An Introduction to Plant Pathology and Plant Disease Management

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Cover photographs courtesy of R. Goth.

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Introduction

Anyone working with plants often will need to determine why plants appear abnormal and what control measures, if any, are appropriate. This manual introduces the subject of plant pathology, and the information it contains will aid in understanding how plant diseases develop as well as the various methods used for control. Terminology important to the study of plant diseases is identified for the reader by printing in ***bold/italics*** and is defined either in the text or in the section titled Plant Pathology Terminology.

The Disease Triangle

Plant disease results when a specific agent, such as persistent unfavorable environmental conditions or the activity of a pathogen, disrupts physiological functions causing plants to deviate from normal development. The word "persistent" is used to distinguish between a ***disease*** which develops over time and an ***injury*** which occurs, more or less, instantaneously.

Noninfectious diseases, more appropriately called ***disorders***, do not spread from plant to plant. Disorders result from the plant's exposure to such factors as unfavorable weather, mechanical damage, nutrient deficiencies, excess salts, or toxic chemicals. Although disorders can ***predispose*** plants to infection by pathogens, disorders are not directly treated using pesticides. The remainder of this manual emphasizes the discussion of infectious plant diseases caused by pathogens.

An infectious disease results when a ***pathogen*** lives in close association with the host plant. The pathogen functions as a parasite as this relationship usually benefits the pathogen at the host's expense.

Although relationships resulting in disease are often complex, three critical factors must be present in order for a particular disease to result. The pathogen must be present; a susceptible host must be present; and the proper environment must be present, permitting infection of the host. These factors give us the concept of the ***disease triangle*** (Figure 1.)

Production practices followed by large growers and home gardeners serve to modify the interaction of these three factors to reduce (or unwittingly increase) the overall impact and severity of plant diseases. Plant professionals use the disease triangle concept to remember and understand how a particular disease develops and why various control strategies are used. The pathogen, host, and environment are discussed in more detail below.

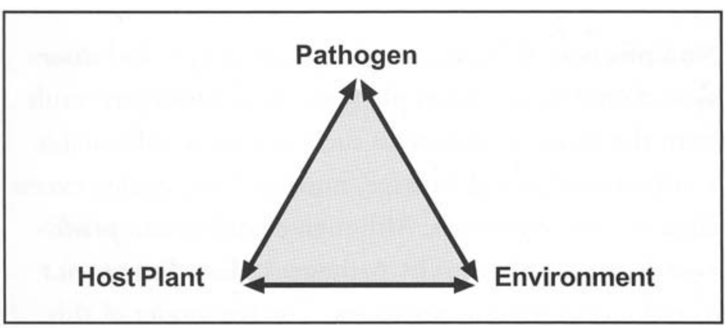

Figure 1 – The Disease Triangle.
Those three factors interact and must be present for disease development to occur.

The Pathogen

Fungi, bacteria, viruses, viroids, nematodes, parasitic plants (dodder and mistletoe), phytoplasmas, and protozoa are examples of various pathogens that cause plant diseases. General descriptions of the most common and economically important classes of pathogens are listed below. It is important to remember that many beneficial microorganisms exist in nature and that only a small fraction infect plants.

Fungi

Bread molds and mushrooms are examples of fungi. Most of the 100,000 fungus species identified by scientists are only ***saprophytes***, meaning they are not capable of infecting plants. More than 8,000 plant pathogenic species have been identified, however, making fungi the most numerous and economically important class of plant pathogens. The great diversity of fungi and the complex life cycles of some plant pathogenic species make generalizations difficult.

Plant infection by fungi occurs via a great variety of mechanisms. Some species directly penetrate plant surfaces or enter through natural openings, while others require wounds or injury sites for infections. During disease development, many species of fungi produce spores that are dispersed by wind, water, or other means. Each spore may cause a new infection, resulting in a rapid increase in disease incidence and severity. Some fungi form special resting spores which permit survival for long periods of time (several months or year) in soil or plant debris.

Fungi are identified primarily from their morphology (physical shape), with emphasis placed on their reproductive structures. Laboratory techniques can be used to induce sporulation (spore production) in many fungi if reproductive structures are not visible on plant tissue.

Bacteria

Bacteria are perhaps the second most economically important class of plant pathogens. Bacteria are considered more primitive than fungi and generally have simpler life cycles. With few exceptions, bacteria exist as single cells that increase in number by dividing into two cells during a process called binary fission. Their ability to rapidly reproduce when environmental conditions are favorable give bacteria their potential for causing an explosive increase in disease.

Some species are able to survive on healthy-appearing plant surfaces as epiphytes. These only cause disease when environmental conditions are favorable or when injuries, such as those caused by hail, occur. Overwintering weed hosts, infected seedstocks, or contaminated crop debris may serve as the initial source of inoculum. The presence of certain bacterial species on plant surfaces increases frost sensitivity, while other species are able to move long distances in aerosols or irrigation water.

Bacterial ooze on plant surfaces or bacterial streaming can aid in the identification of bacterial diseases when working in the field; however, laboratory methods are usually required for identification.

Nematodes

Nematodes are microscopic round worms that reside in the soil. Disease induced by nematodes usually results in poor plant growth and may be overlooked when there are not healthy plants available for comparison. Roots of poorly growing plants should be examined carefully for evidence of nematode feeding. Deformed roots or galls may be symptoms of nematode diseases.

Feeding by plant-pathogenic species can directly interfere with normal plant development. Nematodes may also interact with other disease-causing organisms and may act as vectors for viruses. Although most plant pathogenic species affect only roots, some species infect stem, foliar, and bud tissues.

Viruses and Viroids

Viruses and viroids are extremely tiny particles consisting of either protein and genetic material (viruses) or genetic material with no associated protein (viroids). Biologists disagree on whether viruses or viroids should be classified as living since they are true obligate parasites incapable of carrying out any physiological processes in the absence of a host.

In order for disease to spread, these particles must be physically inserted into a living host cell by vectors, or they may be transmitted through seeds, tubers, grafts, or physical contact between healthy and infected plants. The method(s) of transmission for a specific virus or viroid is a characteristic of that pathogen and the disease it causes. Once inserted into a host, the physiological processes of the cell are redirected into the manufacture of more particles. Chemical controls usually target insect vectors, and some disinfectants inactivate viruses, rendering them noninfectious.

Most virus diseases are identified by characteristic symptoms coupled with electron microscopy and/or serological tests. Viroid identification requires even more specialized detection methods.

The Host

Levels of ***resistance*** or susceptibility of the host plants will affect disease development. Plants with high levels of resistance are essentially immune (or not susceptible) and do not allow the pathogen to become established, even if present. Plants with lower levels of resistance may become infected but only allow the pathogen to develop slowly, limiting the economic impact of the disease to acceptable levels. Stress, such as that brought on by an unfavorable environment, poor fertility, or irrigation, will affect a host plant's ability to resist infection and, therefore, also affect disease development.

In some cases, resistance in the host is overcome by the pathogen, resulting in rapid and devastating disease development. This risk is increased if large production areas are planted to a monoculture of identical hosts. Therefore, genetic diversity of host plants will decrease the risk of catastrophic losses.

The Environment

Environmental conditions play a large role in disease development and disease severity. However, broad generalizations about environmental effects have many exceptions. The disease triangle shows the environment influences disease development by interacting with both the host and pathogen. Environmental stress also can predispose plants to infectious disease. Several important environmental factors are listed below.

Temperature

Temperature greatly influences disease development. Temperatures that are not ideal for the host plant induce stress and predispose plants to disease by lowering host resistance. This may occur for hosts determined to be resistant under normal growing conditions.

Temperature also affects the amount of inoculum available. Cold winters interrupt the disease cycle by killing pathogens or vectors that otherwise may persist until the next growing season. During the growing season, temperature will directly influence the pathogen's ability to reproduce and infect the host. This will directly affect the rate of disease development, disease severity or even if diseased plants will appear in the first place.

Moisture

Abundant, prolonged, or repeated moisture is the predominate factor in most epidemics caused by fungi, bacteria, and nematodes. Although relationships can be complex, rain, increased relative humidity, or prolonged dew periods will increase the likelihood of many, but not all, diseases.

Moisture affects the host by inducing new growth that may be more susceptible or resistant to infection. Moisture also induces sporulation of fungi, replication of bacteria, and mobility of nematodes, increasing the amount and dispersal of available inoculum. For other pathogens, rain may suppress the movement of insect vectors, thus indirectly reducing disease spread.

Wind

Fungal spores, vectors, and, to a lesser extent, bacteria and nematodes can be dispersed by the action of wind. This enables pathogens to move from infected plants to healthy plants. Wind also can injure hosts, providing an avenue for infection and/or increasing susceptibility to some pathogens.

Other Factors

There are many factors, including light intensity, light quality, soil pH, fertility, and soil type, that influence disease development. Relationships can be complex with environmental influences being exerted on the host and the pathogen. Each disease must be studied carefully to determine what interactions are important for its development.

Disease Diagnosis

Diagnosis requires knowledge of what is normal for the host plant as well as knowledge of problems that occurred in the past. Accurate diagnosis is critical when deciding if a disease is present and if effective control measures are available or if they are justified. An accurate diagnosis is based upon recognition of specific pathogenic signs on the host as well as the presence of symptoms on the host.

Signs are defined as the visible presence of the pathogen or products of the pathogen on the host plant. Fungal spores, fruiting structures that bear spores, and bacterial ooze are all examples of signs. In contrast, ***symptoms*** are the external and internal reactions or alterations of the plant as a result of disease. For example, dead spots in leaves or bark, rotten spots in fruits or tubers, swellings on roots or branches, clustered branches, unnatural color or shape, and vascular discoloration in stems are all symptoms that may aid in diagnosis of a plant disease.

Because most diseases encountered have previously been described, it is usually possible to diagnose a specimen by comparison with the symptoms and signs of pathogens already charted for diseases of that particular host. Books, manuals, and pictures are very useful aids in diagnosing many plant diseases. Experience diagnosticians recognize many diseases on sight or can quickly narrow possibilities down to several choices. Although experience is the best teacher, the general guidelines listed in Box 1 will help focus attention on information needed for an accurate diagnosis.

1. Carefully describe the characteristics that make the plant appear abnormal (symptoms).
2. Determine the distribution of symptoms in the host by looking at the entire plant.
3. Determine if evidence of the pathogen (signs) exist.
4. Determine the distribution of affected plants in the field.
5. Record the cropping history associated with the host.
6. Determine if any unusual weather occurred.

Box 1. Information needed to aid in Plant Disease Diagnosis after determining that plants are abnormal in appearance.

If diagnosis is still not possible, contract your local Cooperative Extension educator for assistance. Specimens will be mailed by your Extension educator to the University of Wyoming Plant Pathology Lab when additional assistance is required.

Disease Development

Every infectious disease requires a series of sequential events for development. This series of events is called the ***disease cycle***. Although the specific characteristics are unique for each disease, the general events in the disease cycle are dispersal of the pathogen to the host, penetration and infection of the host, invasion and colonization of the host, reproduction of the pathogen, pathogen dispersal, and pathogen survival between growing seasons and/or in the absence of a host.

Completion of the first five events is one ***generation*** of the pathogen and, depending on the pathogen, can be repeated before the growing season ends. The generation time and the number of generations a pathogen completes during one season determine the dynamics of disease development and the potential for plant or crop loss. Graphic representations of disease severity over time are called ***disease progress curves*** and are discussed below in Figures 2, 3, and 4.

Monocyclic pathogens have a maximum of one generation per growing season and possess a characteristic disease progress curve (Figure 2). Pathogens are monocyclic

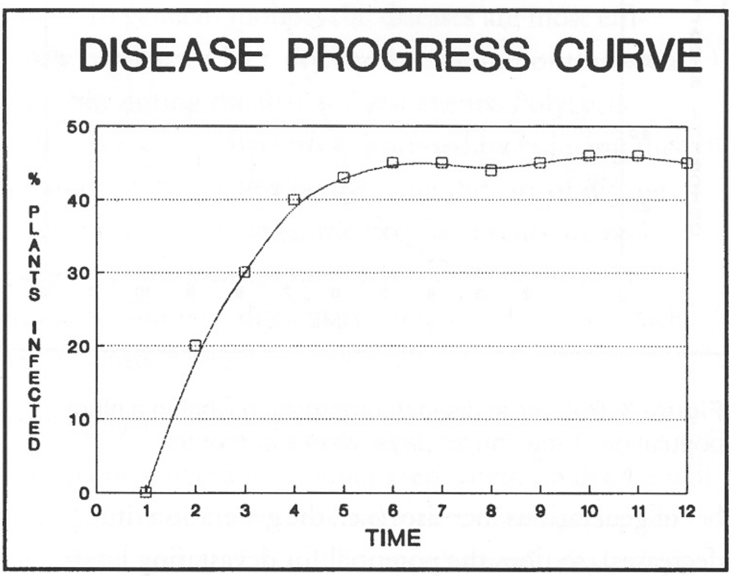

Figure 2 – Monocyclic disease progression within a plant population. Time can be days, weeks, or months.

because environmental conditions or other physical factors prevent repeating events until the next growing season; examples are *Verticillium* wilt and several other soil-borne diseases. Other pathogens are monocyclic because their life cycle requires at least one season to complete – examples are cedar-apple rust and corn smut.

Polycyclic pathogens complete more than one generation per growing season and, therefore, are able to reproduce and infect additional healthy plants during that current growing season (Figure 3). As the potential for the

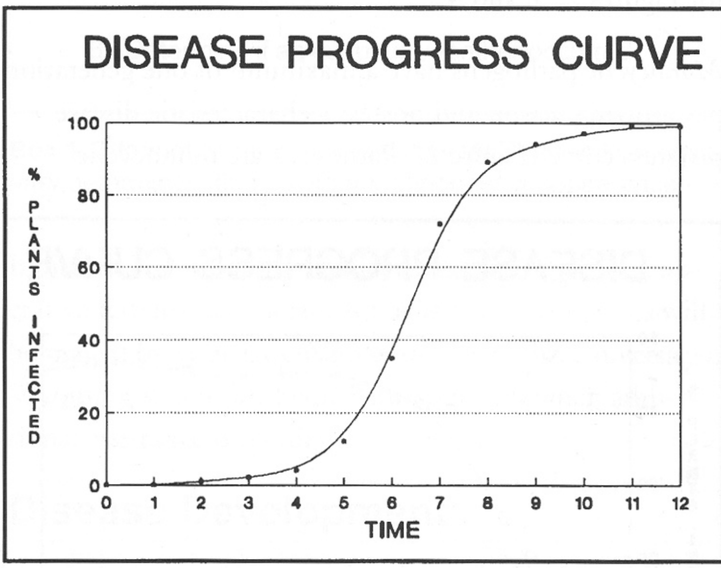

Figure 3 – Polycyclic disease progression within a plant population. Time can be days, weeks, or months.

number of generations increases (i.e., the generation time decreases), so does the potential for devastating losses. Some fungi have such short generation times that steps in the cycle of pathogenesis completely overlap, resulting in a continuous series of new infections giving the appearance of explosive disease development. Examples of polycyclic pathogens can be found in virtually all classes of pathogens, including fungi, bacteria, nematodes, and viruses. Examples are early and late blight of potatoes, wheat rust, and bean rust.

The time it takes a disease to develop in a production area or region can vary from days to years and is a characteristic of the specific disease involved. Severe losses can occur regardless of the speed at which disease develops and can result from both monocyclic and polycyclic pathogens.

Plant Disease Control

Control measures are used to interrupt or weaken at least one of the six sequential events in the disease cycle (see above). In general, monocyclic diseases are most efficiently suppressed by reducing the amount of the initial inoculum during the first and last events. Polycyclic diseases are most efficiently suppressed by reducing the initial inoculum and/or by reducing the rate of disease increase that occurs when the first five events are repeated. Various control methods commonly used to reduce or eliminate disease are categorized below; much overlap exists between categories.

Exclusion

If the pathogen and host remain separated, no disease will develop. Disease control methods that maintain separation can be very effective. This approach to disease control is largely regulatory in nature, however, and includes quarantines, inspections, use of pathogen-free plant materials, certification of seed stocks, and other means.

Evasion

The use of healthy seed, planting and growing plants under environmental conditions unfavorable for disease development, selecting early (or late) planting and harvest dates, and maintaining the proper distance between rows and fields are all examples of methods for evading disease. These practices increase the chance that the host will remain healthy or go through its susceptible stage before the pathogen reaches the host.

Eradication

Eradication is the elimination or destruction of the pathogen. Methods of eradication include temporary removal and destruction of host plants, chemical treatment of soil or seeds to kill the pathogen, and sanitation of equipment and storages. Growers routinely practice crop rotation with a non-host plant to reduce the amount of inoculum present to acceptable levels.

Resistance

Resistance is the growing of plants that are not susceptible or less susceptible to the disease. Resistant cultivars are usually developed through special breeding and selection programs. Immunity or total resistance is often unobtainable and many varieties have partial resistance, allowing the plant to grow in spite of some disease development.

Environmental Modification

Creating unfavorable conditions for the pathogen is a practical disease control method used by some growers. Proper spacing of plants in the field or greenhouse will aid in reducing the humidity that favors development of some diseases. Good soil drainage and proper irrigation practices are also important. Flooding fields during the fallow period may also reduce the incidence of some disease caused by soil-borne organisms. Environmental modification by drying and/or refrigerating harvested products is one of the most common methods used to slow growth of pathogens and reduce disease.

Protection

Infection of plants may be reduced through ***prophylaxix*** or protection. Although biological control agents are used in some instances to protect plants from infection, the most common method of directly or indirectly protecting plants from pathogens is through the careful use of chemicals.

Chemical Controls

Chemical or ***pesticides*** are often used to help control plant diseases. The correct timing of the proper chemical application is essential for good control. Labels provide application information, and the directions must be followed.

Fumigants and Sterilants

These chemicals generally have a broad range of activity, but are not applied to growing plants. Soil fumigation is commonly used to reduce nematode populations as well as other soil-borne pathogens and pests. Total eradication of pathogens and pests is generally not possible. Fumigants are typically expensive, difficult to apply, highly toxic, and nonselective in their activity. Therefore, beneficial microorganisms and insects are affected as well.

Proper soil preparation, soil moisture (approximately 70 percent field capacity), and soil temperature (55-85 degrees Fahrenheit) is critical for achieving uniform chemical distribution and effective disease control. Methyl bromide and chloropicrin are highly volatile fumigants, and plastic sheeting is required to seal the soil surface during their application. In contrast, metham sodium is less volatile, and water can be used to seal the soil surface. Label directions will give precise information on the soil conditions required and suitable application methods.

Nematicides

Fumigants are considered nematicides; however, other liquid and granular (non-fumigant) chemical formulations also are available for nematode control. These products have low volatility and can be applied before and after planting many crops, particularly those that are non-food. Nematicides kill nematodes that come in contact with the chemical and may kill some insects as well. Generally, nematicides are highly toxic and my contaminate ground water when not used properly.

Seed Treatments

Seed treatments are typically fungicides that protect the seed and germinating seedling from infection and/or decay. Pathogens can be seed-borne or soil-borne. Some advantages of seed treatments are that small amounts of chemical are required and that seedlings are able to get off to a strong start. Because treated seed is not to be used for feed, food, or processing, dyes are used to color treated seed and the seed should be properly labeled. An exception is the treatment of high moisture grains with acetic or propionic acid. Acid-treated grain is commonly used for livestock feed.

Protectants

These chemicals are usually applied to the seed or foliage of the growing crop so that a protective chemical barrier over the host surface prevents the initial infection. These products must not be toxic to the host plant.

Systemics

These are applied to the seed or growing crop and are absorbed to varying degrees and transmitted within the plant. These substances may kill or suppress the pathogen growing within host tissue and, therefore, may have a curative or therapeutic effect. Some systemics have very selective activity and, through repeated use, become ineffective due to selection for insensitive fungal isolates.

Integrated Methods

Frequently, a number of control methods are ***integrated*** or used simultaneously to reduce the economic loss of plant diseases. Relying on a single method for disease control frequently results in failure. Integrated methods can reduce costs associated with more expensive control methods and decrease the risk associated with dependence on a single method of control. Added benefits of integrated methods are that disease control is generally greater than for each method used individually (Figure 4).

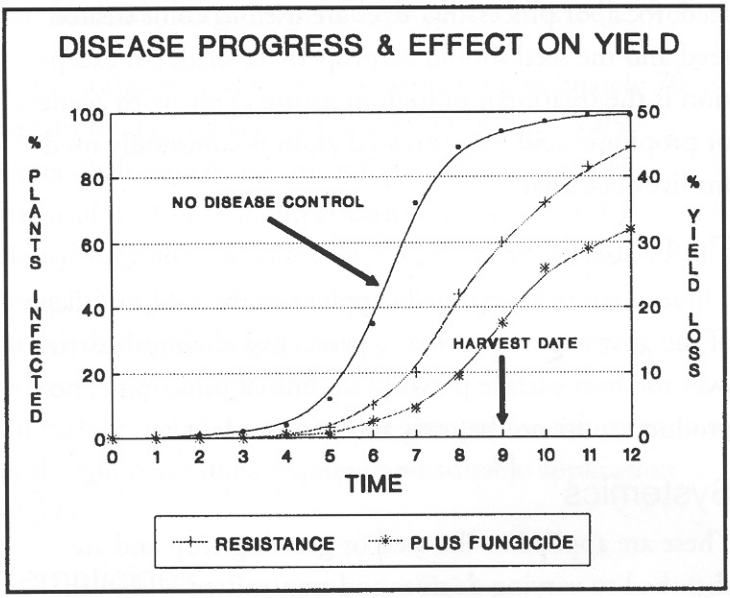

Figure 4 – Integrated control methods (resistance plus fungicide curve) are often more effective for disease control than relying on a single method (resistance).

Additional Information

Summaries of specific plant diseases, their control, and photographs to aid diagnosis are available in numerous reference books and publications. The professional society of plant pathologists, The American Phytopathological Society (APS), offers many of these publications for sale at reasonable prices (approximately $35). Contact *APS* at 800-328-7560, http://www.scisoc.org>, or write 3340

Pilot Knob Road, St. Paul, MN 55121-2097. Some of the publications listed in the section "Additional Reading" are readily available through *APS*.

Plant Pathology Terminology

Atrophy – a lack of development of certain plant parts or tissues

Bactericide – a compound toxic to bacteria

Canker – a diseased or dead area in the bark and wood of trees or shrubs characterized by a drying out of the tissues

Cell – the smallest unit that makes up a plant and consists of the cellular contents (protoplasm) surrounded by a cell wall

Damping-off – a type of seedling disease in which the stem decays in the vicinity of or below the soil line

Disease cycle – the chain of events involved in disease development, including the stages of development of the pathogen and the effect of disease on the host

Ecology – the study which deals with the effect of environmental factors, such as soil, climate, and culture on the occurrence, severity, and distribution of plant diseases

Environment – the external conditions and influences that surround living organisms

Epidermis – the superficial layer of cells occurring on all plant parts

Exudates – material that has been forced out

Fungal – relating to fungi

Fungicide – a compound toxic to fungi

Gall – an unusual enlargement on some portion of a plant

Host – the plant upon which a parasite lives

Hyperplasia – a symptom due to an abnormal increase in the number of individual cells

Hypertrophy – a symptom due to an abnormal increase in the size of individual cells

Hyphae – fungal filaments which collectively form the mycelium of a fungus

Immune – cannot be infected by a given pathogen

Incubation period – the period between the time the inoculum is introduced onto the host and the time when the diseased condition becomes evident

Infection – the process of the pathogen gaining entrance to the host and becoming established as a parasite

Infection court – specific area on a plant where a pathogen gains entrance to the host

Infest – to overrun or contaminate

Inoculum – the pathogen, or its parts, that can cause infection

Inoculation – the process of transferring inoculum to hosts

Lesion – a diseased part of the host

Mummy – a dried, diseased fruit

Mycelium – the group of hyphae that form the fungal body

Necrosis – a symptom marked by rapid death of the host or parts of the host

Nematicide – a compound toxic to nematodes

Obligate – necessary or essential

Obligate parasite – organisms that lives only as parasites

Pathogen – a disease-producing agent

Pathogenicity – ability of an organism to produce disease

Pathology – the study of disease

Pesticide – a compound toxic to a specific pest(s)

Physiology – the study of metabolic processes, activities, and phenomena related to life

Predispose – make favorable for

Primary infection – the first infection of a host by the overwintering or over summering inoculum

Primary inoculum – the overwintering or over summering inoculum

Prophylaxis – methods used to preserve health and prevent spread of disease

Pustule – blister like elevation of the epidermis created as spores form underneath and push outward

Resistance – the ability of a host to exclude or overcome the effect of a pathogen or other damaging factor

Rogue – to remove or pull out

Rust – used to describe a particular fungus, any of its stages, or the disease caused by any of the stages

Saprophyte – an organism that uses dead organic matter for food; not functioning as a parasite

Sclerotia – a hard, dense, compact mass of hyphae that serves as a resting body

Secondary infections – new infections caused by inoculum produced during the same growing season

Sign – the structure of the pathogen itself

Spore – a fungal reproductive unit or seed that serves as an agent of dispersal and propagation

Stomate – a small pore or opening in the epidermis of leaves and stems through which gases pass

Symptom – something that indicates a diseased condition; the plant's response to stress

Tumor – a swelling or protuberance

Virulent – designates the ability to function as a pathogen

Vector – an animal able to transmit a pathogen

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