Plant Diseases Development and Management

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The interactions between plants and disease organisms are complex, and commercial growers and home gardeners alike may have difficulty understanding plant diseases. Confusion can be reduced by learning a few basic concepts and principles of how diseases develop and how they are managed. This publication presents these concepts and is dedicated to commercial growers, commercial applicators, home gardeners and others who want more information on how plant diseases develop and are managed. To serve these diverse groups, examples of common North Dakota diseases were selected from both the commercial farm and from the home garden. Various circulars available at offices of the NDSU Extension Service provide detailed information on many of these diseases.

HOW DISEASE DEVELOPS

WHAT IS A DISEASE?

A disease is any abnormal condition that damages a plant and reduces its productivity or usefulness to man. Under this definition, air pollution can cause disease, as can many fungi and other infectious living organisms. This illustrates the first important concept: there are two basic types of diseases, non-infectious (abiotic) and infectious (biotic).

TYPES OF DISEASES

NON-INFECTIOUS (Abiotic)

Non-infectious diseases are caused by some environmental factor that produces an abnormal plant (Table 1); that is, one that has an abnormal appearance. Non-infectious diseases are *not* caused by a living, **parasitic organism** (an organism that gets its food by attacking other organisms), but are abiotic in nature.

Nutrition

Nutrition is a frequent cause of non-infectious disease. Either too much (excess) or too little (deficiency) can cause problems. For example, plants that are deficient in nitrogen develop a general yellowing, beginning with the lower leaves and progressing upward. Trace element deficiencies such as iron chlorosis, caused by iron deficiency, are common. Iron chlorosis occurs in many North Dakota trees and shrubs, especially silver maple, oak, and spirea. Iron chlorosis is recognized by progressively smaller leaves on the new growth; these leaves are yellow with green veins. When iron chlorosis is severe, leaves may turn brown and become brittle as well. Lime-induced chlorosis is common in our alkaline soils because the iron in the soil is not readily available to plants. Iron chlorosis also is common on certain soybean varieties. Zinc deficiency is common on dry beans and fairly common on flax, causing yellow leaves and stunted growth. Excess trace elements may also cause growth problems, but these are rare in North Dakota.

Moisture

Deficient or excessive moisture (water) can cause disease. Moisture deficiency produces stunted, stressed or wilted plants. In addition, this stress may **predispose** (weaken) plants to infection by infectious organisms or increase the effects of infectious disease. For example, some tree canker organisms commonly infect trees stressed by drought or extreme cold. The effects of stem rust and root rot on small grains are greater when plants are moisture stressed (deficient in water). Excess moisture also has adverse effects, such as suffocation of roots due to lack of oxygen or predisposing plants to water mold infections.

Temperature

Frost is a common problem in spring and fall, affecting tender farm crops and garden vegetables. Extremely high temperatures in summer can also cause problems. For example, heat sterility in small grains is common in North Dakota. In oats, this is referred to as "blast."

Other Meteorological Conditions

High soil temperatures early in the season may injure or kill plant tissues at the soil surface, resulting in a constricted stem; this is called **heat canker**. Bright sun, high temperatures, and strong dry winds may suddenly desiccate (dry) leaves of crops and garden plants, resulting in sunscald. When lightning strikes the ground it may kill plants in somewhat circular patches up to 50 feet in diameter.

Toxic Chemicals

Toxic chemicals injure plants. Salt may damage or kill farm crops growing in saline seeps; road salt may severely damage boulevard trees and other vegetation. Air pollution also damages vegetation. Bronzing of beans caused by ozone is common in the state. The source of the ozone is not known.

INFECTIOUS (Biotic)

Infectious diseases are caused by organisms that attack plants and get their nutrition from them. The plant attacked is called the **host** plant. The organism causing the disease is called a **pathogen**. The pathogen can spread from a diseased plant to a healthy plant. There are five common groups of pathogens (Table 1). A few other kinds of micro-organisms may cause plant disease but are not common in North Dakota.

Fungi

Fungi are the most common pathogens in North Dakota. They produce tiny thread-like filaments called **hyphae**. Most pathogenic fungi produce spores which serve to reproduce and disseminate them. Spores function similarly to the seeds of higher plants. Some spores are formed in masses, like the orange pustules of rust fungi. Other spores develop in specialized fruiting structures. These structures are called **signs** of the pathogen and are useful in field identification of disease. **Symptoms** are also useful in identification of a disease. Symptoms are visible abnormalities such as wilts, rots, and other types of tissue death, stunting, excessive growth, or abnormal color.

Examples of common pathogenic fungal diseases in North Dakota include: rusts of small grains, sunflower and dry beans; cereal smuts and head scab of small grains; Cercospora leafspot of sugarbeet; white mold or Sclerotinia of dry beans, sunflowers, and canola; early blight and late blight of potatoes; root rots of small grains, sugarbeets and dry beans; apple scab; anthracnose of muskmelon; tree cankers; Septoria leafspot of tomato; peony blight; powdery mildews of ornamentals, and plum pockets.

Most fungi that cause plant diseases are **parasites**, organisms that get their food from other living organisms. However, not all fungi are parasites. Many live on dead or decaying organic matter and are called **saprophytes**. Mushrooms that spring up in lawns are among the most spectacular saprophytic fungi. There are also many inconspicuous ones that rot organic matter. The sooty molds seen on wheat heads at harvest also are saprophytic, living on the already ripe or senescing glumes and awns.

Bacteria

Bacteria are tiny one-celled organisms that multiply by cell division. They can be seen only with a microscope. Most are saprophytes, but there are a few common and serious bacterial pathogens that attack North Dakota plants. Examples of common bacterial diseases include bacterial blights of dry beans, bacterial blights and black chaff of wheat and barley, ring rot and blackleg of potato, fireblight of apples and related plants, bacterial wilt of cucumber and muskmelon, angular leafspot of cucumber, and bacterial speck and spot of tomato.

Viruses

Viruses are 1,000 times smaller than the tiniest living cell. Most viruses have a core of nucleic acid, the basic unit of heredity, and have a protein coat covering the core. Viruses are usually in the form of rods or spheres and alter the activities of the host to manufacture more virus. Some viruses are transmitted mechanically (by contact with another plant, or contaminated workers' hands or tools); others are transmitted (carried) by insects and by eriophyid mites. Examples of virus diseases that can cause serious losses are wheat streak mosaic, barley yellow dwarf, bean common mosaic, potato virus diseases, tobacco mosaic, cucumber mosaic, and squash mosaic.

Phytoplasmas

Phytoplasmas lack a rigid cell wall, have no defined shape and can only be seen with an electron microscope. They are usually systemic in the host (distributed internally throughout the host) and are transmitted by leafhoppers. Phytoplasmas cause growth abnormalities such as witches' brooms (a broom-like mass of plant branches) or excessive tillering (stooling of small grains). Our most common phytoplasma is aster yellows. Aster yellows produces witches' brooms and greenish flowers on marigold; carrots develop yellow tops and hairy roots. The disease produces greenish flowers on flax, "purple top" on potato and tomato, and bladder-like pods on canola. Purple top of potato is often accompanied by the formation of small aerial tubers in the leaf axils (the point where the leaf joins the stem).

Nematodes

Nematodes are tiny roundworms. Most can be seen only with a microscope, but a few can be seen with the naked eye. Reproduction is by formation of eggs. Some parasitic forms attack plant roots and can cause severe damage. Nematode problems are common in warm climates but are rare in North Dakota. Two potentially serious nematode diseases occur in neighboring states but are not yet confirmed (2000) in North Dakota. They are the soybean cyst nematode and the pine wilt nematode. The pine wilt nematode is unusual in that it invades the vascular (water-conducting) tissues of pine trees instead of attacking the roots.

DISEASE DEVELOPMENT

This section discusses how plant pathogens produce disease: how they infect the host, how they reproduce, how they are disseminated (spread), and how they survive between crops.

WHAT DOES IT TAKE TO PRODUCE DISEASE?

Three factors interact to produce disease; the host, the pathogen, and the environment (Figure 1). If any one of these three factors is unfavorable or missing, disease will not develop. For example, the flax rust pathogn attacks only flax as a host, and different races of flax rust attack different varieties of flax. Flax rust develops only when a suitable combination of rust race (pathogen) and variety (host) interact under environmental conditions favoring this disease. The environment often limits disease in North Dakota and is the reason that some diseases rarely occur and others occur sporadically. Many diseases are favored by humid or rainy weather and may be more common and severe in years favoring good crop production.

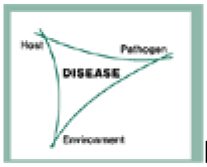

Figure 1. The disease triangle — disease develops only when all three factors are favorable. (4KB illustration)

INFECTION BY PATHOGENS

Pathogens can infect plants in several ways (Figure 2). Fungi and bacteria may penetrate (enter) through natural openings such as the **stomata** — these are tiny "breathing" pores in the leaf that allow the exchange of gases (Figure 3). Viruses, fungi, and bacteria also enter through wounds. Bacteria frequently enter through hail wounds. Many fungi can penetrate the leaf surface directly without wounds or stomata.

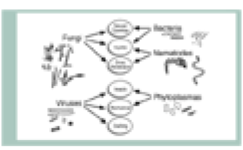
Figure 2. Methods of infection by pathogens. Some typical pathogens are illustrated, but they are not shown on the same size scale. For relative sizes, see Table 1. (14KB illustration)

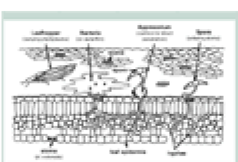
Figure 3. Diagram illustrating some of the ways pathogens can infect a leaf. (Shown in cross section — edge of cut open leaf in foreground.) (30KB illustration)

Some viruses and most phytoplasmas are carried by insects, especially sucking insects such as aphids and leafhoppers. Insects that carry and transmit plant disease organisms by their feeding are called **vectors**. The aster leafhopper, for example, is the vector of both the aster yellows phytoplasma and the oat blue dwarf virus.

Some viruses are transmitted mechanically by the rubbing together of leaves or by humans touching diseased and then healthy leaves. Tobacco mosaic virus and potato virus X are common examples. Many fruit tree viruses are transmitted by grafting.

Many pathogens, especially foliar (leaf) pathogens, need a film of water on the plant to begin growth, penetrate the host, and establish infection. This is why wet or humid weather is so important in the development of many fungal and bacterial diseases.

DISSEMINATION OF PATHOGENS

Pathogens are disseminated (spread) by wind, insects, water, man, animals and birds.

Wind

Wind disseminates fungus spores from plant to plant in a field or across fields. Pathogens such as the wheat leaf rust, wheat stem rust, and barley stem rust pathogens are spread long distances by the wind (Figure 4). Leaf rust is wind-borne from the major winter wheat areas of Kansas, Nebraska and Oklahoma (Occasionally it survives the winter in North or South Dakota). Stem rust is wind-borne from Mexico and Southern Plains states to wheat and barley crops in the Northern Great Plains.

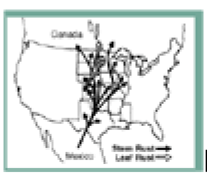

Figure 4. Long distance spread of wheat stem rust and wheat leaf rust spores from their overwintering areas. (8KB illustration)

Insects

Insects are important in carrying viruses and phytoplasmas from southern areas. Common insect vectors include aphids for the barley yellow dwarf virus and the aster leafhopper for the aster yellows phytoplasma. Insects also spread these pathogens from plant to plant. Bacterial wilt of cucumber and muskmelon is disseminated by both the striped and spotted cucumber beetles; only the striped cucumber beetle is common in North Dakota.

Water

Water can carry pathogens from field to field. Rain and splashing water can disseminate many fungi and bacteria. Septoria leafspot of tomato and the bacterial blights of dry beans are common examples. Rain and wind form numerous tiny airborne water droplets called **aerosols**. Many bacteria are disseminated long distances in wind-driven aerosols. Water flowing over the surface of fields spreads disease organisms such as Sclerotinia (white mold), *Verticillium,* and downy mildew.

Man
Man spreads pathogens and weeds over long distances. International plant quarantines attempt to prevent this dissemination by authorizing inspection of planes, ships, cars, and luggage for prohibited pests at ports of entry. The Mediterranean fruit fly as well as many weeds and pathogens are frequently intercepted at ports of entry. The gardener who brings fruit in his or her luggage and the commercial grower who brings seed of a high performance crop in his pocket may introduce a new pathogen or other pest.

Man can also disseminate pathogens and other pests locally. Dutch elm disease was originally introduced into the United States on elm logs; much of its local spread and buildup has been on elm firewood collected from diseased trees. The soybean cyst nematode, not yet reported (2000) in North Dakota, could be introduced on contaminated farm implements from infested areas in neighboring states. Man can locally disseminate bacterial blights, rust and anthracnose of dry beans by cultivating the crop when it is wet.

Animals and Birds
Animals and birds also may disseminate pathogens. For example, the soybean cyst nematode can be disseminated in the feces of birds; animals may spread water-borne pathogens by walking through an infected crop when the plants are wet.

SURVIVAL OF PATHOGENS

In North Dakota we are primarily concerned about pathogen survival between crop seasons. When this is over the winter, it is called **overwintering**.

Soil
Many pathogens form resistant structures that survive long periods of time in the soil. For example, the Aphanomyces root rot pathogen of sugarbeets survives for over 20 years as resistant spores in the soil, and the sunflower downy mildew pathogen survives for at least 14 years as resistant spores in the soil. The white mold pathogen of dry beans and sunflower survives for six to eight years or more as resistant bodies in the soil. The Verticillium wilt pathogen of potatoes, tomatoes and other crops survives for at least several years in the soil.

Plant Parts
Pathogens may survive on crop refuse. These include the leafspot pathogens of wheat and barley which survive on stubble, and the tomato Septoria leafspot pathogen which survives on the old dead vines. Destroying or burying this crop refuse reduces next year's disease potential.

Seed and Vegetative Plant Parts
The smuts of small grains survive on or in the seed and survive in storage as long as the seeds remain viable (can germinate). Vegetative plant parts such as tubers, roots

and corms provide a mode of survival for many pathogens. Many potato pathogens are carried on or within the tubers.

Insects and Mites
The bacterial wilt pathogen of cucumber and muskmelon is suspected to overwinter in the digestive tract of cucumber beetles. The wheat streak mosaic virus overinters in wheat curl mites that survive on winter wheat and some perennial grasses.

Mild Climates
The cereal rust pathogens usually do not overwinter in North Dakota but survive year-round in the southern United States and Mexico and are carried north each year by wind.

HOW DISEASES ARE MANAGED

This section focuses on management of infectious diseases. Non-infectious diseases are not discussed as their management involves a remedy of the physical factors that induce them.

The four basic methods of infectious disease management are: exclusion, eradication, host resistance, and protection (including the use of fungicides). These four methods reduce pathogen populations or slow their development. Protectant fungicides and resistant varieties slow down the development of pathogen populations. Cultural practices also can reduce the pathogen's population. In short, management practices **prevent or delay the introduction of pathogens or reduce initial pathogen populations and retard their subsequent increase.**

Sound management is based on correct diagnosis. This is essential to distinguish infectious from similar appearing non-infectious diseases as well as to correctly identify the pathogen involved in infectious disease.

Correct identification of the pathogen is essential to know the pathogen's life cycle and how it relates to the cycle of disease development. This information is needed to develop a management program that attacks the pathogen at the weakest point in its life cycle. When fungicides are used, the type and the timing are important. For example, in the case of dry bean diseases three different types of fungicides are used for management of each of three major diseases: rust, bacterial blights, and white mold. In each case timing is important and application must be started before the disease is widespread. For head scab of wheat and barley, timing of fungicide application is critical as well, at early heading for barley and early flowering for wheat.

EXCLUSION

Exclusion means exclusion of pathogens. Pathogens can be excluded (or kept away) from hosts by quarantines that prevent their introduction, and by use of seed stocks certified to be pathogen-free or within certain prescribed tolerances for low levels of pathogens.

QUARANTINE

International quarantines are familiar to anyone who has traveled overseas. Planes, cars, trucks and luggage are checked at ports of entry to prevent the introduction of pathogens and other pests into areas where they do not occur. Many disease organisms would flourish in our state if they were introduced. State and local quarantines are used to keep black wart of potato and the golden nematode restricted to a few localized areas of the eastern United States. International quarantine has prevented new introductions of pathogens from other countries.

SEED CERTIFICATION

Seed certification is used to certify that potato seed tubers and seed of dry beans have low levels of pathogens or are pathogen-free in the case of potato ring rot. The crop is grown from seed produced under carefully controlled conditions. Sometimes the seed crop is grown in an isolated area to reduce disease potential. For example, foundation seed potatoes are grown in Golden Valley County, a western county isolated from the rest of the potato production in North Dakota. Crops are field inspected and must meet certain tolerances to be certified. Certification may be done in conjunction with indexing. Many seed potatoes are now produced in greenhouses.

INDEXING

Indexing involves laboratory or greenhouse tests to determine infection by pathogens in vegetatively propagated plants such as potatoes and fruit trees. Only the healthy materials are saved for further increase.

Culturing

Plant parts to be used for increase are laboratory cultured to determine if they are infected with pathogenic fungi or bacteria. Plant parts found free of pathogens are used for further vegetative increase and propagation. This technique is used on chrysanthemums, carnations and potatoes.

Indicator Hosts

Indicator hosts are plants that produce rapid and distinctive symptoms when inoculated with a virus. They are used to detect specific viruses in individual plants. Fruit trees and potatoes are commonly indexed for viruses. Only those trees free of virus are used as sources of budwood for graft propagation. Indexed nursery stock is commonly used for orchard plantings, as this is the only practical way to control fruit tree virus disease.

Serology

Serology is the use of specific antibodies present in the antiserum of warm-blooded mammals. These antibodies are produced in the blood of rabbits (usually) that have been immunized with a specific pathogen. This procedure is used to index barley and potato seed stocks for specific viruses. It is also used to detect some bacteria. Many highly specific and sophisticated tests are available now.

Embryo Test For Barley Loose Smut Detection

The embryo test determines if loose smut is present and, if it is, the percentage of infection. If the loose smut infection exceeds 1 or 2 percent the seed lot should be treated with an effective systemic fungicide prior to planting. The embryo test is not available for use on wheat seed.

ERADICATION

Eradication means elimination of the pathogen. In actual practice, this term may be used when the pathogen is not completely eliminated but the populations are greatly reduced.

CROP ROTATION

Crop rotation involves growing different crops in the same field or plot in succeeding years. Pathogens such as the fungi that cause tan spot of wheat, dry bean rust, Cercospora leafspot of sugarbeet, and Septoria leafspot of tomato attack only one host, and populations of the pathogen increase when the same host is grown repeatedly on the same land. Crop rotation helps keep populations of these pathogens at low levels. There is one precaution, however: the grower must consider nearby areas as well. Disease organisms may spread from nearby fields or garden plots if disease was present in those areas the previous year. Disease can be expected to develop first in the area next to last year's crop. If weather favors disease development, the entire field or garden plot may eventually become diseased.

Crop rotation is an effective tool for reducing many pathogen populations. However, some pathogens survive many years in the soil and are not affected much by normal crop rotations. Long rotations may be necessary but often are impractical. The sunflower downy mildew pathogen, the sugarbeet *Aphanomyces* pathogen and the white mold organism survive many years in the soil. The pathogen that causes Verticillium wilt of tomato survives several years in the soil and also attacks many other garden vegetables, so it is difficult to eliminate by rotation. In the case of Verticillium wilt in tomato, use of resistant host varieties is the practical solution. In the case of white mold, some navy, kidney and black beans show partial resistance to white mold. In the case of sunflower downy mildew, only a few hybrids are resistant to all races of the mildew fungus.

ERADICATE ALTERNATE HOSTS

Many rust fungi require two hosts to complete their life cycle. The second host, called the **alternate** host, is essential to overwintering of many rusts in northern climates. Some of these same rust fungi reproduce indefinitely without the alternate host in warm climates. Examples of alternate hosts include common barberry (not ornamental barberry) for wheat and barley stem rust, buckthorn for oat crown rust, and juniper for apple rust. The rust fungi's sexual phase occurs on these alternate hosts.

It was hoped that eradication of barberry from the Upper Midwest in the 1930s would break the pathogen cycle and eliminate the stem rust fungus. After most barberry had been eradicated, stem rust still occurred. It was determined that stem rust survives year-round in Mexio and the Gulf Coast in the summer spore stage, without requiring the barberry for the overwintering stage. These spores are wind-blown thousands of miles north to the Upper Midwest every year (Figure 4).

Nevertheless, the barberry eradication program had two very important accomplishments: 1) stem rust infections started later in the season, and 2) the sexual phase of the fungus was eliminated, which slowed down the development of new rust races. Elimination of buckthorn near oat fields produces similar results.

To manage apple rust, commercial growers try to remove all junipers within two miles of their orchards. This is not feasible for the homeowner, who must use fungicides or resistant varieties for management of apple rust when weather is wet in spring and early summer.

SANITATION

Sanitation is the removal of crop refuse. Tillage is sometimes used to bury the refuse. The quantity of a pathogen available to produce infection is called the **inoculum**. Burial by tillage reduces the inoculum of the wheat tan spot pathogen, the barley spot blotch pathogen, and many garden pathogens.

All diseased tomato vines and refuse should be removed, and apple leaves that had apple scab should be raked up and detroyed by burning, burying or sending to the landfill. Diseased leaves and vines also can be composted if the compost is allowed to heat sufficiently, as described in Extension Circular PP-737 Rev., **"Home Garden Disease Control Begins This Fall,"** or PP-469 Rev., **"Plant Disease Control in the Home Garden."**

When Septoria leafspot of tomato is severe, picking off badly diseased leaves (sanitation) before spraying with a fungicide helps reduce the inoculum and improves fungicidal control.

HOST RESISTANCE

Resistance is the ability of a host to resist infection by a pathogen. Resistant varieties are favored by commercial growers and gardeners when they are available.

Resistance has been the best and most cost-effective method of managing stem rust and leaf rust of wheat. Homeowners who have the Verticillium wilt pathogen in their garden soil must grow a resistant tomato variety to manage the disease.

Some **foliar** (leaf) **pathogens** may rapidly develop new races quite capable of attacking certain types of host resistance. Many foliar pathogens are extremely variable and produce billions of spores that are disseminated great distances by the wind. Consequently, new races of some foliar pathogens may become widespread in a short period of time. This results in disease outbreaks and a continued need for plant breeding programs.

Soil-borne pathogens (root and vascular wilt pathogens such as Verticillium) are also variable, but new races may not become widespread as quickly.

There are two types of host plant resistance: **race specific resistance** and **general resistance**.

Race specific resistance usually provides a high level of resistance, but it fails when new races of the pathogen develop. In the late 1990s new races of wheat leaf rust developed that attacked some of the previously resistant wheat cultivars.

General resistance is usually a stable type of resistance that is effective against all races of the pathogen. General resistance usually does not exhibit as high a level of resistance as race specific resistance. However, general resistance slows down disease development compared to that on a susceptible variety.

PROTECTION

Protection means protecting plants from infection. Storing potatoes and other vegetables in cold storage protects against infection because it is too cold for many pathogens to develop, or development is greatly slowed down. Seed potatoes are grown in isolated areas where aphid populations are low (exclusion) and thus easily managed (protection); this minimizes aphid-borne virus infection.

CULTURAL PRACTICES

Time of planting may help plants escape infection. Winter wheat is planted in September after the destruction of volunteer wheat. Destruction of volunteers prior to winter wheat planting destroys the green bridge that wheat curl mites survive on between the summer and fall crops. The wheat curl mite is the vector of the wheat streak mosaic virus. Delayed planting of winter wheat also reduces the risk of survival and buildup of the mite in the fall of the year and exposure of the wheat crop to high wheat curl mite populations.

Many dry bean and garden bean pathogens are disseminated in water, so beans should not be cultivated when they are wet.

A plastic mulch used on tomatoes greatly reduces blossom end rot, a non-infectious disease that develops under conditions of drought or fluctuating soil moistures. The mulch produces a more uniform soil moisture.

Most powdery mildews are favored by high humidity. Powdery mildew is a common problem on alpine current, lilac, roses and shaded lawns. Pruning shrubs and trees to allow better air circulation and sunlight penetration may help reduce powdery mildew in shady locations.

HANDLING PRACTICES

Development of potato late blight in storage can be minimized by proper handling practices during the growing season. This includes hilling the soil around the plants to reduce the chances of late blight spores coming into contact with the tubers. The vines should be killed several weeks before harvest by using approved vine killers or chopping the vines off at ground level. The late blight fungus on the tops will be minimal at harvest and tubers will be mature. Mature tubers are less prone to infection.

MANAGING INSECT VECTORS

Many insects carry disease organisms such as viruses and bacteria. Managing these insect vectors may reduce the chance of disease. A prime example is the cucumber beetle, vector of the bacterial wilt pathogen of cucumber and muskmelon. The bacterium is carried from plant to plant by the beetle and overwinters in the beetle. A good program for managing the cucumber beetle, started as soon as the plants emerge, will prevent serious losses from the bacterial wilt disease. Similarly, good aphid management is essential for raising virus-free seed potatoes.

In addition to successful management of insect vectors, weeds and other hosts that can serve as a reservoir for both vectors and pathogens must be managed. Weed management is essential around plantings of potatoes, tomatoes, cucumbers, melons, peppers and many other commercial and garden crops.

FUNGICIDES

Protectant fungicides act on the plant surface to protect against infection, and **systemic fungicides** are taken up by the plant tissues and then function to prevent infections. Some new fungicides have limited **therapeutic** (curative) properties.

Current fungicide recommendations are given in Extension Circular PP-622, **"Field Crop Fungicide Guide,"** and Circular F-1192, **"Insect and Disease Management Guide for Woody Plants in North Dakota."**

Protectant Fungicides

Protectant fungicides work on the plant surface to prevent spore germination or kill developing fungus hyphae before the host plant is penetrated and infection becomes established.

Protectant fungicides commonly used on North Dakota farms include maneb (Maneb 80, Maneb 75 DF), mancozeb (Dithane DF, Manzate 200 DF, Penncozeb DF), triphenyl tin hydroxide (Super Tin, Agri Tin), chlorothalonil (Bravo), and copper fungicides. Protectant fungicides commonly used on North Dakota home gardens or ornamentals include captan (Orthocide), chlorothalonil (Daconil, Ortho Multi Purpose Fungicide), maneb, mancozeb, thiram, and copper fungicides. The dicarboximide fungicides iprodione (Rovral) and vinclozolin (Ronilan) also are protectant fungicides that provide good control of Sclerotinia (white mold) on certain field crops.

Most protectant fungicides cannot stop development of a pathogen once infection occurs. Leafspots become visible a number of days after infection: four to five days for tan spot of wheat, potato late blight and sugarbeet Cercospora leafspot, and seven to 14 days for many other pathogens. If a protectant fungicide is applied **after** infection has occurred but **before** leafspots show, the disease is not cured but continues developing and symptoms appear. Then frustrated growers and gardeners may claim that the fungicide "didn't work." **Protectant fungicides do not cure infections and will not work unless the application is timely** (early enough). Waiting too long usually results in failure. A few examples will illustrate this.

Gardeners sometimes begin spraying their tomato plants with a protectant fungicide such as Ortho Multi-Purpose Fungicide when all the lower leaves on their tomato plants are dead and the middle leaves already are heavily spotted with *Septoria* leaf spot. The disease continues to develop on the middle leaves resulting in **defoliation** (loss of leaves). Since some upper leaves were already infected before spraying started, symptoms may develop on these leaves, too. Only two or three tip leaves were uninfected at the first spraying. These leaves were all that was protected against infection and are all that will be left after disease has defoliated the rest of the plant. If the gardener had sprayed when the first few spots showed on the lower leaves, some lower leaves might have been lost to *Septoria,* but the rest of the plant would have remained healthy.

Timely application of protectant fungicides also is critical for crop diseases, such as rust of dry beans or leaf rust of winter wheat. Rust diseases have a tremendous capacity to reproduce in a short period of time. Rapid development of these diseases is favored by very susceptible varieties and rainy, humid weather. If rust is detected on these susceptible crops in a given area, if environmental conditions are favorable, and if those crops have good yield potential, growers should apply protectant fungicides to the crop prior to rust formation on the healthy leaves. Applying too late will mean that rust infections will already have occurred and new spore formation will **not** be stopped.

Protectant fungicides are often combined with a spreader-sticker which reduces wash-off of the fungicide during rainfall. These compounds help to wet the leaf and to bind the fungicide to the leaf. Protectant fungicides must be applied so that thorough coverage of the foliage is obtained. Protectant fungicides are redistributed on the plant by dew and rain, but uniform coverage is still essential. A fungicide should be applied **before** a rainy period to provide protection during the rainy period. The application must be made early enough so that the spray droplets have dried before the rain begins. If necessary, another application can be made after the rains are over (Figure 5).

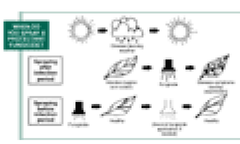

Figure 5. Effect of spraying a protectant fungicide before or after an infection period (disease-favoring weather). Note that spraying after infection even though symptoms are not yet evident, will not prevent disease development. Spraying before an infection period protects against infection. (15KB illustration)

Protectant fungicides are used both as foliar fungicides and as seed treatments. Seed treatment is discussed in extension Circular PP-447, **"Seed Treatment for Disease Control."** Seed treatments are used to control both seed-borne diseases and soil-borne diseases that can cause death of seedlings.

Sulfur is a protectant fungicide that effectively reduces powdery mildew on a number of crops, including sugarbeets, garden and dry peas and ornamentals. Sulfur also has some eradicant action against established powdery mildew infections. This therapeutic effect of sulfur is an exception to the general rule that protectant fungicides do not cure infections.

Systemic fungicides

Systemic fungicides are taken up (absorbed) by the plant. They include some seed treatment fungicides such as carboxin (Vitavax), the benzimidazole fungicides, the sterol inhibitors, the phenylamides and the strobilurins. Benzimidazoles are commonly used as foliar fungicides and include benomyl (Benlate), thiabendazole (Mertect, TBZ, Arbotect), and thiophanate methyl (Topsin M). These fungicides move upward in the plant but cannot move down the leaf or stem. They function as **locally systemic** fungicides and usually do not move into new foliage. Most sterol inhibitors and strobilurins are locally systemic.

Locally systemic fungicides have several advantages: they protect both sides of the leaf even if only one side was sprayed, they are not washed off by rain or decomposed by sunlight, the interval between sprays may be longer than that with the protectant fungicides, and some have a **therapeutic** effect. The therapeutic effect ranges from 24-36 hours for the benzimidazoles and up to four days for some sterol inhibitors.

Benzimidazole fungicides

Benomyl (Benlate) and thiophanate methyl (Topsin M) are currently registered for control of white mold *(Sclerotinia)* on dry beans and give good control if properly applied at the right time. The white mold fungus infects dry beans by means of airborne spores which must begin growth on dead plant tissue, and then growth spreads to green tissue. The site of this dead tissue is the dead blossoms or dead lower leaves. Since these fungicides cannot move down the plant, they are effective only if there is complete coverage of the entire plant. Canopy penetration is essential to good control.

Phenylamide (acylalanine) fungicides

Metalaxyl (Allegiance) and mefenoxam (Ridomil Gold, Apron XL) are systemic fungicides with activity against water molds and related fungi such as *Pythium, Phytophthora* (potato late blight pathogen) and the downy mildew organisms. Oxadixyl (Anchor) is a systemic seed treatment fungicide with similar mode of action to metalaxyl and mefenoxam.

Sterol inhibitor (ergosterol biosynthesis inhibitor) fungicides

The sterol inhibitor fungicides inhibit the formation of ergosterol in the higher fungi, but not the water molds. This prevents cell wall formation and stops growth of the fungus. Sterol-inhibiting fungicides currently available in North Dakota (2000) include imazalil (several brand names), triforine (Funginex, for home garden use), difenoconazole (Dividend seed treatment), triadimefon (Bayleton) triadimenol (Baytan), propiconazole(Tilt), tebuconazole (registered Raxil seed treatments, registration pending for Folicur foliar treatments), and tetraconazole (registration pending for

Eminent). They have therapeutic activity, many for up to four days after infection has initiated, may suppress spore formation in established infections, most are taken up by the plant (some are only locally systemic), and they are used at very low dosages.

Strobilurin fungicides

The strobilurin fungicides were developed recently. This is a methoxyacrylate class of chemistry which is related to naturally occurring products found in a group of forest mushrooms called "pine-cone mushrooms." Some are locally systemic and many have an extremely broad spectrum of activity against all four classes of fungi, something that is extremely rare with most classes of fungicides. These fungicides are environmentally friendly. Azoxystrobin (Quadris) and kresoxim-methyl (Sovran, Cygnus) were the first of this class. Other strobilurins include trifloxystrobin (Flint), BAS 500 (Headline, expected to be registered for the 2002 season) and a product with a related mode of action called famoxadone (Famoxate, registration expected in several years). Some strobilurins such as azoxystrobin are locally systemic, moving into and up the leaf toward the tip. Other strobilurins such as kresoxim-methyl and trifloxystrobin have only slight uptake by the leaf and are redistributed on the plant through vapor action. Most fungicides in this class are strongly bound to the cuticle (leaf surface) and so are not easily washed off the leaf. They inhibit fungal respiration, which is a different mode of action from that of other fungicides.

New Classes of Fungicides

Several other fungicides have been developed recently, each of which is in a unique class of chemistry. Hymexazol (Tachigaren) is an isoxazole class of chemistry that is environmentally friendly and has excellent activity against *Aphanomyces* and also *Pythium.* It is registered for use as a seed pelleting for sugarbeets for early season control of Aphanomyces seedling disease.

Another new chemistry is fludioxanil (Maxim), a phenylpyrrole class of chemistry that is an environmentally friendly product registered for seed treatment on many crops and also as a potato seed piece treatment. It has excellent activity against silver scurf of potato, as well as Rhizoctonia black scurf of potato and Fusarium dry rot.

Fluazinam (Omega) is a pyridinamide class of chemistry that is a contact fungicide with a broad spectrum of activity, including activity against Sclerotinia (white mold).

Fenhexamid (Elevate) is a hydroxyanilide class of chemistry that is used as a protectant fungicide.

Some fungicides that are in varying classes not listed above include the registered fungicides cymoxanil (Curzate), dimethomorph (Acrobat) and propamocarb (Tattoo or Previcur) and the registration pending product zoxamide (Gavel). All four have good activity against the potato late blight pathogen and the downy mildews. Cymoxanil is an acetimide fungicide that is locally systemic, has a short residual and has both curative and protectant properties. Dimethomorph is a cinnamic acid derivative that is locally systemic and has curative and preventive activity. Propamocarb is a carbamate fungicide that is systemic and is translocated into new foliage. Zoxamide is an amide fungicide with a different mode of action from other potato late blight fungicides.

Some products such as acibenzolar (Actigard) and several others act to enhance the natural defenses of the plant. Currently there are no uses registered for North Dakota crops.

Resistance to Fungicides

Fungi may develop resistance to fungicides. Repeated use of the same fungicide or fungicides with the same mode of action can lead to development of resistance.

Fungi are less likely to develop resistance to the older protectant fungicides that have multiple sites of action against fungi. Nevertheless, the Cercospora leafspot pathogen of sugarbeet has developed tolerance to triphenyltin hydroxide. This tolerance is expressed as a reduced sensitivity to the fungicide, requiring higher application rates to control Cercospora leafspot.

Fungi are more likely to develop resistance to systemic fungicides with a single specific mode of action. Resistance to the benzimidazoles and the phenylamides can occur rapidly, with resistant strains of fungi showing insensitivity to high rates of the fungicide. Resistance also can develop rapidly to the dicarboximides, the sterol inhibitors, and the strobilurins.

The Cercospora leafspot pathogen of sugarbeet is resistant to benzimidazole fungicides in many areas of the world, including many fields in Michigan, Minnesota and North Dakota. The Fusarium dry rot pathogen and the silver scurf pathogen of potato have developed resistance to this class of fungicide across much of the United States and Canada. These three fungicides are closely related, and a pathogen that develops resistance to one of the benzimidazole fungicides will be resistant to all three. This is called **cross resistance**.

The potato late blight fungus can develop resistance rapidly to the phenylamides metalaxyl and mefenoxam. Certain genotypes of the fungus have resistance, including the US8 genotype now present in North Dakota and many other parts of the United States and Canada. The presence of this new genotype has seriously limited the usefulness of this class of fungicide for potato late blight management.

The gray mold fungus has rapidly developed resistance to the dicarboximide fungicides iprodione (Rovral) and vinclozolin (Ronilan) under greenhouse conditions. Certain grape pathogens have rapidly developed resistance to this class of fungicide in California.

Cases of resistance to sterol inhibitors are fairly common, and resistance management practices are recommended for this class of fungicide. Although the strobilurin fungicides have been used but a few years, it is recognized that resistance can occur to this class of fungicide, and cases of resistance are already being reported world-wide.

Resistance Management

There are several ways to retard the development of resistance. These include:

- *Tank mix with a fungicide with a different mode of action.* Mancozeb or chlorothalonil can be tank mixed effectively with benzimidazole or phenylamide fungicides.
- *Alternate applications between or among two or more classes of fungicides with different modes of action.* This is a good strategy for resistance management of triphenyltin hydroxide, the sterol inhibitors, the dicarboximides and the strobilurins. Although the sterol inhibitors and the phenylamides have some post-infection activity, they are best used in a preventive manner, which reduces the likelihood that resistance will develop.
- *Apply a limited number of applications in a block at a critical period in the pathogen disease cycle.* A different mode of action should be used at other less critical times in the disease cycle, so as to minimize the exposure of the "at risk" fungicide. This has been recommended with some of the strobilurins.
- *Limit the number of applications of an "at risk" fungicide per year.* This has been done with the phenylamide fungicides, the sterol inhibitors, and the strobilurins. Use of these fungicides may be restricted to the most critical parts of the season.
- *Avoid reduced rates of fungicides.* These reduced rates may facilitate the development of resistance in fungi.
- *Do not use phenylamides as soil treatments against airborne pathogens.*

Use of Fungicides

All pesticides are poisons, and they should be used with care. Most commonly used fungicides have a relatively low level of toxicity, but triphenyltin hydroxide (Super Tin, Agri Tin) is an exception in that it is quite toxic. Many fungicides have information on the label restricting the number of days before harvest that the last application can be made to food crops. Most have a 24-hour period during which re-entry in a field should be done only if wearing protective clothing (long pants, long-sleeved shirt, shoes, chemical-resistant gloves).

Most fungicides can be stored successfully from year to year, but a dry storage area is essential, especially for the maneb and mancozeb fungicides. Care should be taken in storing liquid or flowable fungicides as some will not stand freezing. Check the label for information on use and storage.

INTEGRATED DISEASE MANAGEMENT

Effective, practical disease management usually involves several techniques. Management programs based on only one or two techniques can be effective in the short term but may become ineffective if used frequently. The development of fungicide resistance is a good example; the epidemics of rust caused by newly prevalent races of the fungus is another. Growers need to integrate as many different management tools as possible for long term success.

Stem rust of wheat is managed by host resistance, the elimination of barberry (this prevents the sexual phase that produces new rust races), and by constant monitoring of the rust races by plant pathologists. Monitoring provides early warning for plant breeders of the buildup of new rust races and the need for alternative management for the grower.

The main tools for management of dry bean rust are sanitation, crop rotation, tolerant varieties and fungicides. All of these procedures must be done well and in a timely fashion to produce effective management.

Tan spot of wheat can be reduced by sanitation, crop rotation, and protection (fungicides); researchers are developing varieties with improved tan spot resistance. When wheat is planted directly into standing wheat stubble, both sanitation and rotation are eliminated as management tools and growers must rely primarily on variety choice and fungicides for tan spot reduction.

Homeowners should make every effort to remove diseased plant debris from the yard and garden in the fall - sanitation is the first step to disease management for next spring. Sanitation should be followed by seed treatment, rotation, use of resistant varieties, and timely fungicide applications.

Whenever possible, all the principles of management, eradication, exclusion, host resistance, and protection, should be practiced. The use of these combined practices usually produces the most reliable and stable plant disease management.

Finally, all growers should keep close watch on the weather forecasts, as this helps to anticipate disease-favoring weather and allows more timely preventive measures. Some Disease Forecasting models for major crop diseases have been developed and are now available on the Internet or through toll-free telephone numbers. The disease forecasting information aids in predicting disease outbreaks and the need for fungicides.

Table 1. Common causes of diseases.

Type	Cause	Description	How They Reproduce	How They Can Be Seen: Equipment	How They Can Be Seen: Magnification Required*	Examples
Non-Infectious (Abiotic)	Nutrition	Deficiency or excess of essential elements	--	Visual (no special equipment needed)	--	Nitrogen deficiency, iron deficiency, zinc deficiency
	Moisture	Deficiency or excess of water	--	Visual	--	Moisture stress or wilting, suffocation of roots in wet soil
	Temperature	Cold or heat	--	Visual	--	Frost, heat sterility
	Other Meterological Conditions	Sun, wind, etc.	--	Visual	--	Heat canker, sunscald, lightning injury
	Toxic Chemicals	Salt, air pollutants, etc.	--	Visual	--	Salt injury (road salt, saline seeps), ozone injury
Infectious (Biotic)	Fungi	Grow as tiny threadlike filaments; large fruiting structures may develop	Spores, Cell division	Microscope (occasionally a hand lens)	20-250	Rusts, smuts, leafspots, white mold (canola, dry beans and

	from these filaments.				sunflower), powdery mildew, tree cankers, apple scab, wheat and barley scab.
Bacteria	Tiny single-celled organisms.	Cell division	Microscope	400-1,000	Bacterial blights of beans, bacterial blights of small grains, fireblight, bacterial wilt of cucumber.
Viruses	Very tiny rod-shaped or spherical particles, composed of RNA with a protein coat.	Cause host to manufacture virus	Electron microscope	20,000-100,000	Wheat streak mosaic, barley stripe mosaic, potato viruses, tobacco mosaic, cucumber mosaic.
Phytoplasmas	Very tiny organisms without a cell wall, no definite shape.	Division	Electron microscope	20,000-50,000	Aster yellows (purple top in potato and tomato).
Nematodes	Tiny Roundworm	Eggs	Microscope (naked eye	1-60	No serious problem in

s	for larger forms)	North Dakota. Soybean cyst nematode and pine wilt nematode occur in neighboring states.

*The number of times a pathogen must be magnified to be visible. For example, a pathogen 1/1,000 inch in size when magnified 100 times would appear to be 1/10 inch in size; a pathogen 1/1,000,000 inch in size when magnified 100,000 times would appear to be 1/10 inch in size.

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