result in catastrophic epidemics that can wipe-out entire tree species and destroy native forest ecosystems. Chestnut blight was the first of many such epidemics, which virtually eliminated the most common tree species in the eastern U.S., the American chestnut, from its natural range in less than 40 years. Dutch elm disease, dogwood anthracnose, beech bark disease, sudden oak death, and laurel wilt have since followed. Other diseases pose little or no threat to tree survival, but are no less problematic because they reduce growth significantly, degrade wood, destroy fruit and seed crops, or make landscape trees and ornamentals unsightly or hazardous.


The remains of the chestnut blight epidemic

Forest pathology is the study of tree diseases including diseases of trees in forests, plantations, nurseries, urban areas, and landscape settings. In addition, forest pathology also encompasses the science of wood degradation and decay. In fact, the field of forest pathology is considered to have begun with Robert Hartig's investigations of wood decay by fungi in the 1850's. Forest pathology is a sub-discipline of ***plant pathology*** which is the study of plant diseases. A ***plant disease*** is defined as a sustained disruption in physiological or structural functions of a plant due to an attack by a pathogen that results in death, damage to cells or tissues, reduced growth or vitality, or economic losses. A disease is an interaction between a pathogen and its host that can only occur under certain environmental conditions. This can be demonstrated by the ***disease triangle***, which visualizes disease as an interaction between three components: host, pathogen, and environment. If one of the three components is lacking, disease cannot occur.



Pathogens are parasitic microorganisms that cause disease, meaning they attack plants to obtain the energy and nutrients necessary to complete their life cycle resulting in harm to their host plant. Pathogenic (disease-causing) microorganisms include bacteria, viruses, nematodes, and most commonly, fungi. Not all microorganisms are ***pathogenic***; in fact, most microorganisms are ***obligate saprophytes*** meaning they can only feed on dead organic material. These microorganisms play an important role in decomposing dead plant material and recycling nutrients. Most plant

Oyster mushrooms (*Pleurotus ostreatus*) are obligate saprophytes

pathogens are ***facultative pathogens***, meaning that they can live on dead plant material, but can also attack living plants and cause disease. Other pathogens are ***obligate pathogens*** that can only survive on a living host plant.

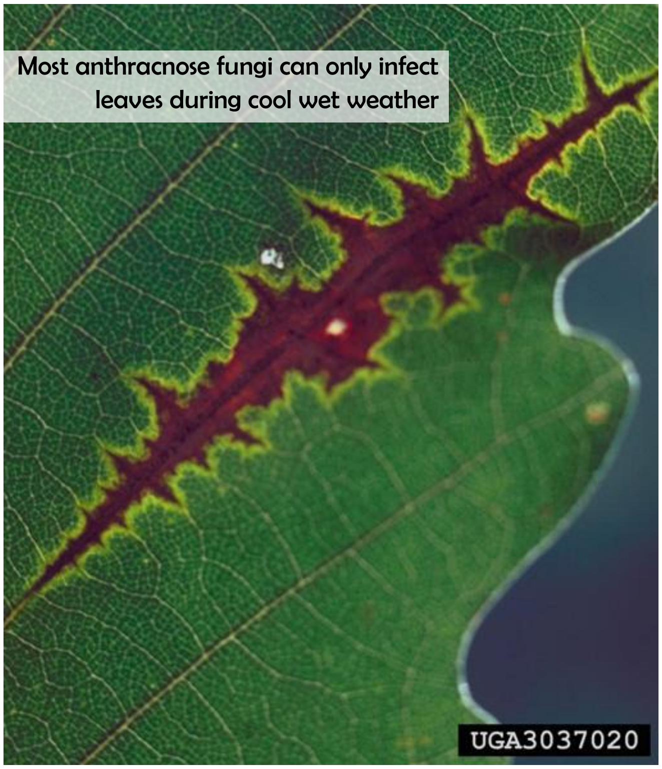
All plant pathogens are infectious and transmissible, meaning they can spread from one host plant to infect another. Plant pathogens cause disease, they are not diseases themselves. For instance, the fungus *Cryphonectria parasitica* is the name of the pathogen that causes chestnut blight in American chestnuts. Remember: a disease is the resulting interaction between a host, pathogen, and environment.

Plant pathogens cannot attack and parasitize any plant species; instead, plant pathogens are host-specific. A ***host*** is a plant that can be infected and parasitized by a specific plant pathogen. Most plant pathogens have only one or a few suitable host species; however, some pathogens can attack hundreds of plant species. The mechanisms that determine which pathogens can attack which plants are very complicated and result from complex interactions and signals between the two organisms.

Trees have evolved structural and chemical defenses such as thick bark, waxy leaf coatings, root secretions, and anti-microbial toxins that prevent infections. These “pre-formed” defenses are always in place and provide general protection from all microorganisms. But certain plant pathogens have developed ***virulence factors*** that enable them to overcome general plant defenses. Virulence factors such as enzymes that degrade plant tissues, special structures that can pierce plant cells, or specialized metabolic pathways that can neutralize host toxins, may allow a microorganism to become pathogenic. In response, plants have developed methods to detect pathogens that can overcome pre-formed defenses, and in response, they initiate powerful “induced” defenses. When one of these pathogens is detected during the infection process, induced defenses such as increased production of anti-microbial compounds or instantaneous death of infected cells can prevent the pathogen from parasitizing the plant and causing disease. Of course, pathogens continue to adapt induced plant defenses by hiding the chemical signals that alert plants to an attack or adding developing additional virulence factors.

A plant that possesses the ability to prevent infection is completely ***resistant*** to that specific pathogen. Some resistant plants can become infected, but are able to minimize disease development and are therefore considered to be partially resistant. ***Susceptible*** plants are vulnerable to pathogen attacks that result in severe and damaging disease. Resistance and susceptibility form a continuum that ranges from completely resistant to highly susceptible. A plant can be resistant to one pathogen but susceptible to another. Each host-pathogen interaction is unique.

Regardless of how susceptible a plant may be to a given pathogen, disease cannot occur unless the environmental conditions are just right. Pathogens have very specific environmental requirements to complete their life cycle. Many fungi only produce spores within a very narrow temperature range. Some spores can only spread in splashing rain, high winds, or with a specific insect vector. Certain fungal spores can only germinate if the leaf surface is wet, and can only infect through a natural plant opening or wound. Even if all these conditions are met, some fungi can only infect a host that has been sufficiently weakened by predisposing factors. The environmental conditions for each host-pathogen interaction are unique. If conditions are not correct, disease will not result.



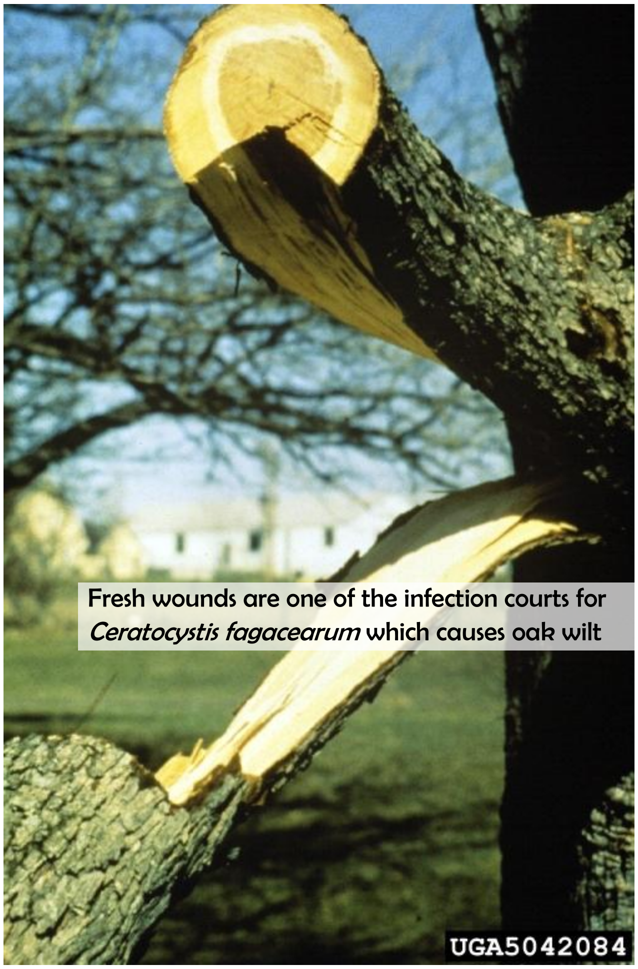
Most anthracnose fungi can only infect leaves during cool wet weather

The interactions between a host, pathogen, and environment that result in disease occur in several distinct stages that together make up the ***disease cycle***.

The Disease Cycle

1) ***Transmission*** is the movement of the pathogen from one host plant to another. While some pathogens can simply grow through the soil from one plant to another, most pathogens cannot survive for very long outside their host, so transmission usually involves special mechanisms. Many pathogens require an insect vector to carry them from one plant to another; the insects unknowingly carry the pathogen in their mouths or on their bodies and transmit them to new hosts while feeding. Some fungi produce special spores that can be carried by the wind or splashed around by rain drops. Phytophthora species (fungus-like organisms) and nematodes can swim through moist soil in search of new hosts. Some pathogens are transmitted in plant seeds or can grow from one tree to another through interconnected root systems.

2) ***Infection*** is the act of the pathogen entering the host. Some pathogens can directly penetrate plant cells or tissues by physical force; others must enter through natural plant openings such as stomata. Some pathogens can only infect through open wounds in the plant, and insect vectored pathogens may only enter the plant during the insect's feeding process. The actual location of the infection is known as the ***infection court***. Many infection courts are only vulnerable to infection under certain environmental conditions, for example when leaves are wet, when wounds are fresh, or when young seedlings first emerge from the soil.



Fresh wounds are one of the infection courts for *Ceratocystis fagacearum* which causes oak wilt

3) ***Colonization*** is the invasion of plant tissues by the pathogen. The pathogen must spread through the plant by growing through or between cells, or by spreading through the plant's vascular system. Most fungi for instance grow through the plant using long, filamentous structures called mycelia. Bacteria on the other hand, must swim or be carried in the

plant's vascular system. The extent of colonization by some pathogens is very limited (e.g. leaf spot diseases) while other pathogens colonize the entire plant (e.g. vascular wilt diseases).

4) ***Parasitism*** occurs when the spreading pathogen begins to feed on plant tissues. In most cases, plant cells are penetrated and killed by the pathogen, and the nutrients are absorbed. It is the act of parasitism that causes most damage to plants by killing plant cells and tissues, interfering with physiological processes or structural functions, and draining a plant of its energy reserves.

5) ***Symptom development*** occurs in response to the damage caused by the pathogen. Symptoms are a plant's reaction to colonization and parasitism by the pathogen. Some symptoms are a direct result of pathogen activity (leaf lesions caused by a fungus killing leaf cells), while others may be caused indirectly (wilting of a tree due to a pathogen attacking the root system). In most cases, symptoms are the only visible evidence that a plant is diseased.

6) ***Reproduction*** of the pathogen is necessary to complete its life cycle. Different pathogens reproduce in different ways. Viruses are replicated by the plant cell's own genetic machinery. Bacteria and some yeast-like fungi simply divide to create new individuals. Nematodes are animals that lay eggs or may even give birth to live offspring. Most fungi produce special fruiting bodies that are capable of producing hundreds of billions of spores. Most plant pathogenic fungi produce microscopic fruiting bodies, but some produce larger fruiting bodies that we know as mushrooms. All plant pathogens are capable of reproducing asexually (without mating), and most are capable of sexual reproduction in some form.

7) ***Transmission*** is most often accomplished by reproductive structures such as spores, so therefore successful transmission follows reproduction and is necessary for the pathogen to complete its life cycle. Diseases caused by pathogens that complete their life cycle only once per year are known as ***monocyclic diseases***; diseases caused by pathogens with the ability to complete their life cycle more than once in a growing season are ***polycyclic diseases***. Pathogens that are not transmitted before the end of the growing season must reside within the host plant or form survival structures to overwinter.

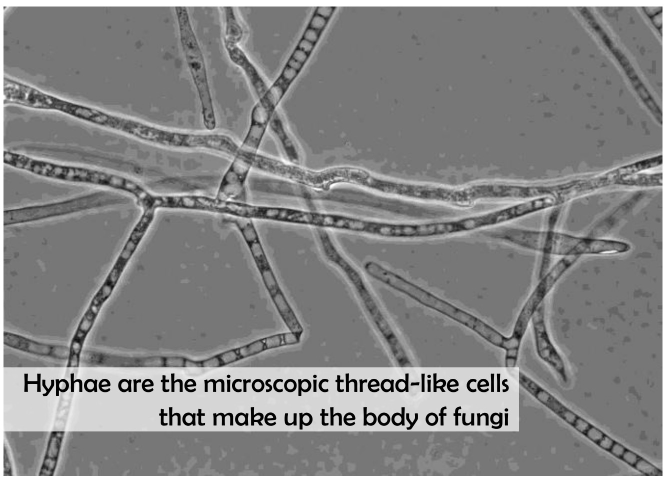
The disease cycle for each host-pathogen-environment interaction is unique. Therefore most forest pathology references provide detailed information on the disease cycle for each specific disease. Identifying "weak points" or vulnerabilities in the disease cycle is the first step in designing control or management strategies. Familiarity with the disease cycle of common or potentially damaging diseases is important for proper forest management.

Fungi

Fungi are filamentous microorganisms that lack chlorophyll and must therefore obtain nutrients from living hosts or organic matter. At one time, fungi were considered to be plants. However, they differ from plants in so many ways that they are now classified in their own kingdom separate from both plants and animals. Over 75,000 species of fungi have been named and described, but it is thought that over one million species of fungi may exist world-wide. Mycology is the study of fungi and closely related organisms such as slime molds and water molds (e.g. *Phytophthora* species) which are not true fungi.

The diversity of fungi, their biology, roles, and uses are so vast and varied they cannot be described in detail here. Most fungi can only feed on dead organic material. These fungi play crucial roles in decomposition and nutrient recycling. Some fungi produce chemicals or have special metabolisms that are utilized by humans to produce antibiotics, beer, wine, bread, soy sauce, industrial enzymes, and detergents. Some fungi are edible, and the mushrooms of many fungi are prized by mushroom hunters and chefs alike. Others are highly toxic or even psychotropic to humans and/or other animals. Some fungi cause disease in humans; others parasitize insects and nematodes and can be used as biological controls. Fungi are also the most common and important plant pathogens. The vast majority of plant diseases are caused by fungi, even though only a relatively small percentage of fungi are pathogenic.

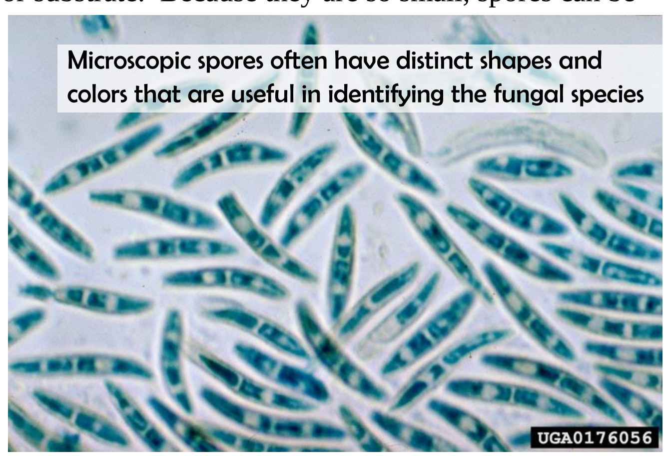
In their most basic form, fungi are networks of filamentous or thread-like strands known as ***mycelium***. A single thread of mycelium is called a ***hypha***. Hyphae are microscopic tube-like cells that can branch, grow very quickly at their tips, and are generally considered to be the main body of the organism. The cell walls of fungi are composed of chitin (as opposed to cellulose in plants), and each hyphae is filled with protoplasm that flows throughout the mycelium network. Some species form dense clusters of mycelium that can be visible to the naked eye. For instance, some *Armillaria* species (common wood and root rotters) form dense mycelial strings called ***rhizomorphs*** beneath the bark of their host that resemble black shoestrings. Others may form thin fan-like mats, or even thick clumps that can rupture the surface of tree bark. However, the most commonly visible sign of fungi are mushrooms, which are the large spore-producing fruiting structure of the fungus. Compared to the network of mycelia, mushrooms are a relatively small structure produced on the surface of the ***substrate*** the fungus is growing in. Mushrooms are only formed by a relatively small percentage of fungi however; most mushroom-forming species are saprophytes as opposed to plant pathogens.


Hyphae are the microscopic thread-like cells that make up the body of fungi

Most plant pathogenic fungi do not form mushrooms. Instead, they produce microscopic spore-producing ***fruiting bodies*** that are seldom visible to the naked eye. Some fruiting bodies, and the spores they produce, are very colorful and become so numerous that they may occasionally become visible on the surface of an infected plant. Spore shapes, colors, and sizes vary widely, and can be used to identify fungi when examined under a microscope. The number of spores produced by a fungus is nearly incomprehensible. For instance, a single "artist's conk" from the common wood rotter *Ganoderma applanatus* can produce 30 billion spores each day (the equivalent of 350,000 spores per second). Because of their small size and tremendous numbers, the air we breathe is literally filled with fungal spores. This is necessary for the fungi to ensure that at least some of their spores will land on a suitable host plant or substrate.

Orange tendrils of thousands of sticky spores emerging from small fruiting bodies called pycnidia

Spores are specialized fungal structures that serve many purposes. First and foremost, spores are like fungal seeds that germinate under the right conditions, forming new hyphae that grow down into their host plant or substrate. Because they are so small, spores can be carried for hundreds or thousands of miles, allowing transmission of fungi over long distances. Some fungal spores are specially adapted to survive in water or in the mouths of insects. Some may be excreted in sticky secretions that allow them to adhere to insects or the legs of birds and small mammals. Others may be so small they can be translocated in a plant's vascular system. Many spores serve as a fungus's overwintering structure.



Microscopic spores often have distinct shapes and colors that are useful in identifying the fungal species

Some fungal spores can survive for years without germinating and still remain viable. Fungicides used to kill plant pathogens may be ineffective against spores because they are generally physiologically inactive or dormant. Only after they germinate will those compounds be effective.

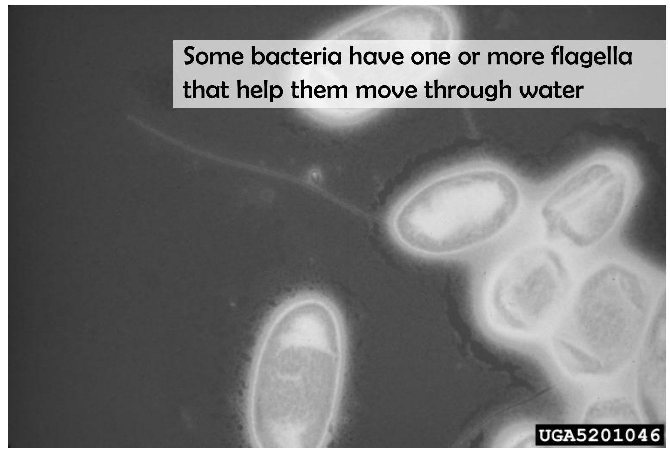
Bacteria

Bacteria are single celled organisms that lack a nucleus or organelles. They are much smaller than fungi, and are only visible under very powerful microscopes. There are several important tree diseases caused by bacteria but none are responsible for major losses of forest trees. However, bacterial diseases such as fire blight can have a significant impact in fruit orchards for example, and many such as wetwood and crown gall commonly affect landscape trees and ornamentals.

Bacterial leaf scorch can be a serious problem on landscape trees and ornamentals

Plant pathogenic bacteria are either spherical or rod-shaped, and some have one or more flagella that enable them to move through water. Bacteria multiply by division (or fission), which can occur in as little as 20 to 30 minutes. Therefore, bacterial populations can grow exponentially, meaning they have remarkable potential for rapid population growth. For example, single bacteria can give rise to a population of 2 sextillion bacteria in a single day!

Bacteria do not form spores, and therefore cannot be disseminated on the wind. Instead, most bacteria are spread in water droplets (e.g. in rain splash or wind-driven rain) or by insect vectors. Bacteria can also be spread from plant to plant on contaminated equipment used for pruning or cultivation. Unlike fungi, bacteria lack the ability to directly penetrate their host. Instead, they must enter through natural plant openings or wounds. As they spread through an infected plant, they release extracellular enzymes that degrade and digest plant cells, providing the nutrients necessary for growth and multiplication. Bacteria invade and colonize the spaces in between plant cells, and as populations grow rapidly, plant cells can be crushed by the vast number of bacteria and overwhelmed by high concentrations of bacterial enzymes. In addition, bacteria produce large amounts of gummy polysaccharides that clog the plant's vascular system and reduce water movement in the xylem. Toxins that prevent photosynthesis or other essential physiological processes may also be produced.

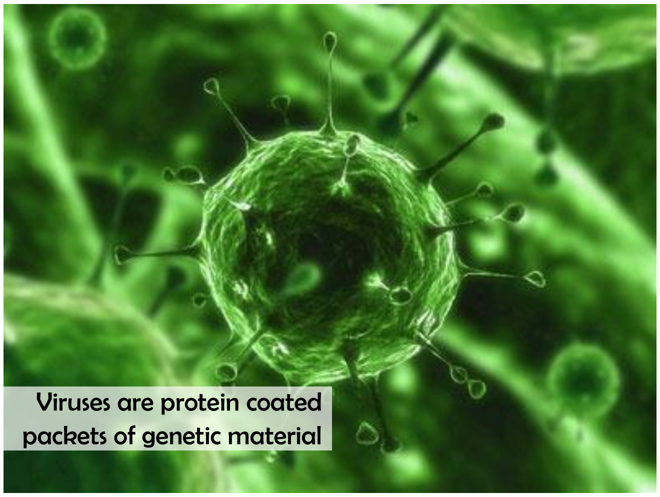


Some bacteria have one or more flagella that help them move through water

Bacteria cannot survive complete desiccation, and therefore, their survival is dependent upon a constant association with water. During the winter months, bacteria survive either within their host, in the soil, in seeds, or in their insect vectors. In the case of trees, many bacteria will survive at the edges of perennial cankers, within the vascular system, or in association with the roots. Some bacterial colonies will produce a gummy substance that prevents desiccation. Bacteria that cause foliage diseases usually perish after leaf fall because they cannot compete with other saprophytic bacteria and fungi that feed on the dead plant material. Instead, these bacteria overwinter in and are transmitted to new hosts in the spring by insect vectors.

Viruses

Viruses are extremely small pathogens that cannot be seen using normal light microscopes. Instead, they can only be seen using very powerful electron microscopes. Unlike other pathogens, viruses are not cellular organisms (in fact, most scientists do not classify them as living organisms), but are instead composed of a nucleic acids (DNA or RNA) protected by a protein coat. They come in a variety of shapes including rod-shaped, spherical, or crystalline. Because they are not classified as living organisms, they are simply named for the host they infect and symptoms they cause (e.g. tobacco mosaic virus). While most viruses are species specific, a few can cause disease in a wide range of hosts. This occasionally leads to some confusion in the naming of viruses because two distinct diseases in two different hosts may actually be caused by the same virus.



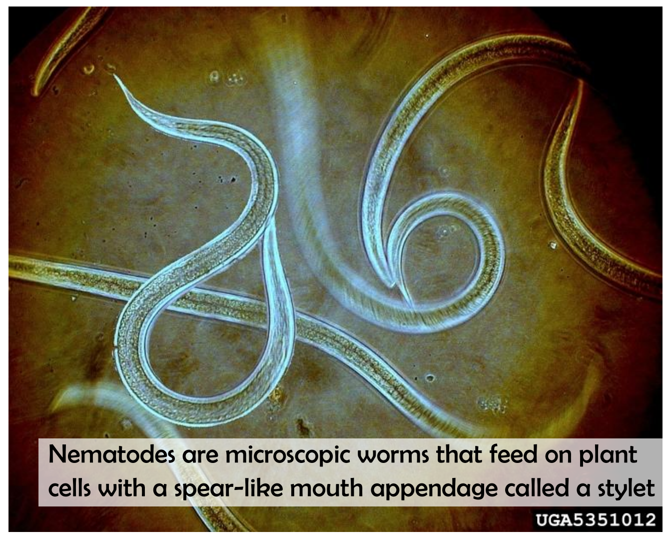
Viruses are protein coated packets of genetic material

Viruses are not true parasites because they do not feed on the cells of their host, and they lack an ability to replicate themselves. Instead, viruses are able to replicate and cause disease because of their ability to "reprogram" infected host cells to produce more viruses, and in the process, the host cell is damaged or killed. After entering a host, the virus injects its nucleic acids (usually RNA for plant viruses) into a host cell. The nucleic acids contain all of the genetic information necessary to replicate the virus in its entirety. The host cell does not distinguish the virus' genetic material from its own DNA, and as a result, it is essentially tricked into producing thousands of copies of new viruses. Eventually, the cell is overrun with the virus and is destroyed. The viruses are then released from the cell to attack surrounding cells.

Because viruses cannot survive for long outside of their host, their transmission is limited to insect vectors, seeds, and vegetative propagation of plant material. Insects feeding on an infected plant may harbor the virus in their digestive system for weeks or months, and can transmit the virus to every plant it feeds on during that time. Fortunately there are few serious tree diseases caused by viruses. Most tree viruses, such as elm mosaic virus, maple mosaic virus, ash ring-spot virus, and birch line pattern virus are minor nuisances. Others, like blackline disease of walnut caused by the cherry leafroll virus, can cause death.

Nematodes

Nematodes are the only animals that are considered to be plant pathogens. Nematodes are microscopic roundworms that posses a stylet (spear-like mouth appendage) that is capable of piercing the plant cell wall, injecting digestive enzymes, and sucking out nutrients. While nematodes lack the ability to multiply as rapidly as fungi, bacteria, and viruses, the damage they cause when piercing cell walls and injecting toxins can be devastating. A single nematode can destroy hundreds or thousands of plant cells during its lifetime, and each plant can be attacked by millions of nematodes at once. Parasitized plants are seldom killed, but may be stunted and weakened making them more susceptible to nutrient deficiencies, cold damage, drought, and other pathogens and insects.



Nematodes are microscopic worms that feed on plant cells with a spear-like mouth appendage called a stylet

Each generation of nematodes takes approximately 30 days to develop, and each female can lay 200 - 500 eggs. Nematode larvae resemble small adults and seek out feeding sites. During feeding, the nematodes mature into adults. Some plant parasitic nematodes become sedentary when mature, while others remain mobile and may continue to move from cell to cell to feed. Some species of nematodes have separate male and female individuals and are capable of sexual reproduction. If males do not exist or are rare in a species, the females are capable of **parthenogenesis**. Nematodes prefer warm soil temperatures and the length of the life cycle may be shortened considerably in warmer climates resulting in larger populations. Nematodes overwinter in all life stages, but populations may dramatically decline if the winter is particularly cold.

Nematodes are capable of moving for short distances through the soil, but movement is generally limited to a few feet annually. These organisms are not very strong and can only travel through porous soils or existing passageways formed by other soil-inhabiting organisms. Nematodes are also able to spread more rapidly through well cultivated and aerated soils because of the decreased soil density in these situations. Nematodes are easily transported in soil or on contaminated equipment, and can be spread rapidly in irrigation water and runoff. A few plant parasitic nematodes can be transmitted by insect vectors.

There are few serious tree diseases caused by nematodes; most nematode infections go undetected and only become problematic because they weaken the tree and make the host more susceptible to other stress agents. However, some nematodes such as the pine wilt nematode of Japanese black pine have drawn serious attention because of their ability to spread and cause disease in both introduced and native southern pine species.