TERMS AND CONCEPTS IN PLANT PATHOLOGY. SURVIVAL AND DISPERSAL OF PLANT PATHOGENS

Terms and concepts in plant pathology

Introduction

Plant diseases in the landscape and garden are very important and can be a significant source of frustration and loss to the gardener. There are about 30,000 diseases of economic importance. Plant pathology is the study of the biotic and abiotic agents that cause disease in plants; of the mechanisms by which these causal agents induce disease in pants and of the methods of preventing or controlling disease and reducing the damage caused.

Plant Diseases in History

Certain diseases have had tremendous impacts on our society. Perhaps foremost among these is *Phytophthora* late blight which caused the potato famine (1845) in Ireland. It is estimated that 1.5 million Irish died from starvation and just as many immigrated to the United States. Two forest tree diseases which caused great economic losses in America are Dutch elm disease andchestnut blight. Both were introduced accidentally to the United States and while the former continues its destruction, the latter completely destroyed valuable trees in the Appalachians. These examples are prominent because they caused so much damage. In reality, total crop loss due to plant disease is rare. Most disease loss in the garden is due to endemic diseases.

Disease Defined

Diseases result from more or less continuous irritation of the plant tissues by a primary causal agent. Disease is a process that takes time, is physiological in nature, abnormal, and detrimental. Diseases cause damage by reducing yield and/or quality of plants and/or plant products.

Types of Plant Diseases

There are two types of plant diseases: those whose primary causal agents are biotic (infectious), and those that are abiotic (not infectious). The causal agent of infectious diseases is called the pathogen, and the susceptible plant the suscept. Diseases caused by microorganisms or microbes, are infectious. Diseases caused by parasitic plants are also infectious. Diseases may involve more than one causal agent and often involve secondary causal agents.

Noninfectious (Abiotic) Diseases

Examples of abiotic diseases include:

Nutrient Deficiencies -- A lack of essential elements such as iron or zinc may cause plant foliage to yellow.

Lack of or Excess Soil Moisture -- A plant can become dehydrated during drought periods, and may suffocate when poor drainage cuts out oxygen around the roots.

Too Low or Too High Temperature -- Plants grown out of their adapted habitat can be injured or killed by extremes in temperature.

Air Pollution -- Ozone, sulfur dioxide and automobile exhaust fumes can injure plants.

Soil Acidity or Alkalinity -- Adverse soil pH can injure plants

Mechanical Damage - *G*irdling from roots, nylon twine or wire; injury from construction

Biotic Diseases

Biotic (infectious) diseases occur when a host plant is invaded by a living organism. Most of these organisms are microbes, and can also be referred to as parasites which attack plants. A **host** is a plant which has been invaded by a parasite. A parasite is an organism which obtains its nutrients from living organisms, often plants. In the process of feeding, the parasite not only consumes plant tissue, which weakens the host, but also produces toxins, enzymes, and growth regulating substances which disturb the normal metabolic processes in the plant. In some cases the parasite actually blocks the movement of food and water in the plant's conducting tissue. Any of these disorders caused by a parasite will result in a diseased plant. Microbes are the major biotic pathogens of plants. The four major groups of microbial plant pathogens are fungi, bacteria, nematodes, and viruses. Less commonly, phytoplasmas (bacteria-like) and viroids (virus-like) also cause diseases. Parasitic flowering plants are also pathogens.

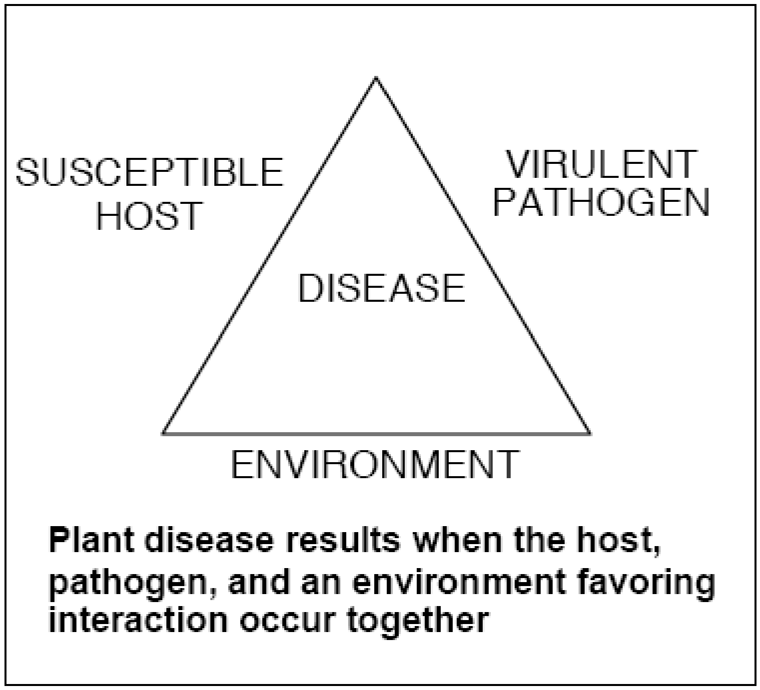
Much can be learned by studying the pathogens as groups, and a working knowledge of those groups is needed for an understanding of plant pathology. Knowing how a pathogen obtains nourishment is important to understanding the disease process and developing control strategies. Most microbial pathogens are primarily parasites, but some are mainly saprophytes and can sometimes cause disease. Saprophytes usually feed on non-living organic matter. Most microbial pathogens have some saprophytic abilities, which are important in survival and in the disease process. Pathogens with saprophytic ability can be cultured away from their host plant.

Some pathogens can only grow in nature on their live host, (e.g. powdery mildew and rust fungi) and are called obligate parasites. Obligate parasites feed and reproduce on living plant material.

Conditions Necessary for Disease

In order for disease to occur, three conditions must be met. First it is necessary to have a susceptible host plant. Each species of plant can be infected by only some pathogens. The plant must also be in a stage of development susceptible to infection by the disease agent.

The second requirement is the presence of an active pathogen. If there is no pathogen present, there can be no disease. Also, the pathogen must be in a stage of development conducive to infecting or affecting the host plant. The third condition is an environment suitable for the pathogen to cause disease of the plant. The interaction of host, pathogen, and environment can some times be represented by a triangle. The "disease triangle" cannot be constructed unless all 3 legs are present simultaneously. Break any leg of the triangle, and there is no disease. Disease control strategies can be based on breaking a leg of the triangle.



Plant disease results when the host, pathogen, and an environment favoring interaction occur together

Diseases Caused by Fungi

A fungus is a multicellular organism made of thread-like material known as mycelium. Fungi cannot make their own food, so in the process of obtaining food from higher plants, fungi injure roots, stems, leaves, and fruit. This action causes what we know as plant diseases. Not all fungi, however, cause disease.

Types of Fungi

There are many types of fungi. Many saprophytic fungi are beneficial to mankind. Beneficial fungi rot leaves, cause fermentation in the manufacture of alcohol and cheese, and produce antibiotics used to treat human infections. Yeasts, which are used in fermentation, and *Penicillium*, an important antibiotic producer, are fungi. Thousands of species of parasitic or pathogenic fungi cause plant diseases. Some species attack only one plant; others attack many different plants. Some plants are susceptible to more than 50 fungal diseases. Fungi are mainly composed of mycelia. Mycelial threads resemble spider webs in appearance. Bread mold is a fungus and is typical of the vegetative structures fungi produce.

How Do Fungi Reproduce?

Fungi reproduce by forming spores, sclerotia and mycelial fragments. These fungal parts provide a means for the fungus to be moved from diseased to healthy plants and for the fungus to survive from one season to the next.

Spores: Fungus spores can be compared to seed in higher plants. A fungus can produce millions of spores which are too small to be seen with the naked eye. Each fungus species produces a spore or group of spores which is different from that of all other species. A fungus can be identified by the spore it produces, just as an individual can be identified by finger prints. Spores come in a variety of shapes or colors and can have one cell or be multi-cellular. Some types of fungi mate and form sexual spores, but most fungi are asexual, and fertilization is not necessary for reproduction. Some fungal spores are short-lived, and some are resting spores which can last many years even under adverse conditions.

Sclerotia: The mycelium of some fungi becomes hard and forms reproductive structures known as sclerotia. These sclerotia or hard bodies will remain dormant in the soil for several years or until a susceptible crop is planted. *Sclerotium rolfsii*, which causes crown rot of vegetables, is a good example of a fungus with this kind of reproduction.

Mycelial Fragments: Some fungi are spread from one area to another by fragments of their mycelium. This form of reproduction is similar to vegetative reproduction in higher plants. *Rhizoctonia*, which causes damping off of seedlings, is spread by mycelial fragments.

Where Are Spores Produced?

In Soil Water: Some fungal-like organisms (Oomycota) produce motile spores with flagella, known as zoospores, that move from root to root in soil water. Other members of the Oomycota which form motile spores such as *Pythium* and *Phytophthora* thrive in low wet areas and cause such diseases as root rots and stem rots.

Special Structures: Some fungi produce spores in special structures inside the infected plant tissue. Numerous spores are produced inside these fruiting bodies, and upon maturity the spores are discharged on the surface of the diseased plant where they can be carried away by air currents or splashed into the air by raindrops.

Stalks or Conidiophores: Many fungi produce their asexual spores on exposed stalks known as conidiophores. Fungi on the surface of the plant tissue form stalk-like structures which produce numerous spores known as conidia. A conidiophore resembles a small plant with fruit hanging on it. This type of spore is usually carried away by air currents since it is produced on the surface of plant tissue.

Penetration of Plant Tissue

In order for infection to occur, the spore must germinate and penetrate the plant tissue. When a spore germinates on moist tissue, it enters the tissue by direct penetration, through natural openings such as stomata or lenticels, or via wounds.

***Direct Penetration*:** In direct penetration, the spore forms a germ tube which penetrates using enzymes and physical pressure. Young, tender leaves, roots, and blooms are more likely to be invaded by direct penetration. Many foliage infections occur in early spring while the new growth is tender. Some fungi penetrate only the cuticle layer (outer layer) of leaves or fruit. The disease

apple scab is a good example of a subcuticular infection. Other fungi such as powdery mildew penetrate only the epidermal layers.

Penetration through Stomata: Some fungi penetrate through stomata (natural openings). Fungi which enter through stomata can attack older and tougher leaves. Rust fungi such as cedar apple rust or bean rust penetrate via stomata.

Penetration Through Wounds: Some fungi enter plant tissue only through wounds. Pruning wounds make an excellent avenue of penetration. Many fruit rots occur when fungal spores come in contact with bruised areas.

Factors Necessary for Infection

There are millions of fungus spores in our environment but infection does not occur every time the spores are deposited on plant tissue. Certain favorable factors are necessary before infection can occur.

Moisture: In order for most fungus spores to germinate and penetrate plant tissue, free water must be available on the plant surface. If the leaf is dry, infection will not occur. A dry spring can reduce disease development for the entire season since the dry weather protects the young tender tissue from fungus infection. If sufficient moisture is available later in the season, the foliage may be tough and spores less numerous. Thus, free moisture especially early in the season favors most diseases.

Temperature: Some crops grow at a temperature below which fungi can infect, but most crops grow at temperatures most suitable for fungal reproduction. Most fungi grow well at temperatures between 70^o and 90^o F and are dormant in winter. Diseases are more common, and more damaging, in tropical climates than the temperate climates.

Stage of Plant Growth: Fungi infect susceptible plant tissue. Some fungi attack any young, tender leaves. Others prefer new shoot growth, young feeder roots, or ripe fruit. If the plant passes through this susceptible stage before spores are available or during unfavorable weather conditions, then it might escape injury for the entire season.

Disseminating Agents: Fungus spores must be carried from infected to non-infected tissue by some agent such as wind, insects, man, transplants, or seed. A disease spread by wind or blowing rain might not reach epidemic proportions during calm, dry periods. The spores of downy mildew can be spread all the way across the continent by wind currents. Dutch elm disease is spread from tree to tree by insects.

Duration of Spore Release: Some fungi produce spores during the entire spring or summer, but others produce only one crop of spores during a short period in early spring. A fungus which produces spores for only a few days can be more easily controlled since the infection period is very short and the plant might not be in a susceptible stage of growth when spores are available. Dispersal of fungal spores frequently occurs daily and corresponds closely to current critical environmental events that favor infection or pathogen reproduction, e.g., moisture, temperature, etc.

Diseases caused by Bacteria

Bacteria are minute one-celled microbes closely related to fungi. Plant pathogenic bacteria do not produce spores. They reproduce by simple cell division. The tiny rod-shaped cells reproduce very rapidly. Cells may divide every 20 to 30 minutes. At this rate, one cell will give rise to 17 million cells in 12 hours. This rapid growth rate accounts for the seemingly explosive nature of bacterial diseases. Large cell numbers confer great bacterial cell surface area for release of enzymes, toxins, or slime. These bacterial products are responsible for much of the damage caused by bacterial infection.

How Are Bacteria Spread?

Blowing Rain: Bacteria ooze out of infected tissue and form a mass of sticky material on the plant surface. Rain drops hit the bacteria and splatter them to new infection sites.

Insects: In the process of pollinating plants, bees crawl through the bacterial ooze and then deposit the organism in blooms. This is the primary means of spreading fire blight of apple and pear from tree to tree. Some bacteria live inside insect vectors and are spread from plant to plant.

People: While picking beans or suckering tomatoes, people can come in contact with bacteria and transfer them from plant to plant on their hands. Never work in the garden when plants are wet.

Seed: Bacteria can live from year to year inside seeds. When infected seeds are shared between gardeners, bacterial diseases can spread. This is why seeds grown in a dry western climate are clean. Avoid saving seeds from your garden unless you are preserving a unique variety.

Diseases caused by Viruses

Viruses are very tiny particles of nucleic acid and protein which can multiply only inside living cells. Virus particles in the cell disrupt normal cell functions and can affect the production of chlorophyll and starch. Infected plants may become yellow or be distorted due to malfunctioning cells. Other symptoms include mottled or puckered leaves, streaks on the leaves or, in some cases, distorted fruit.

How Are Viruses Spread?

Mechanically: Virus diseases can be spread from plant to plant on tools or hands. Some tobacco products may contain tobacco mosaic virus. Gardeners who use tobacco should wash their hands with soap and water, or in milk, before handling plants.

Insects: Insects remove virus particles from infected crop or weed plants when they suck out plant material. The insect can later inject the virus into another plant nearby or some distance away.

Seed: A few viruses are seedborne and are spread when infected seeds are planted.

Diseases caused by Nematodes

Nematodes are very tiny, eel-shaped worms which live mainly in the soil. These tiny worms cannot be seen by the naked eye. Many nematodes feed on plant roots, causing root injury which interferes with the movement of food and water in the plant. Other nematodes may not feed on roots. The pine wilt nematode mainly inhabits and feeds in the resin canals of pine stems and branches. Most nematodes go through several life stages including egg, larva, and adult.

How Do Nematodes Feed?

Nematodes have a spear-like mouth part that works like a hypodermic needle. The nematode inserts this spear or stylet into the root tissue, injects a chemical substance, and then withdraws plant material as it feeds. Root feeding sometimes causes root galls. Root knot and cyst nematodes are examples of root gall forming nematodes. Root feeding by nematodes causes plant tops to be stunted, yellowed, or wilted.

Where Are Nematodes Found?

Nematodes are found in many garden soils. Nematodes can be brought into the garden in the roots of transplants. Once garden soil is infested, the nematodes will generally remain there year after year for the life of the garden since most vegetables make ideal hosts.

Plant disease symptoms and Signs

Symptoms are the plant's expression of being diseased. Examples of symptoms include: blights, cankers, galls, rots, necrosis, and spots. Symptoms are expressed either locally or systemically, and they frequently reflect the structural, functional, or physiological systems disturbed. Diseases that produce few noticeable symptoms are termed "symptomless". Signs are the physical evidence of the pathogen (primary or secondary, vegetative and/or reproductive structures). Some examples include: conks, mildew, mycelium, ooze, pycnidia, and rhizomorphs. Diagnosis of plant disease is based on looking for symptoms and signs.

A dictionary of Plant disease Symptoms and Signs

blight: sudden death of twigs, foliage, and/or flowers.

blotch: large and irregular-shaped spots or blots on leaves, shoots, and stems.

Canker: dead places on bark and cortex of twigs or stems; often discolored and raised or sunken.

Chlorosis: yellowing of normally green tissue due to reduced chlorophyll content, such tissue is *chlorotic*

Conks: fungal fruiting structures formed on rotting woody plants (shelf or bracket fungi).

Damping-off: destruction of seeds in the soil, or seedlings near the soil line, resulting in reduced stand, or the seedling falling over on the ground

Decline: progressive, gradual weakening and death of a plant or population of plants

Dieback: progressive, gradual weakening and death of individual branches of a plant, often leading to decline

Distortion: malformed plant tissues

Flagging: the loss of rigidity and drooping of leaves and tender shoots preceding the wilting of a plant.

Fleck: a minute spot

Galls: abnormal, localized swellings or tumors, on leaf, stem or root tissue

Gum: complex of sugary substances formed by cells in reaction to wounding or infection

gummosis: production of gum by or in a plant tissue

Inoculum: amount of pathogen available for infection

Leaf spot: a self-limiting lesion on a leaf

Lesion: a localized area of discolored, diseased tissue

Malignant: tissue that divides and enlarges autonomously, forming a tumor or gall

Masked symptoms: virus-induced plant symptoms that are normally, but appear when the host is exposed to certain environmental conditions of light and temperature

Mildew: a plant disease in which the pathogen is seen as a growth on the surface of the host; e.g., downy mildew, powdery mildew, caused by very different fungi, but both having the name Mildew.

Mosaic: symptom of certain viral diseases of plants characterized by intermingling patches of normal green and light green or yellowish colors

Mottle: an irregular pattern of indistinct light and dark green areas

Mummy: a dried shriveled fruit

Mycelium: masses of fungal threads (hyphae) which compose the vegetative body of the fungus

Necrosis: death of tissue

Necrotic: dead or discolored brown to black

Ooze: a mass of bacterial cells usually embedded in a slimy matrix appearing on the diseased plant surface, often as a droplet; or, a flux, a viscid mass of juices composed of host and parasite substances occasionally found exuding from a diseased plant

Pycnidia: minute, usually globose and black, fungal asexual fruiting structures formed on plant surfaces

Rhizomorphs: string-like strands of fungal mycelia sometimes found under bark of trees

Ring spot: a circular area of chlorosis with a green center; a symptom of many virus diseases

Rot: the softening, discoloration, and disintegration of succulent plant tissue as the result of fungal or bacterial infection

Russet: brownish roughened areas on skin of fruit as a result of cork formation

Rust: a type of disease caused by a specific group of fungi, often producing orange-red "rust" colored spores.

Scab: a roughened crust-like diseased area on the surface of a plant organ; a disease in which such areas form

Sclerotia: tough structures produced by fungi for long-term survival.

Scorch: burning of leaf margins as a result of infection or unfavorable environmental conditions

Shot-hole: a symptom in which small diseased fragments of leaves fall off and leave small holes in their place

Signs: visible evidence of the pathogen; signs are not the same as symptoms

Spots: circular or irregular lesions on above ground tissue

Tip blight: death of shoot tips

Tumor: a malignant overgrowth of tissue

Vein banding: retention of bands of green tissue along the veins while the tissue between veins has become chlorotic

Vein clearing: destruction of chlorophyll adjacent or in the vein tissue as a result of infection by a virus or other pathogen

Wilt: loss of rigidity and drooping of plant parts generally caused by insufficient water in the plant

Witches' broom: broom-like growth or massed proliferation caused by the dense clustering of branches in woody plants

Yellows: a group of systemic mycooplasma-caused diseases often resulting in wilt, witches broom, or decline

Controlling Diseases

Control of a disease is basically aimed at suppressing the pathogen by altering one or more sides of the disease triangle. This requires knowing as much as possible about a disease. Disease forecasting would be of great value for disease control, but it requires greater knowledge of the disease situation than is available in most cases. Biological, environmental, cultural and chemical controls are all useful, but have their limitations. Thus, it is often necessary to integrate several practices to get good disease control. Plant disease control in the garden is practiced on the population level as well as on the individual plant level. All production practices have some influence on the disease situation, and the disease situation often can be changed dramatically through changes in cultural practices. People are the hardest factors to manipulate in most disease situations. Disease control is a cost to consider in gardening: financially and ecologically.

The importance of understanding the disease development process becomes obvious when considering control options. By the time symptoms are expressed, the pathogen (with few exceptions) is already inside the host plant and is relatively safe. Therefore, control efforts in most cases must occur before penetration has taken place. The overall principle in effective disease control is to keep the inoculum density of the pathogen at very low levels. Success in controlling plant disease will occur when a combination of the following methods of control are used

Avoidance -- A grower can avoid certain diseases by choice of geographic area or by choice of planting site in a local area. Diseases can be avoided by planting at a time that does not favor disease development. Using disease-free planting stock or modifying cultural practices also helps to avoid disease.

Exclusion -- A grower can inspect planting stock for signs of disease and reject or treat any which is suspect. Plant quarantines are designed to exclude certain pests from areas that are free of that pest. Elimination of insect vectors can exclude a disease.

Eradication -- Once a disease is established in an area, eradication is unlikely. However, significant reduction in disease inoculum can be attained by destroying diseased plants or alternate hosts, by rotating crops, or by certain soil treatments.

Protection -- Spraying or dusting plants with fungicides or bactericides is done to protect them from disease. Sometimes modifying the environment or cultural practices may protect the crop. Control of insect vectors will also protect plants.

Resistance -- Breeding and selection are used to develop resistant crops, and resistance can be enhanced through proper culture of a crop. Resistance is not immunity. Improper culture of a resistant variety may negate that resistance. Plants resist pathogens naturally by a variety of defensive measures, both active and/or passive. Resistance to a specific pathogen is the rule, while susceptibility is the exception. Disease resistance follows Mendelian genetic principles. Disease resistance can be either specific or general in nature.

Therapy -- Surgical removal of diseased parts of a plant will sometimes control the disease. There are a few diseases which can be treated with chemicals or heat to gain a degree of control. Familiarity with crops and the diseases and insects that affect them is useful in planning control programs. Some diseases occur every season; others occur sporadically. Some can be controlled easily by using proper methods; others must be tolerated. Knowing which problem falls into which category comes with experience.

Controlling Plant Diseases during the Resting Stage

Many plant disease organisms have a dormant or overwintering stage coinciding with plant dormancy. Where the organism overwinters and how it is disseminated have a considerable influence on the kind of control developed. The following are practical suggestions for controlling disease causing microbes at rest.

Organisms Over wintering on Soil Surface

Many organisms survive on old leaves, branches, mummied fruit, and other debris on the soil surface. Certain control measures are designed specifically to handle surface organisms.

Mulch: Placing a pine needle or leaf mulch beneath shrubs or between the rows in the garden forms a barrier which prevents organisms from moving from soil to plants. Before a new mulch is laid, all diseased debris should be removed.

Cultivation: Cultivating under fruit trees destroys old, mummied fruit and prevents the organism from reproducing and infecting the new crop.

Deep Plowing: When soil is turned four to six inches deep, organisms on the soil surface are buried so deeply that they cannot come in contact with plants.

Sanitation: Removing all old leaves and stems from beneath trees and shrubs eliminates most of the disease organisms on the soil surface. Many diseases reproduce in dead tissue on the soil surface.

Organisms Living in the Soil

Certain organisms live their entire life in the soil, and practically all soil contains parasitic organisms. Most pathogens can live in the soil from 1 to 4 years in the absence of a susceptible host. However, a few pathogens can live in the soil for 30 years without feeding. Crop rotation is a procedure in which non-host crops are used until the pathogenic organisms die out and susceptible crops can once again be grown. This works very well in areas where pathogens die within one to four years in the absence of a susceptible host. Some soil organisms attack only certain crops so these crops should not be grown in the same part of the garden each year. Resistant varieties are the only solution to soil organisms that can live in the soil for 20 to 30 years without a susceptible host. Wilt-resistant tomatoes are a good example of this kind of disease control. Always select disease-resistant vegetable varieties. Chemicals can be used to treat soil in cases where crop rotation is ineffective or when resistant varieties are not available.

Organisms Living in Dead Wood

Several diseases which attack apples, stone fruits, grapes, and many woody landscape plants live and reproduce in dead wood. Pruning all diseased and dead wood will destroy a major portion of this inoculum. Less spraying is necessary when this source of infection has been removed.

Organisms Disseminated by Wind

Many diseases are brought into the garden from great distances by the wind. The only means of controlling diseases spread in this way is to protect the foliage with chemicals. Since we do not know when the wind might blow spores into the garden, we should use protective chemicals on a regular basis. When spores are blown into the garden during dry weather, they do not germinate and penetrate the tissue, so less fungicide is needed during dry weather. Wind-blown spores need a wet surface in order to germinate. For this reason, it is best not to water the garden in late afternoon, allowing the foliage to remain wet during the night. Some spores can penetrate wet tissue in 12 to 15 hours.

Organisms in Seeds

Organisms can easily live in seed and are often spread from garden to garden in this way. For this reason, unless a unique garden variety is being preserved, gardeners should not save seeds from their garden, but should purchase seeds that were produced in parts of the country where diseases do not occur. Seedborne diseases can also be greatly reduced by using a chemical seed treatment.

Survival of Plant Pathogen

Any pathogen can cause disease under favourable conditions. The only requisite factor is that the pathogen must come in contact with the host for the development of the disease. Pathogen itself or its parts that are capable of causing disease when brought near a host is called inoculum. Fungal pathogens are diversified, where the vegetative body (hyphae), dormant mycelium, (embedded in the embryo of seeds or other plant parts), special reproductive structures (rhizomorphs, sclerotia, chlamydospores), various types of asexual spores (sporangia, sporangiospores, zoospores, conidia) and sexual spores (oospores, zygospores, resting spores, ascospores, basidiospores, *etc.)*, serve as inocula. In the case of viruses and plant pathogenic bacteria, the individuals are acting as inocula, since they do not produce any special type of infective units like resting spores or endospores, *etc*. But in the case of *Streptomyces* sp. (Actinomycetes), fragments of filaments and spore-like cells serve as inocula. In phanerogamic parasites, seeds are the potential inocula.

Seeds in the soil survive for longer period. *Orobanche* seeds survive for about 13 years. Seeds are abundantly produced for their multiplication, which could attack the host plants. But dodder is an exception because broken bits of shoot can attack host plant. In any locality a time lag exists between harvest of a crop and subsequent sowing. Year after year, diseases appear in the newly sown crops. There should be some link between the previous crop and the subsequent new crop to revive or continue the life cycle. The existence of the pathogen between the two crop seasons is the vulnerable period in its life cycle. Hence knowledge of the survival ofthe pathogen in the off-season is useful for the plant pathologists to device effective control measures.

The establishment of a plant pathogen in a geographical location presupposes its ability to survive, not only during its parasitic relations with its hosts, but also during off-seasons in which the hosts are not growing. In temperate zones, plant pathogens must be adapted for survival overwinters or oversummers, like the powdery mildew pathogen that attacks fall-seeded wheat. In the Torrid Zone, plant pathogens must be able to survive the dry seasons, during which susceptible plants are not growing.

These sources of survival of pathogens or the sources for renewal of infection chain can be grouped as follows:

1. Survival by means of specialized resting structures
2. Survival as saprophytes
3. Survival in vital association with living plants
4. Survival in association with nematodes and fungi
5. Survival in association with insects
6. Survival on agricultural materials
7. Survival on surface water

1. Survival by means of specialized resting structures

Enduring structures of plant pathogens may be as simple as conidia or as complex as perithecia. Apparently, ascospores or conidia derived from them, serve to carry the pathogen causing peach-leaf curl *(Taphrina deformans)* over the winter. Conidia of *Alternaria solani,* the pathogen of early blight of potato and tomato, survive for eighteen months in dried diseased leaves. Specialized thick-walled chlamydospores of *Fusarium* and other Imperfect fungi, spores of many smut fungi and the amphiospores, uredospores and teliospores of certain rust fungi also are important enduring structures. The resting spores of *Plasmodiophora brassicae* may survive for ten years in soils infested upon the disintegration of clubbed roots. The oospores of downy-mildew fungi survive in the soil between growing seasons. In fact, oospcres of the fungus that causes onion mildew do not germinate until several years after their formation.

Some fungi survive unfavourable seasons in the form of sclerotia. Those produced by the omnivorous cottony-rot fungus, *Sclerotinia sclerotiorum,can* survive for years in a dry atmosphere. They decay rapidly, however, in warm moist soil. Cold induced dormancy probably accounts for their ability to survive winters in temperate zones. Some powdery mildew fungi and other ascomycetes survive with plant refuse. Parasitic phanerogams survive in the form of seeds and as eggs, cysts and larvae of parasitic nematodes serve as overseasoning structures.

2. Survival as saprophytes

The ability to live saprophytically enables many plant pathogens to survive in the absence of growing susceptible plants. Saprophytic survival usually occurs in the soil. Waksman (1971) distinguished between soil inhabitants soil invaders; the former comprise the basic fungal flora of the soil, whereas the latter are short-lived exotics. As applied to the root infecting fungi soil inhabitants are unspecialized parasites with a wide host range that are able to survive-indefinitely in the soil as saprophytes; soil invaders (root inhabiting fungi) are more specialized parasites that survive in soils inclose association with their hosts. Most plant pathogenic fungi and bacteria are soil invaders, but some pathogens, notably *Rhizoctonia solani* and *Pythium debaryanum* that cause seedling blights and root rots, live saprophytically in the soils.

The microbiological balance in the soil markedly affects the survival of saprophytic plant pathogens there. Apparently, Sanford (1926) was the first to suggests that control of potato scab by green manuring with grass might be due antagonistic action of saprophytic organisms flourishing on the green manure. Not only do soil saprophytes antagonize other microorganisms by toxic but also some such as *Trichoderma Iignorum* actually parasitize Rhizoctonia *solani* and other soil-borne pathogens. Despite antagonism and parasitisim by other organisms, many plant pathogens survive in the soil as inhabitants or invaders. The special conditions that favour biological control of plant pathogens in sterilized soil or in culture are nonexistent in field soil, in which there is a complex microflora and a low concentration of nutrients.

Certain plant pathogens survive between growing seasons as saprophytes in the dead tissues of susceptible plants. Such organisms are only incidentally associated with the soil, and live only as long as tissues of susceptible plants are available to supply nutrients. Most plant-pathogenic bacteria and many specialized parasitic fungi survive in this manner. The apple scab pathogen *(Venturia inaequalis)* lives parasitically in leaves and fruits during the growing season, but becomes saprophytic in fallen leaves. Perithecia form in these leaves during the winter, but ascospores do not form until spring. Ascospores of certain other ascomycetes mature during the winter, but are protected from adverse conditions by perithecial walls. Soil inhabitants include obligate saprophytes and facultative parasites and they are exo - pathogens. Whereas soil invaders (root inhabitants) include facultative saprophytes and obligate parasites and they are endopathogens (root infecting fungi).

Plant pathogenic bacteria can saprophytically survive or actively multiply in the rhizosphere or rhizoplane of healthy host and non-host plants. *Erwinia carotovora* subsp. *carotovora* has been considered to survive in soil. However, some recent studies have shown that soft rot *Envinia cannot* persist for a long time in fallow soil. *E. carotovora* subsp. *carotovora* multiplies in the rhizosphere of many cruciferous plant species, where the population can readily increase from 10^2 cells/g in fallow soil to 10^4 to 10^6 cells/*g* in soil subjected to the rhizosphere effect of chinese cabbage. *Pseudomonas glumae,* the causal agent of bacterial grain rot of rice, remains on rhizosphere and / or rhizoplane of the rice plant from germination to tillering stage. *Burkholderia solanacearum* and species of *Agrobacterium* are best known with a prolonged soil phase, which can be regarded as the true soil-borne pathogens.

3. Survival in vital association with living plants

Survival of the plant pathogens in vital association with living plants is grouped into

a. Seed

The pathogen of loose smut of wheat, *Ustilago nuda tritici,* enters the stigma and style and infects the young seed, in which it survives as mycelium. The seed-infecting pathogens that cause loose smut of wheat and loose smut of barley are strikingly different from other smut fungi that attack cereal crops. Most of the others survive from season to season either in non-pathogenic association with seed or as spores in the soil. *Colletotrichum lindemuthianum,* the causative organism of bean anthracnose, can also infect the seed; unless the seed is killed, the fungus in newly sprouted bean seedlings initiates new infections. The bacteria that cause bean blights and bacterial blight of cotton survive the winter in infected seed. In Mexico, the fungus of late blight of potatoes *(Phytophthora infestans)* produces oospores but in colder regions of the world, the fungus overwinters as mycelium in diseased tubers.

Lenticels of potato tubers may carry soft rot *Erwinia* at the maximum level of 100 cells/lenticel, although the infested tubers do not necessarily develop soft rot in the field. Examples of the plant pathogenic bacteria that survive in seed/planting materials are given in the following Table 1.

Table 1. Plant pathogenic bacteria surviving in seeds and planting materials.

SI. No	**Disease**	**Bacteria**
	a. Seed	
1.	Bacterial canker of tomato	*Clavibacter michiganensis* subsp *michiganensis.*
2.	Bacterial brown stripe of rice	*Pseudomonas avenae*
3.	Bacterial blight of cotton	*Xanthomonas axonopodis* pv.

		malvacearum
	b. Planting material	
3.	Ring rot of potato	*Clavibacter michiganensis* subsp. *sepedonicus*
4.	Bacterial wilt of carnation	*Pseudomonas caryophylli*
5.	Bacterial wilt of potato and ginger	*Burkholderia solanacearum*

b. Collateral hosts

Collateral hosts are those, which are susceptible to the plant pathogens of crop plants and provide adequate facilities for their growth and reproduction of these pathogens. Weeds, which survive and live during non-cropping season provide for the continuous growth and multiplication of the pathogen. For example, the fungal pathogen for blast disease of rice, *Pyricularia oryzae* can infect the grass weeds like *Bracguarua mutica*, *Dinebra retroflexa*, *Leersia hexandra*, *Panicum repens,* etc., and survive during off-season of rice-crop. As soon as a fresh rice crop is raised, the conidia (inoculum) liberated from the weed host disseminated by wind infect the fresh rice crop. Thus the weed hosts help to bridge the gap between two rice crops. Hence the pathogen can be able to line continuously in the vicinity on these hosts inspite of the non-cropping period intervening between two cropping periods. Intensive cultivation of particular crop repeatedly and constantly also provides perpetual inoculum. Powdery mildew and viral diseases of cucurbits are also best examples, where, number of cultivated crops serves as collateral hosts.

The survival of the plant pathogens on collateral hosts/ alternative hosts which include the weed hosts also. The collateral/weed hosts which are present in the field and in the bunds harbour the plant pathogens during cropping season. But the collateral/weed hosts present in the bunds harbour the plant pathogens during off-season. The pathogens can survive in active sporulating stage on wild collateral hosts and from their wind or insect to primary inoculum. Plant pathogenic bacteria may be able to disseminate in the parasitic form on annual and perennial weeds. For example, the long-term survival of *Pseudomonas avenae* in Florida is attributed to *the* association with a perennial grass, *vasey* grass *(Paspalum urvillei), through* repeated infection of its vegetative *growth as* well *as* seed transmission. Bacterial leaf *blight* of maize may have its origin in the infected vasey *grass* distributed in *the* field. *This* list of collateral weed *hosts* for the plant pathogens is given in the Table below:

Table: Collateral *hosts* (alternative *hosts)* of plant pathogens

Pathogen	**Disease**	**Principal *host***	**Collateral *hosts* / Alternative hosts**
	1. Fungal diseases		
Sclerospora graminicola	Downy *mildew*	Pearlmillet, Fox-tail, *Millet*	*Echinochloa* sp., *Euchlaena* sp., *Panicum* sp.
Peronosclerospora heterogoni	Downy mildew	Com	*Euchlaena* sp., *Heteropogon* sp.
P. sorghi	Sorghum downy mildew	Corn, Sorghum	*Andropogon* spp., *Euchlaena* sp., *Heteropogon contortus,* *Panicum trypheron*
Erysiphe cichoracearum	Cucurbit powdery mildew	Cucurbits weeds	Many cucurbitaceous
Rhizoctonia solani	Web blight	Cowpea	*Amaranthus spinosus, Aspilia africana*
	Bacterial diseases		
Xanthomonas oryzae ov oryzae	Bacterial leaf blight	Rice	Cyperus spp Leersia hexandra
Pseudomonad rubrilineans	Red stripe anad top rot	Sugar cane	Sorghum halepense S. sudanense
X. axonopodis pv. malvacearum	Bacterial blight	Cotton	Eriodendron anfructuosum, Jatropha curcas Lochnera curcas Thurbaria thespesoides
	Virus and Phytoplasma diseases		
Cucumber mosaic	Mosaic	Saffflower	Amaranthus blitum, datura

virus			metel Physalis minima Solanum nigrum
Rice tungro virus	Rice tungro	Rice	*Oryza* spp, *Echinochloa colona,* *E. crusgalli,* *Leersia hexandra*
Bhendi yellow vein mosaic virus	Bhendi yellow vein mosaic virus	Bhendi	*Hibiscus tetraphyllus*
Tomato spotted wilt virus	Ring mosaic	Groundnut	*Bidens pilosa* *Tagetes* sp.
Phytoplasma	Little leaf	BrinjaI	*Datura* sp., *Catharanthus* sp.

c. Alternate hosts

The role of alternate hosts is not important as of collateral hosts. However, when a pathogen has very wide host-range and is tolerant to wide range of weather conditions the alternate hosts become very, important source of survival of the pathogen. These alternate hosts are very important for the completion of the Iifecycle of heteroecious rust pathogens. e.g. in temperate regions the alternate host *Berberis vulgaris* of *Puccinia graminis tritici* (black/stem. rust pathogen on wheat), the barberry bush, grows side by side with the cultivated host, wheat. In such areas this wild host belonging to a different family is important for survival of the fungus. It helps in completion of heterogeneous infection chain of the rust fungus. The list of alternate hosts for important plant pathogenic survival is given in the Table 4.

Table 4. Alternate hosts of plant pathogens

Fungal pathogen	**Disease**	**Primary host**	**Alternate host**
Puccinia graminis tritici	Stem rust / Black rust	Wheat	*Barberis vulgaris*
Puccinia recondita	Leaf rust / Brown rust/ Orange rust		*Thalictrum flavum*

Puccinia coronata	Crown rust	Oat	*Rhamnus*
Puccinia anomala	Brown rust	Barley	Lily
Puccinia dispersa	Brown rust	Rye	*Anchusa* sp
Puccinia purpurea	Rust	Sorghum.	*Oxalis corniculata*
Puccinia substriata var. *penicillariae*	Rust	Pearl- millet	Brinjal
Puccinia sorghi	Leaf rust	Maize	*Oxalis corniculata*
Cronartium ribicola	Blister rust	Currant	Pine
Gymnosporangium juniperi-virginianae	Cedar rust	Cedar	Apple

d. Self sown crops

Self-sown plants, voluntary crops and early sown crops are reservoirs of many plant pathogens e.g., groundnut rust pathogen, *Puccinia arachidis* and ring mosaic of groundnut caused by tomato spotted wilt virus. Self-sown rice plants harbour the pathogen as well as vector. e,g., rice tungro virus and its vector, *Nephotettix virescens.*

Perennial crops also playa major role in the survival of the plant pathogens. Pathogens, which infect perennial plants, can survive in them during low winter temperature and/or during the hot, dry weather of the summer. They survive in the lesions on perennial host plants, which may be actively growing or are donnant. Disease like bunchy top of banana survives continuously in the suckers produced by the mother plants. In citrus canker the bacterium, *Xanthomonas axonopodis* pv. *citri* survives in the cankers formed on the leaves and twigs of the standing tree. They mostly survive in mild or vigorous active form on hosts, *Citrus* sp. Other examples are *Erwinia amylovora* and *Xanthomonas campestris* pv. *pruni.*

e. Ratoon Crops

Sometimes ratoon crop also harbour the plant pathogens e.g., sugarcane mosaic.

f. Survival by latent infection

Latent infection refers to the conditions in which the plant pathogens may survive for a long time in plant tissue without development of visible symptoms. Eg. *Pseudomonas syringae* pv. *syringae* and *X axonopodis* pv. *citri* can survive in apparently healthy bark tissues of their tree hosts. *Xylella fastidiosa,* the causal agent of Pierce's disease of grapevine and leaf scorch disease of various fruits and leaf ornamental trees infect diverse kinds of weeds without developing visible symptoms. Because these weeds are usually favourable habitats for the vector insects, latently infected weeds become an important source of the carrier insects.

g. Survival as residents

S.No	Disease	Bacteria
1.	Fire blight of apple and pear	Erwinia amylovora
2.	Soft rot of chinese cabbage	*Erwinia carotovora subsp.carotovora*
3.	Bacterial grain rot of rice	*Pseudomonas glumae*
4.	Bacterial blight of soybean	*Pseudomonas· syringae pv. glycinea*
5.	Angular leaf spot of cucurbits	*Pseudomonas syringae* pv. *lachrymans*
6.	Bacterial canker of stone fruits	*Pseudomonas syringae pv. morsprunorum*
7.	Bacterial brown spot of bean	*Pseudomonas. syringae* pv. *syringae*
8.	Bacterial speck of tomato	*Pseudomonas syringae* pv. *tomato*
9.	Bacterial blight of cotton	*Xanthomonas axonopodis* pv. *malvaceqrum*
10.	Bacterial blight of cassava	*Xanthomonas axonapodis pv.manihotis*
11.	Common blight of bean	*Xanthomonas campestris* pv. *phaseoli*

Plant pathogenic bacteria have the capacity to grow on the surface of host and non-host plants utilizing the small amount of nutrients that are secreted on the plant surface. Survival as residents in the phyllosphere by bacteria is given below:

4. Survival in association with nematodes and fungi

Plant viruses like wheat mosaic, wheat spindle streak virus, lettuce big vein, tobacco necrosis, tobacco rattle and tobacco ring spot viruses survive with nematodes or fungi found in the soil between crop seasons. Tobacco ring spot virus is associated with the nematode, *Xiphinema americanum.* The fungus, *Polymyxa graminis (Barley yellow mosaic, oat yellow mosaic, wheat soil-borne mosaic, wheat spindle-streak mosaic)* and Spongospora *subterranea* (potato mop top) carry the viruses internally and transmit.them through their resting spore. Viruses are retained by nematode vectors for long times (stable). *Xiphinema* sp. retained viruses for a considerable Iength of *time, while Longidorus* spp *and Trichodorus* spp. retained them for a much less period of one or two months only.

5. Survival in association with insects

Many insects are carriers of inocula during the growing season and several important plant pathogens survive between growing seasons within insects. Some bacterial plant pathogens may survive within the insect body and over winter therein. The com flea beetle, *Chaetocnema pulicaria* Melsh carries inside its body, the com wilt pathogen, *Xanthomonas stewartii and* thus helps in its overwintering. The cucumber beetles, *Diabrotica vitata* Fabr. and *D. duodecimpunctata* Oliv., which chew the plant parts affected by *Erwiniatra cheiphila* carry the pathogen inside their body, where it over winters. In the following seasons the insect passes on the bacterial pathogen to the host plant.

These insect vectors effectively transmit the bacterial pathogen causing wilt of cucurbits. It is reported that the bacterial pathogen and the -insect vectors live in a symbiotic relationship, the insects helping the bacterium with protection from adverse weather conditions and the bacterium helping the insects with a supply of some digestive enzymes while it is inside the insect's body. Plant viruses and phytoplasmas multiply within the vectors and can overwinter in those insects. Semi-persistent viruses are retained in the vectors for periods ranging from hours to days. Example, citrus tristeza virus is retained in the aphid T*oxoptera Citricida. Persis*tent viruses retain the viruses from days to week. Most of the hopper borne viruses multiply in their vectors. Viruses are retained through the moult and the vectors frequently remain viruliferous for life important. Vectors, which retain the viruses, are given below:

Leaf hopper transmitted viruses

	Vector	**Virus**
Leaf hopper	*Circulifer tenellus*	Beet curly top virus
Plant hopper	*Cicadulina mbila*	Maize streak virus
Green leaf hopper	*Nephotettix cincticeps*	Rice dwarf virus
Brown plant hopper	*Nilaparvata lugens*	Rice grass stunt virus
Hopper	*Agallia constricta*	Wound tumour virus

Transovarial transmission of the virus to the eggs of the vectors occurs and the virus can multiply within a viruliferous hopper even if the insect is feeding on an inimune host plant. Eggs carrying viruses may overwinter and provide a source of virus to infect spring crops, even in the absence of diseased plants. Phytoplasmas attacking plants also multiply in the insects and remain infective throughout their life period. e.g. Rice dwarf virus (RDV) is transmitted through the eggs to about 60% of the progeny of the infective female leafhopper, *Nephotettix cincticeps.* RDV passes through the eggs to six succeeding generations. Clover club leaf is transmitted through 21 generations of the leafhopper vector, *Agalliopsis novel/a* over a span of five years.

6. Survival on agricultural materials

Clavibacter michiganensis subsp. *michiganensis* has been shown to survive in air-dried conditions for 7 to 8 months on the surface of wooden stakes and boxes or wires or for 15 months in air-dried tissues of diseased tomato plants.

7. Survival on surface water

Erwinia carotovora subsp. *carotovora* is detected from water from drains, ditches, streams, rivers and lakes in mountainous upland and arable areas of Scotland and Colorado throughout the year.

Dispersal of Plant Pathogens

Transport of spores or infectious bodies, acting as inoculum, from one host to another host at various distances resulting in the spread of disease, is called dissemination, dispersal or transmission of plant pathogens. It is very important for spread of plant diseases, for continuity of the life cycle and evolution of the pathogen. The spores of some fungi are expelled forcibly from the sporophore or sporocarp by a squirting or puffing action that results in successive or simultaneous discharge of spores up to a centimetre or so above the sporophore.

The seeds of some parasitic plants are also expelled forcibly and may arch over distances of several metres. These are dispersed mechanically by various means. In bacterial diseases, the bacterial cells come out on the host surface as ooze or the tissues may be disintegrated so that the bacterial mass is exposed and then dispersed by various physical and biological agencies. Insects, mites, phanerogamic parasites nematodes and human beings transmit viral diseases, which have no such organs.

The knowledge of these methods of dispersal is essential for effective control of plant diseases because possibilities of preventing dispersal and thereby breaking the infection chain exist.

The dispersal of infectious plant pathogens occurs through two ways,

I. Autonomous or direct or active dispersal

II. Indirect or passive dispersal

I. Autonomous dispersal

It is also known as active or direct dispersal. In this method the dispersal of plant pathogens (fungi, bacteria, and viruses) takes place through soil and seed or planting materials during normal agronomic operations.

1. Soil as means of autonomous dispersal

Soil-borne facultative saprophytes or facultative parasites may survive through soil. The dispersal may be by movement of the pathogen in the soil or by its growth in soil or by movement of the soil containing the pathogen. The former is known as dispersal in soil while the latter is called dispersal by soil.

a. Dispersal in soil

The following are the three stages of dispersal in soil.

i. Contamination of soil
ii. Growth and spread of the pathogen in soil
iii. Persistence of the pathogen

i. Contamination of soil

Contamination of the soil takes place by gradual spread of the pathogen from an infested area to a new area or by introduction of contaminated soil, plant debris to a new area or by introduction of infected seed or planting materials.

ii. Growth and spread of the, pathogen in soil

Once the pathogen has reached the soil it can grow and spread "depending on the multiplication and spread. Multiplication and spread depends on the characters of the pathogen, presence of susceptible host and cultural practices. The adaptability of the pathogen to the soil environment includes saprophytic survival ability. The survival ability of the pathogen is governed by high growth rate, rapid spore germination, better enzymatic activity, capability to produce antibiotics and tolerance to antibiotics produced by other soil microorganisms. The active saprophytic survival of facultative saprophytes and facultative parasites in soil is affected by soil structure, moisture, organic matter, pH; antagonism etc., Specialized facultative parasites (or saprophytes) can pass their life in soil in the absence of the hOst plants, but they depend more on the residues of their host plant. e.g., *Armillariel/a mel/ea, Ophiobolus graminis, Phymatotrichum omnivorumand Fusarium.* The non-specialized facultative parasites can pass their entire life in the soil. e:g., *Pythium* sp., *Phytophthora* sp., The soil-borne obligate parasites. such as *Plasmodiophora brassicae*, *Synchytrium endohioticum* requires the presence of active host.

Ill. Persistence of the pathogen

The pathogens persist in the soil as dormant structures like oospores *(Pythium; Phytophthora, Sclerospora,* etc.) chlamydospores *(Fusarium)* or smut spores *(Ustilago)* or sclerotia *(Rhizoctonia, Sclerotium,* etc.)

b. Dispersal by the soil

The pathogen enters the soil, grow and spread in the soil. During the cultural operations in the field, soil is moved from one place to the nearby place through the agricultural implements and irrigation, worker's feet. Propagules of fungi or the dormant structures of fungi and the plant debris containing the fungal and bacterial pathogens thus spread throughout the field.

2. Seed and seed materials as the source of autonomous dispersal

The seeds serve as medium for autonomous dispersal of pathogens. Since most of the cultivated crops are raised from seed the transmission of diseases and transport of pathogens by seeds has much importance. The dormant structures of the pathogen (e.g., seeds of *Cuscuta*, sclerotia of ergot fungus, smut sori, etc.,) are found mixed with seed lots and they are dispersed as seed contaminant. The bacterial cells or spores of fungi present on the seed coat (such as in smuts of barley, sorghum, etc.,) are transported to long distances. Dormant mycelium of many fungi present in the seed is transmitted to long distances.

This type of dispersal is highly erratic. The most important methods of dispersal of pathogen by the soil are transfer of soil from one place to another along with plant parts or propagating materials. e.g., transfer of papaya seedlings from a nursery infested with *Pythium aphanidermatum* (the cause of stem or foot rot of papaya) C311 introduce the pathogen in new pits for transplanting the seedlings. Similarly grafts of fruit trees transported with soil around their roots can transmit pathogens present in the nursery to the orchards. By this method, pathogens are not only spread from field to the field but also from district to district, State to State and often from country to country. There are three types of dispersal by seed *viz.*,

a. Contamination of the seed

b. Extemally seed - bome, and

c. Intemally seed - bome

Contamination of the seed

Seed -borne pathogens move in seed lot as separate contaminants without being in intimate contact with the viable crop seeds. The seeds of the pathogen or parasite and the host are getting mixed during harvest of the crop. In many cases, the identity ofthe seeds of the two entities (host and the parasite) is difficult to separate. e.g., smut of pearl millet *(Tolyposporium penicillariae)*, ergot of rye and pearlmillet *(Claviceps purpurea* and C. *jusiformis* respectively). Smut soil and ergots mix easily with the seed lots during harvest or threshing. In many smuts such as Kamal bunt of wheat *(Neovossia indica)* and bunt of rice *(Neovossia horrida)* the infected kernels containing smut sori are mixed with the seed. In leaf smut of rice *(En tyloma oryzae)* leaf pieces containing smut sori are mixed with the seed.

Externally seed-borne

Close contact between structure of the pathogen and seeds is established in

diseases like covered smut and loose smut VI Daney, snoll smut ot sorghum, stinking smut of wheat and bacterial blight of cotton where the pathogen gets lodged in the fomi of donnant spores or bacteria on the seed coat during growth of the crop or at the time of harvest and threshing. In many pathogens the externally seed-borne Structures such as smut spores can persist for many years due to their inherent capaCity for long survival. The spores of *Tilletia caries* (stinking smut of wheat) remain viable even after 18 years and those of *Ustilago avenae* (oat smut) for 13 years.

Internally seed-borne

The pathogen may penetrate into the ovary and cause infection of the embryo while it is developing. They become internally seed-borne. Internally seed borne pathogens like *Usti/ago nuda tritici* are viable for more than 15 years. Other examples include *Helminthosporium oryzae, Sclerospora graminico/a*, etc. The bacterial pathogens include *Xanthomonas oryzae* pv. *oryzae* on rice, *Pseudomonas syringae* pv. *syringae* in cucurbits, *Xanthomonas campestris* pv. *campestris* on crucifers, etc.

Mainly man distributes seeds of cultivated crops. Sometimes animals and birds also help in distribution of crop seeds. Man and animals are the main agencies of dispersal of pathogen through seed. The pathogens thus mixed with the seed or on the seed are transmitted.

Passive dispersal

Passive dispersal of plant pathogens happens through

I. Animate agents

a. Insects

b. Mites

c. Fungi

d. Nematodes

e. Human beings

f. Farm and wild animals

g. Birds

h. Phanerogamic parasites

II. Inanimate agents

a. Wind

b. Water

1. Animate agents

a. lnsects

Insects carry plant pathogens either externally or internally. Gaiiman (1950) used the terms epizoic and endozoic respectively for these two types of transmission. The external transmission of plant pathogens is of special interest in those fungi, which produce their conidia, oidia and spermatia in sweet or honey secretions having attractive' odours. Some Qfthe well known diseases of this type are the ergot, the *Sc1erotinia* brown rot of pear and apple, the honey dew stage in the 'sugary disease' of sorghum and pearlmillet in parts of India and the pycnial nectar in the cluster cup stage of rusts. The spermatial oozing at the mouth of spermagonia in the Ascomycetes attract various types of insects, flies, pollinating bees and wasps which playa dual role *viz.,* pollination and transmission' of pathogens. The fire blight organism *(Erwinia amylovora)* pathogens and citrus canker bacterium, *(Xanthomonas axonopodis* pv. *cirri)* are also carried in this manner, the former by flies (bees) and ants and the latter by the leaf miner. The black leg of potato caused by *Erwinia carotovora* is disseminated by maggots, wilt of com caused by *X. stewartii,* gummosis of sugarcane caused by *X vasculorum* are the other examples for bacterial diseases transmitted by insects.

Ingenious transmission of pathogens, of an internal nature (endozoic) is provided by the

Dutch elm disease *(Ceratostomella ulmi)* and the olive canker *(Bacillus savastano i).* The former is transmitted by the elm bark beetles and the latter by the olive fly *(Olea . europaea).* These insects, unlike the epizoic group, appear to have a close biologic relationship with the pathogens, as they have not been reared without the contaminating pathogens.

Insects spread few important plant pathogenic bacteria. The cucumber wilt bacterium, *Erwinia tracheiphila* is spread by the striped cucumber beetles *(Acalymma vitata)* and the spotted cucumber beetle *(Diabrotica undecimpunctata).* When the beetles are feeding on the diseased plant, the bacterium contaminates the mouthparts and passes into the gut of the insect. During the winter season, the bacterium overwinters inside the beetle. Thus the beetle helps the bacteria in two ways, i.e. in their transmission and survival.

Different types of insects spread more than 80 per cent of the viral and phytoplasmal diseases. The insect, which act as specific carriers in disseminating the diseases, are called insect vector.

Both aphids (Aphidae) and leafhoppers (Cicadellidae or Jassidae) in the order Homoptera contain largest number and the most important insect vectors of plant viruses. Certain species of mealy bugs and scale insects (Coccoidae), whiteflies (Aleurodidae) and treehoppers (Membracidae) in the same order (Homoptera) also transmit virus diseases. Insect vectors of plant viruses are few in true bugs (Hemiptera), thrips (Thysanoptera),beetles (Coleoptera) and grasshoppers (Orthoptera). Aphids, leafhoppers and other groups of Homoptera and true bugs have piercing and sucking mouthparts. Thrips have rasping and sucking mouthparts. All other groups of insect vectors have chewing mouthparts and they transmit only very few viruses.

Aphids

Aphids are the most important insect vectors of plant viruses and transmit the great majority of all stylet - borne viruses. As a rule several aphid species can transmit the same stylet - borne virus and the same aphid species can transmit several viruses, but in many cases the vector-virus relationship is quite specific. Aphids generally acquire the stylet-borne virus after feeding on a diseased plant for only a few seconds (30 seconds or less) and can transmit the virus after transfer to and feeding on a healthy plant for a similarly short time of a few seconds. The length of time aphids remain viruliferous after acquisition of a stylet-borne virus varies from a few minutes to several hours, after which they can no longer transmit the virus. In few cases of aphid transmission of circulative viruses, aphids cannot transmit the virus immediately but must wait several hours after the acquisition feeding, but once they start to transmit the virus, they continue to do so for many days following the removal of the insects from the virus source. In aphid transmitting stylet-borne viruses, the virus seems to be borne on the tips of the stylets, it is easily lost through the scouring that occurs during probing of host cells, and it does not persist through the moult or egg. The examples of aphid transmitted plant viruses are given in the following Table.

S.No	Virus	Vector	Type of transmission
1.	Bean common Mosaic	*Acyrthosiphon pisum*	Non persistent
2.	Bean yellow mosaic	*A. pisum*	Non - persistent
3.	Citrus tristeza	*Toxoptera citricida*	Non - persistent
4.	Pea enation mosaic	*A. pisum*	Persistent
5.	Beet yellows	*M. Persicae*	Semi persistent

Leaf hoppers

Leaf hoppers are phloem feeders and acquire the virus from the phloem region. All leaf hoppers, transmitted viruses are circulatory. Several of these viruses multiply in the vector (propagative) and some persists through the moult and are transmitted through the egg stage of the vector. Most leaf hopper vectors require a feeding period of one to several days before they become viruliferous, but once they have acquired the virus they may remain viruliferous for the rest of their lives. Usually there is an incubation period of 1 to 2 weeks between the time a leaf hopper requires a virus and the time it can transmit it for the first time.

b. Mites

Mites belonging to the families eriophyidae (eriophid mite) and tetranychidae (spider mite) transmit plant viruses.

c. Fungi

C. Fungi

Some soil - borne fungal plant pathogens transmit plant viruses. *Olpidium brassicae, Ploymyxa graminis, P. betae* and *Spongospora subterranea* are the fungi involved in transmission of virus disease. The viruses are apparently borne in or on the resting spores and the zoospores, which upon infection of new host plants introduce the virus and cause symptoms characteristic of the virus they transmit. All these fungi are pathogens of the host, which carry of viruses. The zoospores of the fungi are released from the host and the zoospores carry the virus and transmit it to the susceptible hosts during their infection process. In some cases plant viruses are carried on the outside of the fungi. Examples are tobacco necrosis virus and cucumber mosaic virus.

The viruses like lettuce big vein virus are found inside the zoospores. They persist for years in viable resting sporangia. The types of transmission by fungi can be considered as non-persistent and persistent transmission. The list of fungi and the virus diseases transmitted by them are given in the following table.

S.No	Fungal vector	Disease
1.	Olpidium brassicae	Lettuce big vein, Lettuce necrosis, Tobacco stunt, Tobacco necrosis satellite
2.	Synchytrium endobioticum	Potato virus
3.	Spongospora subterranea	Potato mop top

d. Nematodes

Nematodes are soil borne organisms. Some of the nematodes act as agents for dissemination of pathogenic fungi, bacteria and viruses. For example, the bacterium *Corynebacterium tritici* that causes yellow ear rot of wheat is disseminated by ear cockle nematode. Similarly, some pathogenic fungi such as, *Phytophthora, Fusarium, Rhizoctonia,* etc., are carried on the body of nematodes. Nematodes help these pathogenic fungi to enter into the host through punctures for their own entry and enter into hosts along with the nematodes. Plant nematodes play a vital role as vector in transmitting certain virus diseases. Nematode vectors transmit viruses by feeding on roots of infected plants and then moving on roots of healthy plants. Larvae as well as adult nematodes can acquire and transmit viruses, but the virus is not carried through the larval molts or through the eggs. After moulting, the larvae or the resulting adults must feed on a virus source before they can transmit again. Xiphinema, Longidorus and Trichodorus transmit both the polyhedral and tubular type of viruses. The important viral diseases transmitted by nematodes are given below:

Virus group	Virus	Vector
Tobra virus (Tobacco rattle group virus)	Pea early browning, Tobacco rattle	Paratrichodorous sp. Trichodorous spp
Nepo virus (Nematode transmitted polyhedral virus)	Grapevine chrome virus Tobacco Ringspot Tomato ringspot	Xiphinema index X. americanum X. americanum

e. Human being

Man is the most important factor responsible for short distance and long distance dispersal of plant pathogens. He helps in dissemination unknowingly by his usual agricultural practices. Human being's role in dissemination of plant pathogens is more direc of plant pathogens by human beings is known anthropochory. The ways and means by which human beings help in dispersal are as follows.

i. Transportation of seeds (Seed trade)

Seed trade is one of the different means of dispersal of plant pathogens in which man plays an important role. The import and export of contaminated seeds without proper precautions lead to movement of pathogens from one country to another or from one continent to another. Through this way pathogens of soybean and sugarbeet hither to not prevalent in India got introduced. Human agencies of individual, official and unofficial have transported new plants and plant products, the seed, the tubers, the propagating stock and fruits, which carried the plant pathogens, many times in a latent condition and which ultimately lead to the outbreaks of new diseases in places, hither to free from them. The diseases which are amenable to such transmission are mainly those that are carried in or on the propagative parts and seed such as late blight of potato, the downy mildew of grapevine, citrus canker, chestnut blight, Dutch elm disease, *Fusarium* wilt of banana, Katte disease of cardamom and buncilY top of banana. A few such diseases together with their places of origin and years and introduction are given in Table below:

Disease	Original home	Introduced country	Year of introduction
Citrus canker	Asia	USA	1907
Fireblight of apple	USA	New Zealand	1919

Powdery mildew of grape vine	USA	Europe	1845
Downy mildew of grapevine	USA	France	1878
Late blight of potato	South America	USA	1830
Panama disease of banana	Panama Islands	Bonbay	1920
Bunchy top of banana	Sri Lanka	South India	-

Many of these diseases, not very destructive in their homelands, have brought in ruin and devastation. The sale of seeds for crops badly affected by a seed-borne pathogen is a common method of dispersal of destructive pathogens e.g. loose smut of wheat *(Ustilago nuda tritici)*, grain smut of sorghum *(Sporisorium sorghi)*, ergot of pearl millet *(Claviceps fusiformis)* and Kamal bunt of wheat *(Neovossia indica).*

ii. Planting diseased seed materials (vegetatively propagated materials)

Planting diseased bulbs, bulbils, corns, tubers, rhizomes, cutting etc. of vegetatively propagated plants such as potato, sweet potato, cassava, sugarcane, banana, many ornamentals and fruit trees etc. help in dispersal of pathogens from field to field, orchard to orchard, locality to locality or from one country to another.

iii. By adopting farming practices

Human beings (men and women) engaged in preparatory cultivation, planting, irrigation, weeding, pruning etc. help in dispersal of plant pathogens. The fungal spores (oospores, chlamydospores), dormant structures like sclerotia are carried by worker's clothing, shoes, hand etc. from field to field. Men or women engaged in intercultivation in tobacco field spread the dreaded tobacco.

iv. Through clothing

Palm workers engaged in cleaning coconuttrees spread bud rot disease.

v. By use of contaminated implements

Pathogens are transferred from one area to another through implements used in various cultural operations (weeding, hoeing thinning etc.) in the field. e.g: root rot of pulses and cotton

(Macrophomina phaseo/ina, bacterial angular leaf spot of cucumber *(Pseudomonas /achrymans)* and bacterial canker of tomato *(Corynebacterium michiganensis).* Cutting knives and pruning knives help in dissemination from one plant to another e.g., Bunchy top of banana.

vi. By use of diseased grafting and budding materials

Grafting and budding between healthy and diseased plants is the most effective method of distribution of pathogens of horticultural crops (fruit trees, ornamentals etc.) e.g., Careless selection of stocks and scions in propagation of citrus trees.

f. Farm and wild animals

Farm animals (cattles) while feeding on diseased fodder ingest the viable fungal propagules (spores or oospores or sclerotia) into their digestive system. Animals which feed on downy mildew affected pearlmillet or sorghum take the oospores along with the fodder. Oospores pass out as such in the dung. This dung when used as manure spread in the field and act as source of inoculum. Smut fungi like grain smut of sorghum, loose smut and head smut of sorghum are carried from field to field through the alimentary canals of farm animals. Soil inhabiting fungi especially sclerotia adhere to the hoofs and legs of animals and get transported to other places. Animals passing through the tobacco fields help in transmission of TMV.

g. Birds

In general, transmission by birds is of minor importance. But this method is important in dissemination of seeds of flowering parasites and certain. fungi. Many migratory birds, such as mistle thrush *(Turdus viscivorus)* in the temperate region and the crows *(Crovos brachyrhynchos)* in the tropics, take active part in the transmission of giant mistletoe *(Dendrophthoe* spp.) either through external contamination of their beaks and feathers or internally through the alimentary canals. These birds feeding on the fleshy, sticky and gelatinous berries of giant mistletoe deposit the seeds on the other trees with the excreta.

Stem segments of dodder *(Cuscuta* spp.) are carried by birds for buildingtheir' nests. Thus the phanerogamic parasites are getting transported to new locations. Spores of chestnut blight fungus, *Endothea parasitica* are disseminated by not less than 18 species of birds. Internal transmission of this pathogen is carried out by the birds, which visit such diseased plants and get contaminated by the spores. Birds are also known to carry the spores of fungi on their, body.

h. Phanerogamic parasites

Plant viruses are transmitted from one plant to another through the bridge formed between the two plants by the twining stems of the parasitic plant dodder *(Cuscuta* spp). Dodder is yellow vine without green leaves. In this way viruses are transmitted between plants belonging to families widely separated taxonomically. The virus is transmitted in the food stream of the dodder plant, being acquired from the vascular bundles of the infected plant by the haustoria of dodder. After translocation through the dodder phloem the virus is introduced in the next plant by the new dodder haustoria produced in contact with the vascular bundles of the inoculated plant. *Cuscuta californica,* C. *campestris,* C. *subinclusa* are usually employed for dodder transmission of viruses and phytoplasmas. C. *europaea*, C. *epilinum* and C. *lupuliformis* are also employed in transmission of viruses.

2. Inanimate agents

a. Wind

The wind dispersal of plant pathogens is known as anemochory. It is one of the most common methods of the dispersal of plant pathogens. It is the most dangerous and potent mode of travel for plant pathogenic fungi. It acts as potent carrier of propagules of fungi, bacteria and viruses. Usually the fungal pathogens are light in weight and are well adapted to wind dispersal. Some pathogenic bacteria are carried along with the infected material to short distances by wind. Damping-off pathogen *(Pythium* spp.), wart disease pathogen of potato *(Synchytrium endobioticum);* root rot pathogens *(Sclerotium* and *Rhizoctonia)* and seeds of phanerogamic parasites witchweed *(Striga)* are efficiently carried by wind. Viruses and phytoplasmas are not directly transmitted by wind, but the insect and mite vectors that carry the viruses move to different directions and distances depending upon the direction and speed of air.

The adaptations for wind dispersal in fungal pathogens include, production of numerous spores and conidia, discharge of spores with sufficient force, production of very small and light spores so that they can move to long distances. The duration and periodicity of sporulation and discharge are also important factors for wind dispersal. Some fungal pathogens causing powdery mildews, downy mildews, rusts, smuts, sooty moulds, leaf spots, blast, apple scab etc., produce large number of very light spores and conidia on the surface of the host. Uredial stages of the rust fungi travel long distances through air currents and are thus responsible for destructive epidemics over wide areas.

Wind transmission involves the upward air currents, velocity and the downward movements of wind. All are equally responsible for the spread of infection and ultimate outbreak of diseases and have been of special significance in the rust, smut and t>last fungi. Uredospores of rust fungi have been carried to long distances, both cross-wise and upwards. Christensen (1942) and Stakman (1946) determined by exposure of Vaseline slides in the upper air through aeroplane flights, that uredospores and" aeciospores of *Puccinia gramminis tritici* could be gathered in a viable condition up to a distance of 4,200 m, above infected fields, *Alternaria* sp. at 2,400 m. and those of *Puccinia tritieina* at 3,750 m. The transmission of aecial spores of *Puceinia graminis trWei* from several groups of barberry bushes to the wheat crop showed that these spores traveled successfully over a radius of 3 kms round about these bushes. The blister rust fungus, *Cronartium ribicola,* is known to travel to a distance of 500 metres or 3,750 m. inside a plantation that the range is probably more in the open. Similar observations have been made in respect of dissemination of chlamydospores ofthe smut fungi.

In long distance dissemination with intervening stages of infection, the retention of viability of spores is an important factor that determines the extent and severity of epidemics, over wide areas. The outbreaks of cereal rusts and blast of rice are examples of such dissemination. Spores differ widely in their ability to survive long distance travel through air. Uredospores of rusts, chlamydospores or smut fungi and conidia of *Alternaria*, *Helminthosporium*, *Pyricularia* and others are well adapted for long distance travel in a viable condition and are known to play a vital role in epidemiology. The conidia of downy mildews, powdery mildews and the aeciospores and basidiospores of the rust fungi are unable to withstand such long distance dissemination when they are exposed to desiccation and direct sunshine and thus are only capable of producing local epiphytotics of limited magnitude.

The bacteria causing fire blight of apple and pear *(Erwinia amylovora)* produce fine strands of dried bacterial exudates containing bacteria and these strands may be broken off and they are transmitted by wind. Bacteria and nematodes present in the soil-may be shown away along with soil particles. Wind also helps in the dissemination of bacteria, fungal spores and nematodes by blowing away rain splash droplets containing these pathogens. Wind carries insects and mites that may contain _ or are smeared with viruses, bacteria or fungal spores to short or long distances. Wind also causes adjacent plants or plant parts to rub against each other. The wound created in this manner help the spread by contact of bacteria (citrus canker), fungi, some viruses (Tobacco mosaic virus) and viroids and possibly of some nematodes.

b. Water

Transmission of plant pathogens by water (hydrochory as called by Gaiimann, 1950) is not as significant as wind transmission. Although water is less important than air in long-distance transport of pathogens, water dissemination of pathogens is more efficient, in that the pathogens land on an already wet surface and can move or germinate immediately. In case of some diseases the surface flow of water after heavy showers of rains or irrigation water from canals and wells carries the pathogens to short distances. Soil inhabiting fungi like, *Fusarium, Ganoderma, Macrophomina Phytophthora*, *Plasmodiophora*, *Pythium*, *Rhizoctonia*, *Sclerotium*, *Sclerotinia*, *Sporisorium*, *Ustilago*, *Verticillium* etc., in the form of mycelial fragments, spores or sclerotia, soil-bone bacteria and nematodes carrying viruses are transmitted through the above process. They are transmitted through rain or irrigation water that moves on the surface or through the soil.

All bacteria and the spores of many fungi are exuded in a sticky liquid and depend for their dissemination on rain or (overhead) irrigation water, which either washes them downward or splashes them in all directions.

Raindrops or drops from overhead irrigation pickup the fungal spores (uredospores of *Hemileia*, *Puccinia* and *Uromyces* and bacteria (bacterial blight pathogen of rice, *Xanthomonas Olyzae* pv. *oryzae;* bacterial leaf streak pathogen, *X oryzae* pv. *translucens;* citrus canker pathogen, X *axonopodis* pv. *citri;* tomato bacterial blight pathogen, *Ciavibacter michiganensis* and cotton bacterial blight pathogen, *X.axonopodis* pv. *malvacearum* present in the air and wash them downward where some of them may land on susceptible plants.